Enterprise Integration Strategies Across Virtual Extended Enterprise Networks: A Case Study of the F-35 Joint Strike Fighter Program Enterprise

by

Christopher G. Glazner

B.S., Electrical and Computer Engineering
B.A., Plan II
University of Texas at Austin, 2002

Submitted to the Engineering Systems Division in Partial Fulfillment of the Requirements for the degree of

MASTER OF SCIENCE IN TECHNOLOGY AND POLICY

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
February 2006

SIGNATURE OF AUTHOR ______________________
Technology and Policy Program, Engineering Systems Division
January 18, 2006

CERTIFIED BY ______________________
Dr. Kirkor Bozdogan
Principal Research Associate, Center for Technology, Policy, and Industrial Development
Thesis Supervisor

ACCEPTED BY ______________________
Dava J. Newman
Professor of Aeronautics and Astronautics and Engineering Systems
Director, Technology and Policy Program

Enterprise Integration Strategies Across Virtual Extended Enterprise Networks: A Case Study of the F-35 Joint Strike Fighter Program Enterprise

by

Christopher G. Glazner

Submitted to the Engineering Systems Division on January 18, 2006 in Partial Fulfillment of the Requirements for the degree of Master of Science in Technology and Policy

---

Abstract

Over the last decade, many companies in industries that produce complex and technologically-advanced products have begun to integrate their operations along the value chains of the primary products they design, produce or sustain. Increasingly, integration efforts have moved beyond the boundaries of the core or focal enterprise serving as the prime contractor or system integrator to span the entire value chain, to form *virtual extended enterprises*. These structures allow the members of the virtual extended enterprise to focus on their core competencies in order to collaboratively deliver a world-class product at a competitive price.

While integration offers many benefits to enterprises, a high degree of integration is not always desirable or advantageous in a limited duration virtual extended enterprise composed of autonomous companies. Virtual extended enterprises must find a balance between decoupled collaboration and highly coupled integration, balancing the need to closely coordinate their efforts with the need protect the autonomy of their members.

The objective of this research is to explore the extent to which a focal enterprise, such as a prime contractor or system integrator, should consider integration across its virtual extended enterprise, identify major barriers to integration, and define key enablers of integration overcoming these barriers. Analysis focuses on the extent of integration based on the characteristics of the virtual extended enterprise, such as the duration and scope of the program in question, product system architecture, the organizational architecture, and the external environment. In particular, three key conceptual dimensions of integration are developed and explored—technological integration, strategic integration, and organizational integration. This framework is applied in an in-depth case study of integration strategies on the virtual extended enterprise of the F-35 Joint Strike Fighter (JSF) Program. The knowledge gained from the case study is used to make recommendations for the development of integration strategies for future programs.

Thesis Supervisor:	Dr. Kirkor Bozdogan
Title:	Principal Research Associate, Center for Technology, Policy, and Industrial Development

Executive Summary

Over the last decade, many companies in industries that produce complex and technologically-advanced products have begun to integrate their operations along the value chains of the primary products they design, produce or sustain. Increasingly, integration efforts have moved beyond the boundaries of the core or focal enterprise serving as the prime contractor or system integrator to span the entire value chain, to form *virtual extended enterprises*. These are value chains in which key players have created a set of technical collaboration processes that allow them to work together as an integrated team over the limited life of a program. These vertically coordinated networks of enterprises are becoming increasingly common on time-limited programs and projects, particularly in high-complexity industries such as aerospace and automotive. These structures allow the members of the virtual extended enterprise to focus on their core competencies in order to collaboratively deliver a world-class product at a competitive price.

With the proliferation of information and communication technology in recent years, there has been a movement in many industries towards integration of the individual enterprise. Integration entails uniting communication infrastructures, strategies, organizations, and processes across the enterprise so that they behave in a coherent, directed fashion. While integration offers many benefits to the single enterprise, a high degree of integration is not always desirable or advantageous in a limited duration virtual extended enterprise composed of autonomous companies. Virtual extended enterprises must find a balance between decoupled collaboration and highly coupled integration. They must balance the need to closely coordinate their efforts with the need to not infringe upon the autonomy of their members.

The objective of this research is to explore the extent to which a focal enterprise, such as a prime contractor or system integrator, should consider integration across its virtual extended enterprise, identify major barriers to integration, and define key enablers of integration overcoming these barriers. Analysis focuses on the extent of integration based on the characteristics of the virtual extended enterprise, such as the duration and scope of the program in question, product system architecture, the organizational architecture, and the external environment. In particular, three key conceptual dimensions of integration are developed and explored—technological integration, strategic integration, and organizational integration. This framework is applied in an in-depth case study of integration strategies on the virtual extended enterprise of the F-35 Joint Strike Fighter (JSF) Program. The knowledge gained from the case study is used to make recommendations for the development of integration strategies for future programs. The case study is based on extensive field interviews with technical and management personnel associated with the JSF Program, using a semi-structured in-person interview process employing a questionnaire survey instrument.

This research proposes that any attempt at integration needs to be solidly based upon each of these three dimensions. Two key areas—lack of central authority and level of allegiance—are identified that make integration in virtual extended enterprises unique from other forms of enterprise integration explored in the literature, and make policy and architecture much more important components of integration strategies.

The case study of the JSF Program focuses on the specific drivers that have shaped the integration strategies of the JSF Program such as architecture, political concerns, US export control laws, and funding structures. These drivers of integration are explored using the three-dimensional framework developed earlier in the thesis.

The JSF Program has been heralded as a flagship of defense acquisition reform, and program integration plays a major role in this reform process. When exploring possible integration strategies, the JSF Program strived to go beyond simply minimizing transaction costs and decided to view integration as a *strategic capability*. This entailed a fundamental redesign of the enterprise network, allowing it to perform much more efficiently and effectively over the longer run than a traditional prime-contractor-subcontractor relationship. The systems, policies and structures in place for integration do more than simply reduce or minimize transaction costs to ensure that networked structures are economically feasible. They enable the extended enterprise to behave in revolutionary new ways that allow it to operate as a single entity, and to focus on its performance over multiple time scales—short-, medium-, and long-term. This reflects a new mental model of enterprise architecture and helps to develop a coherent set of strategies, technical plans, and organizational designs that work together in concert.

Through wise application of technology, the JSF Program has made great strides towards overcoming many barriers to integration, such as close collaboration with the international partners within the constraints of US export control law and the establishment of a network-wide knowledge repository. The primary enabler of these integration activities was a large, centralized IT system that integrated tools, processes, and documentation into a collaborative environment that allows for version and access control. This system has been viewed by many both in the program as well as externally as the critical component of the JSF Program's integration strategy. While the computer systems developed for the program are essential enablers, they work in concert with a sound strategic plans and organizational designs to facilitate an integrated, effective program.

Integration for its own sake, however, will not necessarily yield benefits. In some instances, there may have been over-integration in certain areas and not a sufficient degree of integration in others, perhaps reflecting a possible mismatch between the product system architecture and the resulting extended enterprise organizational architecture. For instance, several of those interviewed stated that greater efforts could be made to match the level of integration in the organizational architecture to the level of integration in the product system architecture, especially on more complex systems such as avionics. The varying levels of technical integration across the aircraft product system architecture might suggest similarly varying levels of integration in enterprise organizational architecture in order to achieve the full benefits of enterprise integration at the lowest possible cost. A uniform, undifferentiated, enterprise integration strategy with one-size-fits-all integration policies and practices across the whole program may prove more costly than necessary to derive the expected benefits of integration

An important barrier to optimal enterprise integration that has been suggested in the literature in such large-scale, complex, extended virtual enterprises is the tendency of the individual enterprises, and especially the prime contractor, to retain in-house work that could be outsourced to another organization and performed better in terms of cost, quality and delivery. The literature suggests such a barrier can be overcome using an unbiased "competency manager" or team to assign work based on capability alone. The field interviews suggest that this may be an issue in some areas of the JSF Program, such as the development of the Virtual Processing Center, but to what extent this is an issue that seriously affects network-wide performance is difficult to ascertain. This is an example of a barrier that should perhaps be more generally addressed by the project sponsor, rather than internally by the individual participating organizations, while keeping in mind that although such an approach is appealing in theory it is most likely to prove rather difficult in practice.

Additionally, while the strategic and technical dimensions of integration are fairly strong on the JSF Program, many of those interviewed indicated that the organizational dimension is comparatively weaker. Several instances were identified by those interviewed in which organizational and socio-technical barriers to integration made technical and strategic integration efforts more difficult. This was particularly the case in the implementation of the Virtual Processing Center, which encountered some delays due to socio-technical concerns such as the lack of stakeholder buy-in, disconnects in expected functionality, and inadequate training with the new system. Many of these barriers were directly attributable to the culture of the development environment on the program and potentially could have been mitigated.

In the case of the JSF Program, many barriers to integration, and especially international integration, have been imposed by the US Department of Defense on the program in the name of protecting national security. Some of these policies are shown to significantly hinder the development process on the JSF Program while not positively contributing towards greater national security. One policy recommendation made was to extent the so-called "Canadian Exemption" to the UK, the staunch ally of the US. Another policy recommended to the DoD is to consider using unbiased competency brokers in the network to source contracts, especially after contract awards have come under international scrutiny.

The JSF Program provides an excellent opportunity to examine integration strategies on a large, fully-functional virtual extended enterprise within the US military aerospace context. The lessons learned from this case study are hoped to be helpful to other acquisition programs that are likely to follow in the footsteps of the JSF program.

Table of Contents

List of Tables and Figures

Chapter 1: Introduction and Motivation

In a global marketplace, businesses are relentlessly driven by the competitive pressures of industry to achieve "world class" status. In industries that deal with large, highly complex products and services such as the automotive, aerospace, and large-scale construction industries, it is increasingly impossible for a single firm to become "world class" in all facets of the industry. Instead, the apparent trend has been to concentrate on core competencies while forming temporary partnerships and alliances with other businesses that posses complimentary competencies in order to take advantage of fleeting business opportunities.

The idea of complementary business alliances is not new—it has been common in many industries, such as large-scale construction and the automotive industry, for several decades(Malone, 1991). What is new and makes these arrangements so interesting is that modern information technologies have given these temporary business alliances the potential to integrate themselves to an unprecedented degree, merging processes and computer systems almost seamlessly. This paves the way for a wide range of collaborative structures, ranging from a seamless "virtual enterprise" whose products and processes move transparently and seamlessly between the many firms constituting the alliance, to loosely affiliated businesses alliances that use computer networks to coordinate and collaborate using more traditional business-to-business transactions. Externally, the collaborative, networked organization as a whole may appear to customers as a single entity, but later will disintegrate and reform into a new partnership for a new business opportunity. The key to these collaborative structures is integration across the collaborative alliance. Information technologies serve as a catalyst for new forms of integration, facilitating collaboration and new patterns of behavior in these "enterprise networks"(Venkatraman, 1994).

These structures and the degree of integration they require are fairly new in the market, and are not yet well proven. It has been implicitly assumed that integration and collaborative, networked organizations are necessarily good in much of the literature and by those in the information technology industry without a careful examination of the circumstances where integration is most useful, and where its faces diminishing returns. Over the past decade, several enterprises attempting to integrate their internal processes and computing systems have faced spectacular failures, and some systems when "successfully" implemented did not yield the benefits that they promised to the enterprise. It is not clear that integration is always the correct path to pursue. Beyond the issue of how integration is achieved, the question "should integration be attempted" should first be asked.

Technologically enabled, collaborative alliances have raised many questions on the part of those who architect and manage them even after it is determined that integration is an appropriate strategy within the market. The creation of enterprise networks is still a nascent endeavor, and dominant architectures and strategies have yet to emerge, despite large-scale coordinated attempts to set standards for cross-industry collaboration and communication(NIIP, 1996). Integration of the enterprise network is a critical issue for the architects of such networks, as it drives strategy, organization, and technology across the entire network. Most architects realize the imperative for integration, but the questions remain: how does one integrate, and to what extent *should* one integrate an enterprise network?

To date, there has not been a successful effort to establish a widely-applicable, theory-based approach to the development of strategies for the integration of enterprise networks. Such integration strategies have largely been "one-off" efforts, highly customized, manual, ad-hoc processes, in contrast to more developed methodologies that rely on established theory(Ouzounis, 2001). Firms are rightfully hesitant to share their valuable data and processes that integration might require with other industry members and potential competitors. Further, they are unsure what degree of integration is necessary to both create a viable enterprise network that delivers value to its customer while retaining the core competencies and intellectual property that allow it to add value as an independent entity. It may be that the process of integrating may create more problems than it solves.

Firms participating in enterprise networks often find that there are many unseen barriers to their integration strategies. It is not possible to simply meet cooperative standards or to purchase a particular IT system and then be able to participate successfully in an enterprise network—integration of enterprise networks is a multi-faceted endeavor that must embrace all of the facets—strategic, technical, and organizational—in order to be successful.

1.1 Research Objective and Questions

The objective of this thesis is to identify barriers and enablers to enterprise-wide integration in large, extended, virtual enterprises such as those found in the aerospace industry. The thesis will also examine the extent to which firms adopt integration strategies within these enterprise networks, dependant upon both the architecture of the network and the architecture of the product it produces, focusing on the transfer of knowledge and processes between firms. The thesis will explore integration strategies in greater detail using an in-depth case study of the extended enterprise of the F-35 Joint Strike Fighter Program, focusing on the specific concerns of a virtual, extended enterprise and within the aerospace industry subject to the restrictions of US Export Control Laws. This research aims to identify and examine the fundamental issues of enterprise integration across the enterprise value stream from multiple perspectives and search for underlying principles that can help identify whether, to what extent, how and when enterprise networks should integrate, as well as how to mitigate key barriers.

The hypothesis is that the integration strategies of most nascent enterprise networks are overly focused on specific tools, protocols and off-the-shelf software products with a high emphasis on the enabling technology of integration. They view integration primarily as a concern for the Information Technology division, rather than as a driver of the entire organization. The integration efforts of enterprise networks are far more successful when they take a broader, more holistic approach that aligns the integration strategy and architecture of the network with three key facets of integration: strategy, technology, and organization. This research will examine enterprise integration strategies through these key three areas, relating key concerns in each area with one another, and detailing how effective integration strategies balance the needs and requirements of all three areas.

The key questions that this research hopes to address include the following:

- What are the fundamental integration issues within a complex enterprise network?
- To what extent is knowledge integration necessary and desirable across the network?
- What are the key internal and external barriers to integration in an enterprise network?
- Are there overarching principles that can guide whether, to what extent, when, and how complex enterprise networks might integrate?

1.2 Relevance and Significance

The trend towards the formation of enterprise networks in many industries with complex products is clear(Camarinha-Matos, 1999c; Cummins, 2002). The aerospace industry in particular is good example of one such industry that is greatly affected by this trend. By focusing solely on their core competencies, firms participating in enterprise networks in these industries in theory have a better chance of maintaining their world-class status and advantage within the industry. To achieve this goal, they face the daunting task of integrating large, complex enterprises with disparate policies, organizations, cultures, and technologies.

Although many efforts at integration in the past have failed, modern enterprises continue to direct their energy towards these efforts. As this trend becomes more prevalent and enterprise networks grow larger and more complex, the need for research directed at the barriers and enablers to integrating such design and manufacturing-oriented business structures will grow greatly in importance in many industries such as aerospace. To date, most enterprise integration strategies have often been one dimensional, focusing almost exclusively on technology (and often failing or coming in grossly over schedule and over-budget). Further, there has been little work done in analyzing the relationship between the degree of integration in a network needed and the architecture of the network's product. The guiding mantra to date has been "the more integration the better," without careful analysis of the marginal benefits of integration. Effective research in the domain of enterprise networks integration could potentially make a large impact in the way enterprise networks of many sizes tie themselves together technically, strategically, and organizationally.

This research lies at the heart of the strategies of billion-dollar firms as they seek out more efficient business structures to create and deliver complex, high-value products to their customers. This thesis relies on a multi-disciplinary body of research including work in information technology, business strategy, and organizational theory to elicit principles that will aid both large, established firms already engaged in enterprise networks as well as small and medium sized firms hoping to establish themselves as valuable players in large, complex, fast-moving markets.

1.3 Research Methodology

This thesis is composed of two parts: a literature review of general integration strategies in enterprise networks, and a focused, in-depth case study of enterprise-wide integration strategies of a large, virtual, extended enterprise network in the defense aerospace industry. The case study was conducted on the integration strategies of the Joint Strike Fighter Program, centered on the primary component of the network, the air vehicle (the aspect of the aircraft under prime contract to Lockheed Martin Aeronautics).

Non-attributable, semi-structured interviews were conducted at Lockheed Martin's Ft. Worth facility over two separate three-day site visits six months apart in 2004. These interviews were governed by the Lean Aerospace Consortium agreement with member companies (Appendix A). Attempts were made to speak to those in leadership and other high-level integration positions on the program, and all interviews were generously coordinated through Lockheed Martin Aeronautics' Program Management Core. Interviews were conducted with the heads of program management, material management, system architecture, the Chief Engineer, manufacturing, as well as many other people involved in integrative roles on the program.

All interviews were voluntary; not everyone contacted agreed to interviews. In particular, only one company other than Lockheed Martin with employees in Ft. Worth was willing to allow their employees to be interviewed during our site visit. Further interviews via telephone and in Cambridge, MA during visits to the MIT campus.

2 Chapter 2: Concepts in Enterprise Network Integration

2.1 Definitions and Terms

Although there has been active research into enterprise integration and related fields for almost a decade, the literature has not yet standardized on formal definitions for many key terms. Accordingly, the literature in this multi-disciplinary field occasionally seems confusing or at odds. The most basic concepts, such as *enterprise,* are very commonly used without a universally agreed-upon definition by research communities who undertake closely-related work. It is often assumed in the literature that the reader will be able to infer what is meant by such terms as *enterprise* from its use in context as well as from some common experience. While this may be appropriate if the intended audience is a close-knit community with common experience with the term, it becomes a point of confusion when read by someone in a related field who may have developed these concepts independently, as has sometimes been the case (Caramarihna-Matos and Afsarmanesh, 2004). For this reason, the basic terms and concepts used in this thesis will be clearly defined below as they will be used throughout its remainder.

2.1.1 Enterprise

The term *enterprise* is highly contextual in nature. Much like the concept of *system,* the scope of what an enterprise is largely depends on the perspective from which it is being viewed, allowing small businesses and international multi-program undertakings alike to be hailed under the same banner.

In its most general form, Black's Law Dictionary defines an enterprise as "an organization united by a common purpose," focusing on a common purpose as the defining element of an enterprise. Murman et al. go on define this common purpose as *creating value,* saying that an enterprise "is an integrated entity that efficiently creates value for its multiple stakeholders…,"(Murman et. al, 2002). While these definitions may be accurate descriptions of enterprises at their basic level, they lack a description of the enterprise that motivates their study in the literature.

Bozdogan tackles this issue by defining enterprises as "purposeful, complex adaptive technology-enabled socio-technical, open, dynamic and interdependent social-economic-technological-organizational systems organized to create value for their multiple stakeholders characterized by performing their core missions, functions or businesses that serve societal purposes" multi-level interfaces and interactions"(Bozdogan, 2004). This definition, while less transparent, captures the many aspects and dimensions of enterprises that make them of such interest to scholars, while maintaining the highly contextual nature of the enterprise.

In the realm of business enterprises, an enterprise is often analogous to a traditional firm. As firms grow in size and scope, so can the boundaries of what can be considered an enterprise. A single business unit of a larger firm can be considered an enterprise, as it is united in a common purpose of creating value, while maintaining the qualities of an enterprise described by Bozdogan. The enterprise concept can also be extended upwards a level to include other business units of the same firm that also meets the definition of an enterprise. As long as it continues to meet the definition, the level can be drawn higher to include allied firms and even industries, as the context dictates.

Whenever the concept of an enterprise is extended past the notion of a traditional firm, however, it is usually used with a specific modifier such as "extended," "virtual," or "core" to denote the way in which the term is intended. Even within the boundaries of a traditional firm, some specific structures of enterprises have become common enough that they have merited their own term, such as program enterprises and multi-program enterprises. It is important while using the word *enterprise* that it is placed in a specific context to avoid confusion in its application. The definitions below further distinguish between the terms used to describe single enterprise and networked enterprise structures.

2.1.2 Enterprise Networks

The term "enterprise network" is a broad categorization that encompasses several organizational forms that share common characteristics. Enterprise networks are organizations that are composed of multiple autonomous firms working together towards a common goal as a single coordinated and possibly integrated entity. This is a very general classification—there is no notion of degree of connectivity (integration) or requisite enabling infrastructures. The term enterprise network is analogous to the term *collaborative networked organizations* used by Camarhina-Matos and Afsarmanesh to represent these and other future collaborative-networked enterprise structures (Camarhina-Matos and Afsarmanesh, 2004).

Enterprise Networks are in many ways analogous to organization networks, as defined in the organization science literature(Borgatti, 2003; Child, 2001; Schilling, 2001). In this literature, networks are defined as a separate form distinct from both hierarchies and markets as a form of business organization. Child and McGrath define network organizations as "value creating systems of several organizations possessing complementary strengths and coordinated through a combination of contractual provisions and mutually beneficial relationships that are often orchestrated by a leading member." Network organizations "involve an investment in relationships, a sense of mutual benefit, a level of trust, and a level of coordination—all to a degree that is absent in markets." Further, networks are not held together through employment relationships or managed of the basis of bureaucratic rules and routines(Child, 2001).

The boundaries of an enterprise network are not well defined, but are dynamic and contextual. Afuah suggests that the boundaries are dynamic, and that they may shift over an efficient frontier that is shaped by both technology and industry(Afuah, 2001). The boundaries of the enterprise network can be redefined in context. While an enterprise network may consist of a prime contractor and its value chain, for example, it likely does not extend down to suppliers of raw materials. At some point, a line must be drawn between simple suppliers and suppliers that are integrated into the enterprise network, often based on the density of information exchange, monetary and strategic value of the exchange, etc. The boundaries can be different across otherwise comparable enterprise networks.

Throughout this thesis, unless a more specific term is desired, the general term *enterprise network* will be used in discussion, as it captures the broadest array of collaborative, networked enterprise structures. More specific forms of enterprise networks are described below. Enterprise networks may fall under several of the following classifications.

2.1.3 Core Enterprise

The concept of a "core enterprise," developed by Murman et al., refers to entities that are "tightly integrated through direct or partnering relationships." The concept of the "core enterprise" was developed primarily to compliment the idea of an *extended enterprise, discussed below.* The core enterprise consists of the most tightly integrated firms at the center of an extended enterprise. It could also describe a single focal firm at the center of an extended enterprise.

The term retains little meaning outside the network context. An example of a core enterprise would be the three principal partners on the Joint Strike Fighter's air vehicle platform—Lockheed Martin, Northrop Grumman, and BAE Systems. This is highlighted in the case study described in Chapters 5 through 9 .

2.1.4 Extended Enterprise

Although several somewhat conflicting definitions of an extended enterprise exist, they all agree that extended enterprises are an expansion of the scope of a core enterprise to include a large portion of its value chain. Murman et al. describe extended enterprises as "all of the entities along an organization's value chain, from its customer's customers to its supplier's suppliers, that are involved with the design, development, manufacture, certification, distribution and support of a product or family of products" (Murman, et al, 2002). This expansion of scope is intended to cause firms to to think about themselves in a more holistic sense, and to help them understand their role in the larger network in order to pull value from the entire value stream, including suppliers and customers as part of a team that creates and delivers value.

Camarinha-Matos and Afsarmanesh take a more limited view, and define extended enterprises as networks that arise when "a single dominant firm 'extends' its boundaries to all or some of its suppliers" (Camarinha-Matos and Afsarmanesh, 2004). The boundary extension is not a physical one where the dominant firm acquires suppliers and partners, but rather a partnering of the value stream that enables system-wide optimizations and processes to be put into place, actively driven from the top down. The power and clout of a single dominant firm or cohesive core of firms can be effective in aligning interests through the extended enterprise.

Dyer defines the term to refer to "a value chain in which the key players have created a set of collaboration processes that allow them to achieve virtual integration and work together as an integrated team((Dyer, 2000)." Dyer sees the extended enterprise as more than the simple collection of companies along the value chain, and considers the processes they use as well as their integrated nature to be defining characteristics of extended enterprises. The "key players" that Dyer refers to is the core enterprise. This definition will be used as the reference for extended enterprises through this thesis.

The term extended enterprise as used by Dyer has a notion of high technological connectedness. Extended enterprises are "virtually integrated," which usually is taken to mean in the literature that the relationships are supported using information technology. The term also has no notion of duration, so extended enterprises as a category can include both temporary projects and programs as well as established value chains that are competing in a market over the long-term.

2.1.5 Virtual Enterprises

There have been many conflicting definitions of virtual enterprises over the years, which is largely attributable to differences that exist across the information technology (IT) and management communities. Those in management and organizational science often conceive virtual enterprises without an inherent IT component, while those in the IT community think that the notion of a virtual enterprise is inextricably linked to, if not defined by, an IT infrastructure.

IT infrastructures aside, the literature from both fields involved in this research agree to at least describe virtual enterprises as coordinated alliances formed to execute a task or project with a temporal element. The National Industrial Infrastructure Protocol, an early project in the US with the aim of creating mechanisms and protocols that would eventually allow the formation of virtual enterprises, defines them as "a temporary consortium or alliance of companies formed to share costs and skills and exploit fast-changing market opportunities" (NIIIP, 1996). Here, there is no mention of a required enabling IT infrastructure—they are simply companies linked via an alliance, aligned along a common program, product, or service. Others, such as Byrne et al. emphasize the importance of the infrastructure: "A virtual enterprise is a temporary network of independent companies—suppliers, customers, even rivals—linked by information technology to share skills, costs and access to one another's markets. It will have neither central office nor organization chart. It will have no hierarchy, no vertical integration" (Byrne et al, 1993). In contrast to most definitions, Byrne states that virtual enterprises are largely ad hoc and void of organizational structure.

While it is arguable that such a "virtual" enterprise could exist through alliance and consortium alone(Drucker, 1988), today's market realities and the need for fast and accurate communication require some sort of enabling IT infrastructure. However, this infrastructure *enables* the virtual enterprise, rather than *defines* it. For this reason, Camarinha-Matos and Afsarmanesh, when forming the definition used by the European ESPRIT IV PRODNET project, sought to merge these definitions into one that takes all of these aspects into account: "A virtual enterprise is a temporary alliance of enterprises that comes together to share skills or core competencies and resources in order to better respond to business opportunities, and whose cooperation is supported by computer networks" (Camarinha-Matos and Afsarmanesh, 1999). This definition captures the most salient points from the previous definitions, while acknowledging the role of IT in virtual enterprises. The most crucial aspects emphasized are *networking* and *collaboration.* The aim of a virtual enterprise is to create a network of independent enterprises with aligned goals to collaborate as if they were a single entity. The basic idea of virtual enterprises is not new to the business world, but the use of new technologies and tools to enable collaboration makes the concept much more effective, and has the potential to transform many highly complex, interconnected industries.

The term virtual enterprise is sometimes used interchangeably in the literature with the term virtual organization. There is a difference between the two, however, and interchanging the terms should be avoided. Most definitions of virtual organizations make no mention of a temporal aspect of the endeavor. Ahuja and Carley state that virtual organizations are simply any organization that uses "electronic mail to share information and coordinate their work … allowing them create and sustain an identify without sharing a physical work environment." They are not temporary alliances of organizations, with a specific business objective, but rather a traditional organization that depends on IT for communication purposes(Ahuja, 1999).

2.1.6 Program Enterprises

A *program enterprise* (or *project-based enterprise*) is an enterprise that is centered on a program, "a particular product, system or service that is delivered to the customer and generates revenue." (Murman, et al, 2002). Programs generally have accountability for cost, schedule and performance of a product, system or service. Programs can also vary widely in size and in time. The largest program enterprises, such as those found in defense and civil engineering, are highly complex, multi-billion dollar endeavors, while at the low end, some programs may not be large enough to be considered independant enterprises. The duration of program enterprises is dependant on the life of the program, which could range from short-lived to practically indefinite.

2.2 Enterprise Networks under Consideration: Virtual Extended Enterprises

This research will focus on enterprise networks that can be simultaneously considered extended enterprises, virtual enterprises, and program enterprises. These virtual extended enterprises are extended enterprises formed around a single time-limited program where collaboration and integration is enabled by IT. This form of enterprise network is emerging as a common form of enterprise network in the aerospace industry, and many established industries are moving towards collaborative networks. The characteristics of virtual extended enterprises, as well as a framework for analyzing enterprise networks as a whole, is presented in Section 2.3.

2.2.1 Integration

The term "integration" is a word that is also frequently used without a precise definition. According to the Oxford English Dictionary, integration is "the making up or composition of a whole by adding together or combining the separate parts or elements; combination into an integral whole." When used within the domain of business and information technology, however, the term has often been applied strictly to the bringing together of computer networks and applications to allow them to communicate between each other.

As used in this thesis, the term integration refers to the bringing together of two entities in such a way that unites and coordinates not only their computing resources, but also their strategies, processes, and organization so that the integrated enterprise behaves that behaves as a coherent entity. The constituent enterprises of an integrated enterprise network retain their autonomy, but function in a coordinated fashion using common infrastructure and processes across boundaries.

2.2.2 The Continuum of Integration

Integration can be seen as an extreme on a scale that ranges from free market coordination at one end of the continuum to full integration as described above at the other. *Free market coordination* is the loose, often implicit coordination that exists between enterprises in a free market. Market coordination can be based on price, published strategy, and other indirect forms of communication that are facilitated by the market. There is no explicit relationship between firms, and little trust is built. Moving a step closer to integration on the continuum, the next level is *cooperation.* When two enterprises cooperate, they directly communicate and identify divisions of labor and desired directions and outcomes. They exchange non-sensitive information, and may establish an on-going relationship, building a base level of trust.

Beyond cooperation is collaboration, where enterprises begin to exchange sensitive information such as performance metrics, long-term strategy, and process data. The density of communication in collaborative enterprises is higher than in cooperative enterprises, and a larger degree of trust is built. Strategies are more aligned in collaborating enterprises, as fates could be closely aligned. While communication is high, divisions remain between collaborating enterprises and the processes and infrastructure between them remain separate and distinct. As collaboration is taken further, and these boundaries are gradually erased, integration occurs, with the highest level of inter-firm trust.

2.3 Characteristics and Classification of Enterprise Networks

As seen in theory and practice, enterprise networks, and the smaller subset of virtual extended enterprises, can vary in several dimensions that can affect the approach to integration taken by the network. The purpose of characterization and classification of general enterprise networks in this thesis is to briefly expose the reader to the wide variety of enterprise networks possible, and to describe in detail the characteristics of the enterprise networks that this thesis will consider in order to understand how integration strategies align with enterprise architectures.

2.3.1 Characterization of Enterprise Networks

From the definition of enterprise networks developed in Section 2.1, it is clear that some of the key characteristics of an enterprise network include degree of integration, extent of computer networking, agency of participating enterprises, and limited duration. The degree of integration, and the extent of computer networking can vary widely according to the needs of the network, but are present to some degree in all enterprise networks. While multi-party alliances are very common business arrangements (the top 500 global business have an average of 60 major collaborative alliances each (Dyer, 2001)), most are simply cooperating rather than collaborating or integrating themselves to the point that they could be considered an enterprise network(Camarinha-Matos, 2004).

Although highly integrated enterprise networks may perform as though they were a single organization under central control, they are not. Enterprise networks are networks of independent enterprises, cooperating because they each can achieve more through cooperation than they can by acting in the market as unaffiliated agents. If this condition no longer holds, the enterprise is free to leave the network. Enterprise networks last only as long as they continue to provide value for their members, and then they disorganize. A key characteristic underlying the operation of enterprise networks is their sharp focus on value-added relationships (Hawkins, 2004).

Enterprise networks are not analogous to holding companies and their constituent holdings loosely directed from a corporate headquarters. An enterprise network is not a legal entity with shareholders or an elected board of directors, and as such, it has been argued that it therefore has no obligations as a collective. The enterprise network does not own property, execute contracts, pay taxes, hire employees, or receive benefits from society as an entity—these are rights and benefits reserved for the individual enterprises participating in the enterprise network. As such, it has been argued that many of the basic tenets of Contract Theory would not apply to them, and alternative explanations are sought to understand how ethics and morality in such an arrangement can be rationalized (Hawkins, 2004).

Enterprise networks cannot necessarily be easily characterized by their organizational structure. The concept of an enterprise network is grounded on a diversity of organizational models—namely, those of each enterprise member. There are many organizational forms, and it has proven difficult in the literature to find network-wide behavioral patterns at the regional or even sector levels. Instead, the behavior of enterprise networks is often more tightly linked to the entrepreneurial capabilities of its members(Camarinha-Matos, 2004).

Some have termed the organizational structure of the enterprise network, and especially that of the program-based enterprise network, as an "adhocracy," borrowing from Henry Mitzenburg's book *The Structuring of Organizations,* in reference to enterprise networks' tendency thus far to be managed in an ad hoc, project-centric style, in contrast to more traditional control regimes such as an "entrepreneurial style" or a form of bureaucracy (Mitzenburg, 1979, Hawkins, 2004). According to Mitzenburg, these adhocracies exist in rapidly changing environments, and can allow for greater flexibility and higher levels of innovation.

2.3.2 Enterprise Network Life-cycle

A key characteristic of enterprise networks mentioned above is their temporal nature. While a more general enterprise network may last indefinitely, virtual enterprises and program-based enterprise networks and limited duration networks that are created and destroyed by their constituent members as the network's environmental changes. The common processes of creation, dissolution, operation and evolution make up the basic life-cycle of all limited duration enterprise networks. See Figure 2.1. While others have dissected the life-cycle of these enterprise networks to a much finer level of detail(Spinosa, 1998), for our general purposes these four stages are sufficient to appreciate the importance of understanding enterprise network life-cycles(Camarinha-Matos, 1999c). It is essential that enterprises participating in a limited duration network must share a common understanding of these life-cycle stages. There has been a research emphasis focused on creating common tools and processes for managing each major, and sometimes minor, stage in an enterprise network's life-cycle to reduce many of the coordination barriers to the creation and management of enterprise networks(Spinosa, 1998).

The first major stage is *creation*, which is also the most critical stage to the overall success of the network. The key activities in this initial stage include the definition of many crucial aspects of business, technology, and organizational strategy, and include partner selection, contract negotiation, definition of access rights, data and information sharing, network joining and exiting procedures, and communication definitions. Each of these processes is critical to the long-term vitality of the network and are individually the subject of a great deal of current research in the field of enterprise networks(Field, 2002; Lackenby, 2002; Mejia, 2002).

The second major stage is *operation*. This encompasses the routine day-to-day operation of the network, where the many of the processes designed in the creation stage are put into operation, and other more routine processes are implemented within the information management architecture. Processes in this stage include secure data exchange and information sharing, order management, dynamic planning and scheduling, and task management and coordination(Afsarmanesh, 1999; Gibon, 1999; Schreiber, 1999).

A third stage in the life-cycle of enterprise networks is *evolution.* This stage handles the exceptions to routine operation, such as a change in the environment, a change of network membership, or other events or conditions that would necessitate a change in course and restructuring of the network. In this phase, many of the processes from the creation phase are revisited.

The final life-cycle stage is *dissolution,* when an enterprise network has reached the end of its useful life, either by completing its goals or through the determination of a network partner, and must dissolve. Definition of liabilities for all parties, especially manufacturers with products with their own life-cycle concerns must be assigned.

2.3.3 Roles in Enterprise Networks

In all but the very smallest of enterprise networks, there are specialized roles that have emerged that allow the network to operate smoothly in the various phases of its life-cycle. Some of these roles are filled by pre-existing organizations in the network that have other obligations as well, while some may be filled by organizations devoted exclusively to a necessary role. Some roles can be filled by organizations external to the network. The most common roles in enterprise networks include the Coordinator, Member, Broker, Project Manager, and Auditor(Camarinha-Matos, 1999a; Katzy, 1999). Not all of these roles are necessary in every enterprise network, and many of the responsibilities in smaller enterprise networks are distributed on an ad hoc basis, or handled by the Coordinator. For larger, more dynamic networks with multiple projects, many of these roles become important and have dedicated resources allocated to them.

The Coordinator can be either a specialized, dedicated node in the network, or a pre-existing member in the network can fill the position. In practice, this could be the most powerful member (or members, in the case of a tightly knit core enterprise), or the perhaps a member whose core competency is integration. In more hierarchical networks, such as extended enterprises, this role naturally falls to the firm at the top of the value chain (although not necessarily so). The Coordinator is tasked with many roles related to network coordination, such as new member registration, infrastructure support and evolution, and coordinates the network dissolution. The Coordinator would be tasked with directing the network in pursuit of its common goals.

A Member of the network would, in addition to contributing its competencies towards the completion of the network's product or service, be tasked with managing its own information visibility, information and material exchange between partners, and perhaps contact with customers directly for matters that directly relate to their products. Members will maintain their autonomy to a great extent in the network, and retain responsibility for their effective performance in the network.

One role that is sometimes not considered a dedicated enterprise network role but is essential to the success of the network nonetheless is that of the Project Manager (PM). The PM manages the engineering, order processing, and time and budget constraints of a particular program, while managing enterprise network members who may have problems. Some do no consider this a dedicated position devoted to the organization of an enterprise network, but rather a position that is tied to a specific project(Camarinha-

Matos, 1999c). This could be true of enterprise networks with many concurrent projects, but in project-based enterprise networks that are the focus of this thesis, this distinction can become non-existent and may become folded into the job of the Coordinator.

Other roles in an enterprise network include a dedicated Broker, sometimes external to the network, whose sole duty is to seek out potential new members for the network based on whatever criteria that the network determines. Another similar position is the Competence Manager, who actively seeks out members with complementary competencies and pairs them for suitable tasks. The Competence Manager should ideally be an impartial party that objectively assigns tasks based on best value added, above political and internal pressures. If the role of Competence Manager is not handled by a disinterested party, the will be a risk that tasks within the network will be allocated in a sub=optimal way that benefits some members at the expense of overall network performance.

Network "coaches," dedicated to the design and evolution of the network's computer infrastructure, are seen in larger networks as well as smaller structures. Network auditors can also serve as third parties to perform independent third party assessments of the financial resources of the network.

Table 2.1 - Possible Roles in an Enterprise Network

Enterprise Network Roles	Duties
EN Coordinator	• New Enterprise Registration • Infrastructure support to new members • Infrastructure development and evolution • Network dissolution
Member	• Contribute competencies to goals of network • Manage its own information visibility • Share and exchange data/materials throughout the network • Handle first contacts with customers
Project Manger	• Manage schedule and budget of projects • Direct engineering, order processing • Manage members with problems
Broker	• Recruit new Members into the Network
Competence Manager	• Identify and match competencies within the network
Auditor	• Perform independent financial assessments for the network
Network Coach	• Direct construction and maintenance of network infrastructure • Develop rules for order processing

Classification of Enterprise Networks

The variation among possible enterprise network structures lends itself to classification in order to aid in identifying enabling infrastructures for these forms. The earliest attempt to classify enterprise network structures was done by Camarinha-Matos and Afsarmanesh (Afsarmanesh and Camarinha-Matos, 1997). The original taxonomy suggests looking at five characteristics that can be used to categorize enterprises networks. For purposes of this thesis, their taxonomy has been expanded and modified slightly to define seven key characteristics: *duration, structure, participation, governance, visibility, coupling, and size*. The addition of size has been suggested by (Laubacher, 2003), and coupling has been added as a measure of the degree of integration between enterprises in the network.

Duration

The first characteristic considered in the Camarinha-Matos and Asfarmanesh taxonomy is *duration,* which can vary considerably in enterprise networks. At one end of the spectrum, an enterprise network can form spontaneously to take advantage of a single, short-lived business opportunity. Such a network would need a tremendous amount of pre-existing coordination mechanisms in place to quickly collaborate, and subsequently dissolve. At the other end of the spectrum, enterprise networks may form to fill a long-term business niche. Absent significant competition, such as in a public municipality where several organizations work together to bring various utilities to business and residential areas, there is little change in the network structure over time.

In between these two extremes lie many variations, although currently many enterprise networks tend to have longer, although limited, durations. Even in shorter-term industries, such as the auto industry, business alliances and partnerships tend to be long term as the costs of developing a new partner are often very high. As these switching costs are lowered with advances in IT and as many competencies become more common, it is likely that the average duration of enterprise networks will shorten. In creating scenarios for future organizational development, the MIT Scenarios Working group considered longevity a key characteristic (after size) when considering possible future trends in organization development(Laubacher, 2003).

Structure

Enterprise network *structure* refers not to the static relationships between elements in the network, but the dynamic nature of the network, ranging on a continuum from highly dynamic to completely static. In dynamic, also called volatile, topologies, entities have the ability to enter and exit the network at will, while static networks are created in place with the intention that the network will remain unchanged over the intended life of the enterprise network, as in many older traditional supply chains. More dynamic enterprise networks will require additional infrastructure to facilitate entering, and leaving the network, as well as partner selection.

Participation

The notion of *participation* in this taxonomy addresses the issue of exclusivity within the network: are participating enterprises dedicated to a single network alliance, or are they free to pursue membership in multiple networks, perhaps even with a competitor in order hedge bets? In the non-exclusive case, there are much higher requirements for data security, and more limited knowledge sharing among participants. Non-exclusivity possibly decreases the overall level of trust in a given network, and will likely lead to lower levels of integration and knowledge sharing across the network.

Governance

Governance is a dimension for enterprise network classification that refers to the governance structure in the network. For example, enterprise networks can be centrally coordinated or controlled, employing a star-like structure that is dominated by the core enterprise that makes most strategic decisions for the network. The opposite of star-shaped structures would be flat, decentralized structures that are more democratic in their coordination and control. Between these two extremes, hybrids exist, such as a flat, democratic core with star-like supply chain that feeds this central partnership. See Figure 2.2.

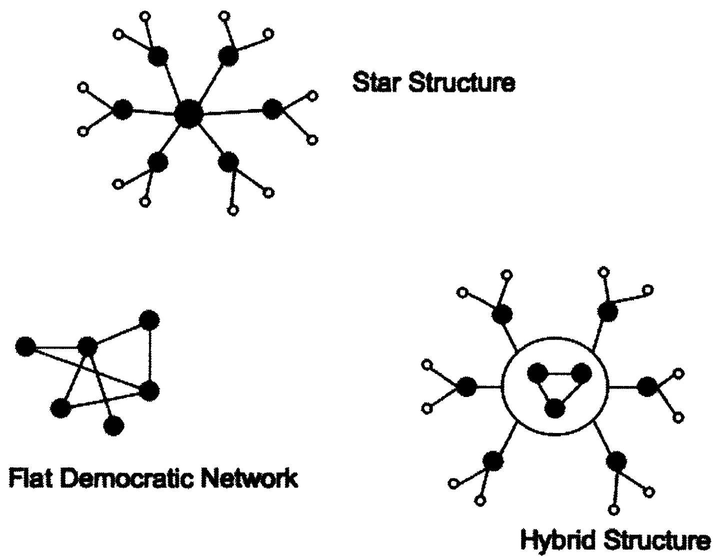

Figure 2.2 – Governance Structures of Enterprise Networks

Regardless of governance structure, control mechanisms of some kind are needed to make the network operable. In the case and star-shaped structure, governance is highly centralized and directed from a single office, which is more straightforward and more in line with traditional supplier networks of larger enterprises from the viewpoint of infrastructure implementation. Although there is no large central authority in decentralized, flat democratic networks, some central coordination is needed (agreement on protocols, schedules, budget), and will be created to aid the network in decision-making and resource allocation. It has been shown in decentralized enterprise networks that a dedicated alliance function that provides an element of control and coordination greatly increases the likelihood of strategic success of the alliance(Dyer, 2001). As such, it is likely that any enterprise network, regardless of structure, will require some level of network governance.

Visibility

Another classification in this taxonomy is *visibility*. Visibility refers to the ability that any given member of a network has to view product and process information from its upstream and downstream neighbors. At one end of the spectrum, a members can only gather information from its immediate neighbors that it has direct contracts with, as would be the case in an older, traditional supply chain. At the other end of the visibility spectrum, enterprises in the network could have multi-level visibility, which includes access to some level of information across the entire network that could be used to fine-tune the activities of individual members with the goal of globally optimizing the output of the enterprise network as a whole. The detail and content of this multi-level visibility might be an architectural element of the enterprise network.

Coupling

Coupling is a measure of how tight the integration is within an enterprise network, ranging from tightly coupled, where all process information is shared and processes are highly interconnected, to loosely coupled, where data is exchanged throughout the network, but processes are not highly interconnected between individual enterprises, allowing for a much higher degree of autonomy in the network.

A highly coupled enterprise network will have processes that couple firms not only in a vertical, single-level supplier-contractor role, but also horizontally at the same level between suppliers collaborating on a system, and at multi-levels, where a sub-tier supplier might work directly with a prime contractor in some situations. A characteristic of a tightly coupled enterprise network will be a shorter average path length (where paths between members are defined by a shared process) in a network theoretic sense between any two randomly selected enterprises in the network than in networks with only single level, vertical paths. The horizontal and multi-level connections in the network will be concentrated within subsystems, however, and not randomly in a network, as has often been studied in network theory. Figure 2.3 illustrates this principle.

Figure 2.3 – Coupling in Enterprise Networks. On the left, all processes flow vertically between two levels and is considered weakly coupled. On the right, processes may flow horizontally between actors on the same level, as well vertically across multiple levels is considered tightly coupled.

Size

The last measure of enterprise networks is *size,* which is a fairly straight-forward metric. Enterprise networks can range across a wide variety of sizes, from small and medium sized, family owned businesses to billion-dollar international programs. The size of an enterprise network can be measured either in terms of persons employed in the enterprise network or in terms of budget.

2.4 Classification and Characterization of Virtual, Extended Enterprises

This thesis chooses to focus on the integration challenges of program-centric, virtual extended enterprises. This class of enterprise networks shares all of the characteristics of an extended enterprise with those of a virtual enterprise. Typically, enterprise networks of this sort have evolved within large, program-centric industries with complex products where large firms have taken an interest in engaging their entire value stream in a collaborative way. There is a high reliance on information technology, and the processes and information that flow between members of the network tend to be more tightly coupled.

The core enterprise takes on many of the leadership roles within virtual extended enterprises. This firm (or firms) usually serves in the role of network coordinator, broker, and program manager. This firm possesses the majority of power in the network and often has budgetary authority over the entire program. Moving from a traditional supply chain structure to an virtual extended enterprises in these cases involves significantly empowering the supply chain and more closely involving the customer in matters of requirements, design, manufacture, and logistics.

Within the taxonomy presented in Section 2.3, virtual extended enterprises can be classified according to Table 2.2.

Table 2.2 – Characterization of Virtual Extended Enterprises (VEEs) using the taxonomy from Section 2.3

Dimension	Virtual Extended Enterprise Characterization
Duration	*Medium to Long* • VEEs tend to be larger, long term projects that justify the development of complex infrastructure and partnering arrangements
Structure	*Relatively Static* • Because VEEs tend to be long term, the relationships tend to be more established, leading to relatively static structures. Firms would only be removed after repeated failures to perform and efforts by the network to correct the situation.
Participation	*Medium Exclusive* • Generally, participating firms have some loyalty towards the center of the VEE, but there is rarely any contractual basis for restricting firms from participating with competing networks
Governance	*Star-Shaped Governance Structure* • VEEs have a focal firm at the center, which usually takes on governance of the network and many network roels.
Visibility	*Medium High Visibility* • VEEs have a medium to high degree of visibility through the network, usually enabled by IT. Lower level suppliers will have access to higher level information when needed.
Coupling	Medium to Tight Coupling • VEEs tend to be more tightly coupled than not, establishing long-term relationships. Without this tight coupling, they may be considered an ordinary extended enterprise.
Size	Medium to Large • VEEs tend to be fairly large, as they encompass the full supply chain of a long-term project or program.

3 Chapter 3: Enterprise Network Integration: Development, Barriers, and Enablers

Integration challenges for enterprise networks can quickly multiply in several directions in the face of growing technological as well as organizational complexity and also in the face of accelerating rates of technological change. Over the past decade, many enterprises have struggled to achieve the promised benefits of achieving greater integration internally, often having to cope with information technologies that have not performed as promised, facing efficiency gains that have failed to materialize, and having to overcome internal resistance to the adoption of new technologies by the various user groups. This has long been the crux of the problem, preventing enterprise networks from achieving a higher level of performance in their respective market segments: namely, integration challenges have proven to be rather difficult, fraught with many barriers. It has not always been clear where barriers to integration have simply held back large gains and where integration has simply proven to be ineffective. To compound the problem, the technology of integration has been evolving quickly, leading some to describe the problem as "hitting a moving target." As such, the virtual, extended enterprise architectures have not become prevalent in many complex industries today, and may well not become viable until these barriers are gradually overcome and the benefits of integration become more of a reality.

This chapter seeks to examine the most common barriers to integration across virtual extended enterprises and to identify best practices and strategies for integration that mitigate the observed barriers, increasing the likelihood of success in enterprise networks. This discussion builds upon the foundational concepts outlined in Chapter 2. The scope of this examination is not limited to purely technical or process-based challenges, but is extended to include all critical barriers, be they technical or socio-technical, such as organizational hurdles or strategic challenges. In practice, the non-technical barriers often prove to be the most intractable and deserve special attention. Further, the integration strategies developed for enterprise networks will be compared with integration strategies for the single enterprise, on which considerable research already exists. More importantly, barriers that are unique to the case of enterprise networks will be given special consideration.

3.1 Background of Enterprise Networks and Integration Efforts

The field of study devoted to the understanding of enterprise networks and their integration is relatively nascent, tracing its origins to the rise of information technology in the 1980s and 1990s. Current studies focusing on the integration of enterprise networks have evolved on the heels of the earlier research performed by those within the information technology (IT) sector, concentrating on the integration of the internal enterprise processes. The early work in enterprise integration focused on integrating the IT requirements across a single enterprise unit into a unified, coherent system, automating processes and combining them into unified operations through the employment of common applications and standard interfaces. Examples include Enterprise Resource Planning (ERP) systems and Customer Relationship Management (CRM) suites(Cummins, 2002; Laudon, 2004). The scope of what constituted an "enterprise" was often narrow compared to more recent definitions given in Chapter 2, and could be limited to the direct oversight of the program champion/sponsor, which could be at a group, facility, program or division level, rather than at the larger enterprise level (Murman, 2002). Much of the earlier work in enterprise integration focused on developing new technologies for communication and sharing, including the development of standards, protocols, and centralized data management such as ERP, CRM and Product Data Management (PDM) systems. Early enterprise integration efforts made good progress towards tackling basically a single dimension of a larger challenge, but this seemingly lopsided approach often suffered from ignoring many of the strategic and socio-technical aspects of integration, which are described below in greater detail.

3.1.1 Internal Enterprise Integration

Since the explosion of information and communication technologies in the 1980s and 1990s, firms have asked the basic question: "How do we take advantage of the many disparate sources of information that we now have across our various applications and databases to aid our decision process?" At the time, many firms had a treasure trove of data spread out across many proprietary systems of varying vintage, but they did not know how to effectively gather it in ways that could create new value for the firm. IT experts termed this process of integrating data for management of the firm "enterprise integration," as it gathered (integrated) information from across the enterprise in a coherent fashion, allowing decision makers to have access to more information in their decision making process. In the early days (and to some extent, continuing today), "enterprise integration" was largely thought of in terms of IT only; it was often not a project that would involve top management, production workers, or knowledge workers, and it did not necessarily alter business processes or long-term strategy.

After more than a decade of both academic research and real-world experience with the challenges of integrating information systems throughout the enterprise, the Enterprise Integration (EI) community has developed new technologies, tools, and strategies for dealing with the challenge of aggregating and integrating the information that exists across a single enterprise not only to provide new aggregations of data but also to potentially serve as a springboard for transforming the fundamental business processes that drive the enterprise (Cummins, 2002; Venkatraman, 1994). The term internal enterprise integration will be used to differentiate the enterprise integration activities in the single-firm enterprise from those in an enterprise network.

The meaning of the term "enterprise integration" in both the literature and in common perception is slowly evolving from an information-centric view of integration to a more holistic, enterprise-wide, view that incorporates strategy, organization, and processes into the scope of integration. Many of those in the IT community have come to see IT as a necessary and critical enabler of internal enterprise integration, but understand that information and communication strategies alone cannot integrate the entire enterprise. To successfully integrate across the enterprise, information systems and technology must be aligned with business strategy, organization, and processes and relevant stakeholders representing all of these areas must participate in the process. Without these essential elements, the integration of information systems and technology can provide only a minimal level of benefit to the enterprise, if at all, and will not provide the level of impact that could fundamentally change business processes or the business itself. There is a litany of businesses that have unsuccessfully attempted technology-centric integration strategies, only to later scrap the entire effort.

3.1.2 Early Integration Efforts: Lowering Transaction Costs Through Technology

The explosion of IT and the proliferating means of communication in the 1990s were expected to significantly lower the transaction costs of collaborative, networked business arrangements by allowing quick and timely information transactions and more coordinated flows of material. Transaction costs are any costs that are incurred in making an economic exchange, ranging from direct costs, such as fees paid to those who move information, to indirect costs, including time and effort to complete a transaction. Ronald Coase's *Theory of the Firm* in 1937, followed decades later by Oliver Williamson's work in transaction cost economics offered the beginnings of an economic theory of business organization based on the concept of lowering transaction costs. This work suggests that as transaction costs are lowered, businesses will seek standard materials and services from those external to the firm if the costs of obtaining them externally are lower than the cost of acquiring them internally, due to economies of scale enjoyed by outside producers able to sell them to multiple customers (Coase, 1937; Williamson, 1975).

This idea is cited as being responsible for the waves of outsourcing and later off-shoring of fairly homogeneous or standardized products and services that began in the early 1980s. It is a very powerful idea that has to a great extent motivated the deployment of IT systems in enterprises around the world in an effort to lower transaction costs, expected to lower overall costs (production and coordination) and increase profitability. The mantra of "drive down transaction costs at all costs" is dangerous if it leads to a myopic and short-term view of integration strategies, however. Transaction costs are a very broad category of costs, and they can occur on different time scales. Some efforts to reduce transaction costs can result in what is often termed the "J curve," or "worse before better" behavior, where strategies will actually decrease performance in the short term, but provide long term benefits, perhaps far in excess of the initial downturn. The converse of this is a strategy adopted to reduce transaction costs in the short term that can do long-term damage to the firm. When looking at transaction costs, a proper stance should be to lower transaction costs, with a multi-scale perspective that leads to long term, sustained growth.

This concept is not new, although it has not always been expressly articulated. There have historically been collaborative networks that have used mutual trust and co-location to lower the transaction costs and structure industries for long term, sustainable gain. Although these practices pre-date transaction cost economics, they can be seen as strategies that fall in line with its thinking.

3.1.3 Early Collaborative Networks

Just as it had opened doors towards the possibility of coordinated information flow and integration across an individual enterprise in the early 1990s, information technology and the Internet infrastructure breathed life into an older idea: collaborative networks of enterprises. Networks of businesses, each contributing their core competencies towards the creation of an end product in a coordinated fashion, have long collaborated to bring a product to market. On small, regional scales, tight collaborative networks of interconnected businesses with complementary skills have ruled many industries such as textiles and shoemaking for several centuries, and this trend is still seen today in the mega-construction and auto industries of the 20^{th} Century (Piore, 1984). Many of these industries are interlinked through strong networks of trust, built on relationships that have been forged on a personal level between family-owned and operated businesses over many years. Others rely on trust that arises in small, close-knit industries where reputation carries great weight. Some have pointed to the American whaling industry of the 19^{th} Century and later to early Hollywood studios as other very influential industries that set both the business and legal precedents for collaborative networks to emerge (Goranson, 1999). The level of trust exhibited in these networks allows transaction costs to be lowered because accuracy of information can be trusted, preventing information re-checking, and formation of networks are often free from onerous legal burdens, instead relying on the good word of two individuals. These networks, however, have long been limited by communication and coordination requirements, and have been limited in the level of integration (especially technical and organizational) they have displayed.

Collocation

Some industries and large producers saw the benefit of a more tightly integrated network of enterprises working in concert, and sought ways to minimize communication and coordination costs in order to develop closer, more integrated relationships. One method of lowering these costs was to locate many parts of the network within close geographical proximity to each other in order to facilitate the timely exchange of information and material (Camarinha-Matos, 1999b). The most cited example of this arrangement is Toyota's establishment of Toyota City, a campus of co-located suppliers developed as early as the 1950s to more tightly integrate suppliers for the purpose of decreasing communication and coordination costs in the production of Toyota vehicles (Dyer and Nobeoka, 2000). Toyota's stance toward supplier relations was highly advanced for its time, as co-location was not a common practice.

The Toyota network was not the first network to co-locate, however. Many industries with collaborative networks throughout history have been highly concentrated in a small geographical area, such as the textile mills or the cobbling industry of northern Italy since the 15th Century, the 19th Century American whaling industry concentrated overwhelmingly on Nantucket Island and New Bedford, Massachusetts, or the movie production industry in Hollywood (Goranson, 1999; Piore, 1984).

Collocation often leads to fairly closed, static networks with high barriers to entry and exit, where such a network has high asset-specificity—it requires a new capital investment for facilities specific to supplying particular customers that would not be optimal if an enterprise wished later to move out of the original network. Without significant legal assurances, investment and strong leadership, this arrangement could often prove to be impractical, especially in the very common case of volatile markets without a very high degree of trust between firms.

Many enterprises are hesitant to co-locate without substantial, long-term, guarantees that often are not possible in program-based virtual extended enterprises that will dissolve at the termination of the program or project.

3.1.4 IT and Transaction Costs

When properly applied, information technology can enable enterprise networks to lower transaction costs due to information transfer between firms. Information can be transmitted at minimal cost once the technologies are in place, and the speed of transfer is almost instantaneous. The volume of information that can be moved at amazing speeds is very large, and growing rapidly. Moving information is seldom a problem today, however; understanding and processing the large quantities of data as well as packaging such data in useful ways is now the greater challenge in managing the costs of moving data. These challenges are large enough that many firms have actually seen *increased* transaction costs as a result of implementing information technologies and systems that were poorly planned and executed (Cordella, 2001).

Coase and Williamson predicted that as transaction costs are lowered, firms will seek alternative structures in terms of relying on markets for obtaining materials and services or producing them internally through vertical integration. Especially in the late 1990s, during the Internet "boom," many businesses assumed that by moving their business online they would automatically lower their transaction costs. It was expected that loosely-connected enterprise networks would quickly dominate the market in many industries through the emergence of Business to Business (B2B) transactions. "Brick and Mortar" enterprises, relying on traditional strategy assessments, were hailed as relics of a past era. In retrospect, this did not, of course, come to pass. With the burst of the "Dot Com" bubble in 2000, brick and mortar firms that had also embraced information technology continued to do well as many of the "dot com" startups floundered. Michael Porter argued that what many of these IT-centric firms failed to realize was that IT was simply an enabler, not a substitute for a well-developed strategy based on established principals and market analysis with the goal of long-term, sustainable competitive advantage (Porter, 2001). By empowering both suppliers and customers with more information, information technology (specifically, the Internet) can potentially weaken the profitability of markets, according to Porter. He argues that successful companies, and by extension, enterprise networks, will distinguish themselves through strategy, not through price alone. Information technology is seen as a critical enabler of traditional competitive strategies, not a wholesale replacement of them. Porter argues that successful strategies enabled by information technology should be focused on interlinking activities in the value chain—the set of activities through which a product or service is created and delivered.

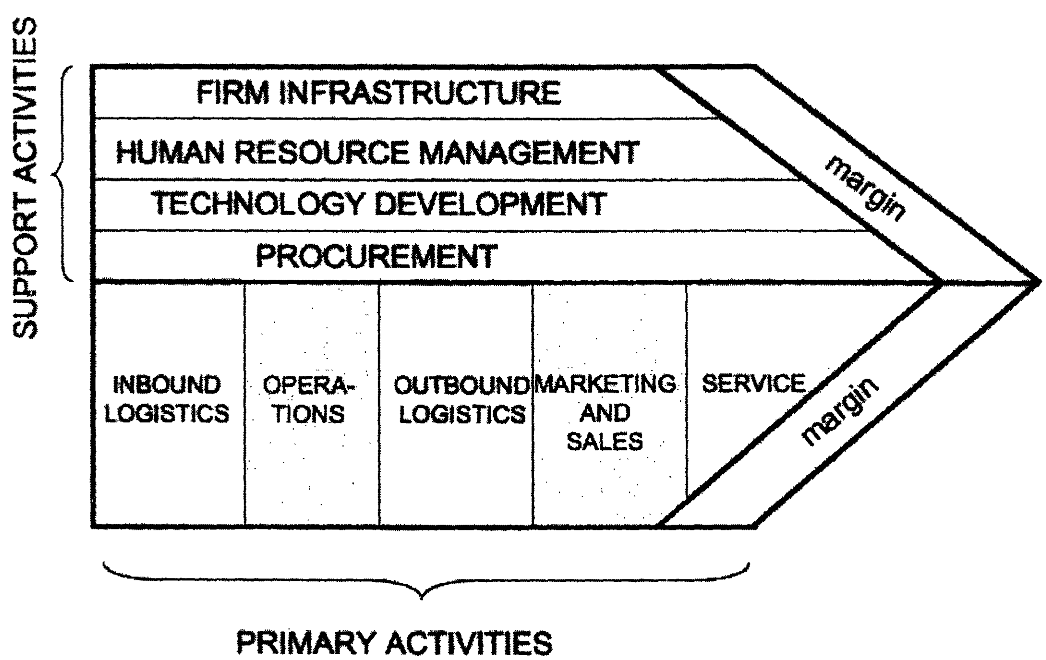

Figure 3.2 – Porter's Value Chain

The value chain, depicted in Figure 3.2, is a widely used basic tool to understand the influence of new activities on an enterprise. It divides the activities of an enterprise into "primary activities," including inbound logistics, operations, outbound logistics, marketing and sales, and after sales service, and "support activities" that each influence the primary activities, including enterprise infrastructure, human resources, technology development, and procurement. At the end is a profit margin, which is affected by how well the enterprise executes is primary and support activities. The value chain concept was developed in (Porter, 1985).

3.1.5 New Directions in Enterprise Integration Research

As the study of enterprise integration continued through the late 1990s and into the new millennium, it became increasingly evident that enterprise integration, internally or in a network, represents a much broader challenge than the adoption of information technologies and systems alone. Consequently, research began to focus on such strategic and organizational topics as business process alignment, organizational structure, socio-technical interfaces within the enterprise, and legal concerns, as well as on larger, more holistic, enterprise architectures. As the dimensions of the challenge faced in enterprise integration expanded, the boundaries of the enterprise itself, too, became broadened.

Researchers in the area began to look more closely at the *extended enterprise*, bringing both the supply chain and its customers into the picture (Murman, et al., 2002). Greater emphasis was placed on the enterprise's position within the larger value chain relative to its suppliers and ultimate consumers, moving towards a more holistic view of how an enterprise creates and delivers value to its customers (Rayport, 1999;

Venkatraman, 1994) and, more broadly, to its multiple stakeholders (Murman, et al., 2002).

3.1.5.1 Interlinked Value Chains

The concept of "value chains", developed by Michael Porter, can be applied to the analysis of enterprise networks that take the form of extended enterprises, and serves as a useful visual model for understanding the various dimensions of enterprise integration. Within an extended enterprise, there are many participants, each with its own value chain with its own primary and supporting activities. When these value chains operate in a synchronized fashion across an extended enterprise or even industry, they operate as part of what Porter terms a "value system." Integration entails the proactive efforts to coordinate, synchronize and even combine the primary and supporting activities throughout the respective value chains of all the enterprises that are members of an extended enterprise. Integration may be technical, in the case of IT, but also includes restructuring of processes, establishing collaborative relationships and building strategic partnerships.

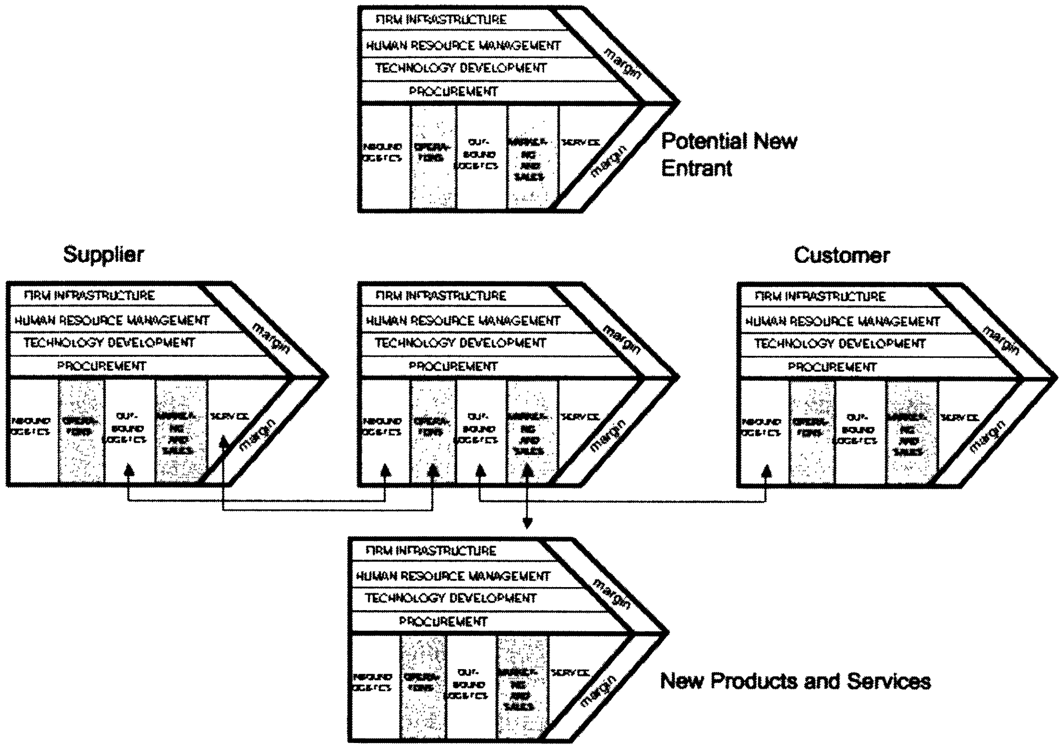

Figure 3.3 – Madnick's Interlinked Value Chains

Madnick has combined the concept of "value systems" with Porter's other widely used tool for strategic analysis, the "five forces model" (Porter, 1980) to develop the concept of interlinked value chains to visualize the role of integration between firms in a network or across an industry (Madnick, 2005). An interlinked value chain analysis places the values chains of a focal firm at the center, surrounded by the value chain of its suppliers, customers, potential entrants, and one representing new technologies and opportunities. This presentation includes the value streams of the entire extended enterprise. Within this framework, shown in Figure 3.3, firms can develop and analyze integration strategies by looking at ways to combine and streamline the primary and supporting processes between two value chains in the value system, combining the outbound logistics of a supplier with the inbound logistics of a manufacturer, for example. Integration strategies can also be pursued to block potential entrants or hasten the adoption of new products. The concept of value systems and interlinked value chains can serve as a simple, powerful mental model and visual aid to represent integration strategies, and can be used to develop strategies that lead to sustainable, multi-scale competitive advantage.

3.2 A Framework for ICT-enabled Enterprise Transformation

Perhaps the most well known framework developed for understanding the approaches to and impact of using IT for enterprise integration and transformation in the broader context was developed by Venkatraman (Venkatraman, 1994). This framework helps one to understand both how the notion of enterprise integration has evolved (and continues to evolve) as enterprises seek more benefits from their IT investment and strategies, and presents a path that leads to the development of enterprise networks and new business scopes flowing out of the efforts at integration within the single firm.

Venkatraman identified five levels in his framework—localized exploitation, internal integration, business process redefinition, business *network* redefinition, and business scope redefinition, each one providing increasing benefits to the enterprise. See Figure 3.4. Venkatraman refers to the first two levels of transformation, Localized Exploitation and Internal Integration, as being evolutionary—that is, they build incrementally on the original business structure and processes and do not significantly alter the enterprise in a revolutionary way. They primarily build on integrating the many technologies across the

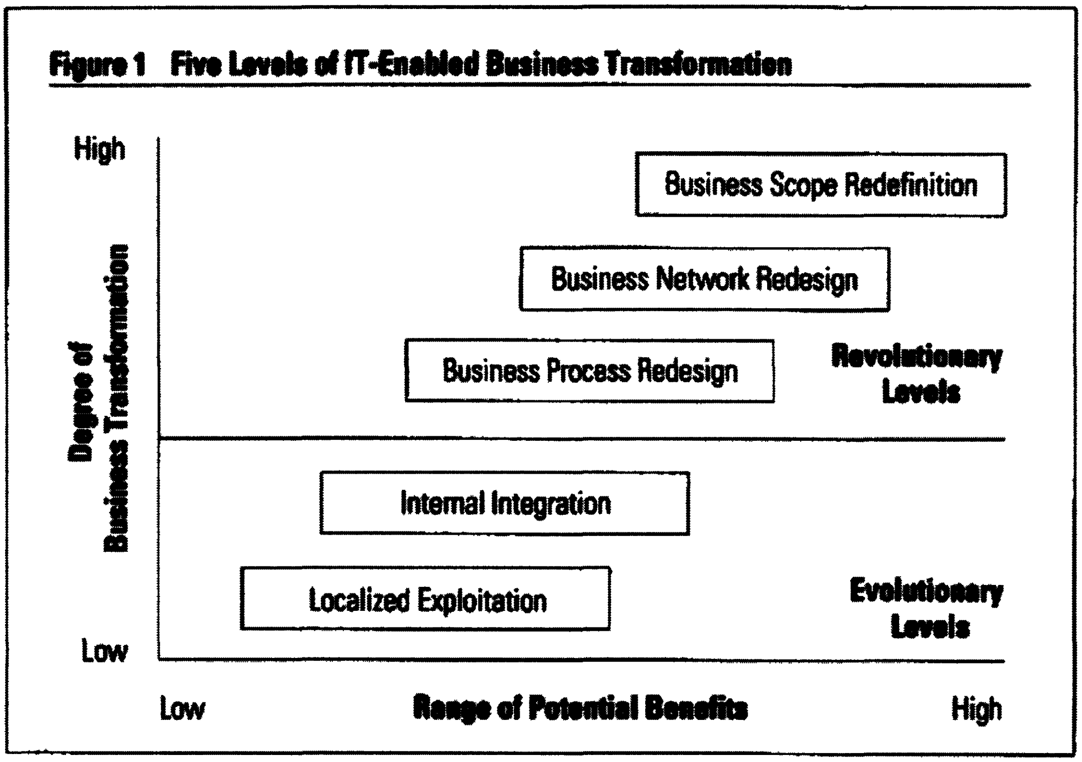

Figure 3.4: Venkatraman's Five Levels of IT-Enabled Business Transformation (Venkataman 1994)

enterprise, and could be considered analogous to the automation of processes already in place.

At the lower two levels, enterprises often exhibit excessive focus on the technical aspects of integration, such as technical interconnectivity and protocols for communication, while paying less attention to achieving business process alignment by using these technologies. Venkatraman recommends that enterprises focus on processes and higher-level strategic issues, especially in the Internal Integration step, but has observed that many enterprises become trapped in this step because they are focused on the technical aspects without turning their attention to the larger enterprise-level issues at stake to be able to take the next step towards revolutionary transformation.

In the early years, the challenge faced by those in the IT-centric enterprise integration community was primarily perceived as being technical in nature, because the most difficult challenges then faced basically encompassed the task of aggregating disparate data sources and tools, which were largely technical. The term "enterprise integration" often meant data collection, compilation, tool alignment and compatibility, and did not necessarily alter the business of the enterprise in a significant way. The term was "owned" by the IT community, and the managers of the enterprise were happy with the arrangement. The benefits that IT professionals promised enterprises could see from the addition of IT in the early 1990s never fully materialized, however, and any competitive advantage that integrated IT systems provided soon became eroded when all businesses acquired the same basic capabilities for data integration (Cordella, 2001). Venktraman refers to this early superficial level of IT-enabled transformation in the framework he developed as "local exploitation" and suggests that it does not and will not provide the revolutionary benefits that IT professionals promised(Venkatraman, 1994).

Beyond local exploitation, enterprises can integrate themselves internally, a level Venkatraman terms "internal enterprise integration." At this level, enterprises tightly coordinate their IT systems across all aspects of the enterprise, but also ideally with their business strategy, processes, and address socio-technical concerns as part of a larger integration effort that goes beyond "islands of success." Despite this intention for a larger sense of integration, many enterprises working on internal enterprise integration often fall short.

The last three levels are "revolutionary" levels, which leverage IT together with new processes, strategies, and ultimately the business models of the enterprise to provide a long term, competitive advantage. In Venkatraman's framework, enterprises should determine which level would best suit their goals, given the effort required to achieve each level. Today, a decade after his framework was published, very few enterprises have progressed to the higher revolutionary levels that are described. Most enterprises today have an understanding of the second level, internal integration, and many enterprises have attempted business process redesign with varying success. Some firms, such as those in the aerospace defense community, have been forced by their business environment to pursue business network redesign and are making some progress, but they are still struggling to identify strategies and architectures for enterprise network integration that are effective enough to deliver truly revolutionary capabilities. The barriers to such transformation remain high.

3.2.1 Learning from Internal Enterprise Integration: Barriers to Enterprise Network Integration

There is much to be learned from the obstacles encountered and the work done to date on enterprise integration in the single enterprise, and there is a logical extension of many of these ideas to the case of enterprise network integration. Many of the barriers to integration are common to both the single enterprise and the enterprise network. Indeed, internal enterprise integration poses many very similar challenges, especially if disparate subsidiaries or an acquired external enterprise are being integrated with a pre-existing enterprise. Often, many of the technical requirements in large, multi-divisional, single-firm enterprises are just as complex as in enterprise networks. Integrating and sharing data over disparate databases and design tools, semantics issues and many of the organizational challenges of integrating distinct cultures and processes in large single enterprises that have grown trough acquisition can bear a striking resemblance to the same issues faced in enterprise networks. Any work in understanding the barriers to integrating enterprise networks must also look to those first encountered by enterprises tackling their internal integration issues.

The key point of departure for enterprise network integration from internal enterprise integration *lies in the issues of central authority and allegiance.* In the case of internal enterprise integration, there is a central authority, such as the corporate headquarters, that can hand down directives and control funding for activities and capital expenses. Additionally, within the single enterprise, there is only one primary organization to which allegiance can be owed (although often rivalries between various business divisions for resources can be intense, the issue of enterprise security between divisions is not as common a phenomenon[1]). In the case of enterprise network integration, there is no such central authority, and integration initiatives across a network are rarely funded by a central source. Allegiance can be divided between the parent enterprise and the network-based project, and therefore the level of trust in communications throughout the network is lower than within the single enterprise, raising the need for providing data security and protecting intellectual property. These two issues can give rise to related issues in other areas, such as those involving leadership and coordination, but most new obstacles can be

[1] One possible counterexample to this general observation is the case of a multi-program defense company with heterogeneous security requirements between programs. For example, the military government customer may require that information must be kept within the boundaries of a particular program, even within the same company which may be engaged in other programs, sometimes for the same customer. In this sense, there may be a higher contractual obligation for allegiance and security to the program rather than the corporate enterprise.

traced back to these two critical issues (Camarinha-Matos, 1999d). Much of the technical design, ideas and strategies developed for internal enterprise integration also can be used to guide thinking on the choice of technologies and strategies towards the integration of the enterprise network as a whole, provided that certain key differences pertaining to such factors as centralized control and allegiances are considered and addressed.

4 Chapter 4: Common Barriers to Integrating Enterprise Networks

Enterprise Network Integration is a multi-dimensional undertaking that requires significant levels of both technical and non-technical effort in order to achieve success. An important part of the challenge is to overcome the barriers and challenges to integration. Technical hurdles can often be anticipated, as they are easier to "see" in the planning stages: either there is a protocol for information sharing or there is no such protocol. While many technical barriers to integration can prove extremely challenging, they can usually be anticipated and can be proactively addressed. Both the academic literature and the practical experiences of third parties selling their technical solutions to enterprises concur on this point. However, non-technical hurdles, which can broadly fall into categories of strategic and organizational barriers, are comparatively harder to anticipate. Nevertheless, they must be anticipated and mitigation measures must be aggressively pursued, as they can have an equally devastating effect on the outcome of any integration effort. Such a proactive approach is necessary since strategic and organizational barriers have often been the ultimate cause of failure for many very large internal enterprise integration efforts in the past.

Many of the most common barriers to Enterprise Network Integration are listed below in Table 4.1, organized into technical, strategic, and organizational categories. Within these categories, particular types of barriers that are wholly unique to enterprise networks are italicized.

Table 4.1 – Common Barriers and Challenges to Integrating Enterprise Networks

Technical	Strategic	Organizational
• *Tools and data sources can not always be standardized across network* • Identifying standards for data exchange and tool interoperability where possible • Maintaining a reliable infrastructure for communication • Semantic resolution (data)	• *Maintaining balance between network and firm allegiance* • *Financing network infrastructure* • *Assessing and sharing risk and liability in the network* • *Lack of frameworks for cooperation (security standards, legal standards, etc)* • *Establishing control and decision making in the network*	• *Integrating, aligning and motivating distinct cultures with conflicting incentives in a single direction* • *Mismatches between organizational and technical architectures* • Developing cultures that can handle high clockspeed change. • Semantic resolution(process, organization) • Data and process ownership disputes

The following sections will discuss the barriers to enterprise network integration, divided into technical, strategic, and organizational categories. Special attention will be paid to barriers which are wholly unique challenges faced by enterprise networks, while barriers that are also faced in internal enterprise integration will receive less emphasis.

4.1.1 Common Technical Barriers to Enterprise Network Integration

The integration of Enterprise Networks in complex industries would simply not be possible without the technology provided by information and communication systems. Even as technical systems have developed over the last three decades into usable, deployable systems at a rapid pace, the demands of business have continued to push the boundaries of technology even faster. The Information Revolution has ushered massive changes in the workplace, as fast-paced changes in the available technology have given rise perhaps to as many problems as they may have solved. New developments in technology have no doubt served as a catalyst for the information revolution and have brought staggering progress in terms of connectivity and Internet-enabled information infrastructure systems. Still, these systems continue to present both challenges and barriers for those wishing to achieve enterprise integration, particularly in the context of integrating disparate legacy systems and sustaining the installed infrastructure to maintain and enhance their capability.

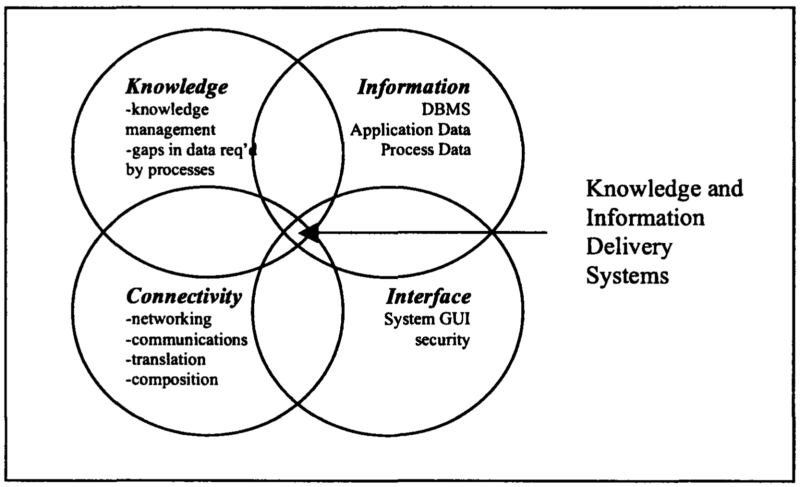

Figure 4.2 – Categories of Technical Barriers to Integration. Adapted from Madnick and Wang, 1988

Madnick and Wang describe four categories of technical barriers to integration: Knowledge, Information, Connectivity, and Interface. See Figure 4.2. Although this framework was developed to address internal enterprise integration concerns, its logic can be readily applied to the enterprise network case. The four categories of technical barriers, as they can been seen in the diagram, are not meant to be mutually exclusive and may overlap somewhat. Individual barriers can have elements of any of these four categories, and generally grow in difficulty as the overlap increases, causing more "tangled" technical problems. The most tangled technical problems at the core involve what Madnick and Wang term "knowledge and information delivery systems"—the systems at the heart of enterprise network integration. Many of the technical challenges that lie in only one category, such as database management systems or networking, are topics of broad field of academic inquiry and technology development, and therefore are diminishing as barriers to integration and the technologies mature.

The following sections will highlight these four categories of technical barriers, and discuss common enterprise network integration barriers that apply to each category.

4.1.2 Informational Barriers

Information barriers are often very clear-cut obstacles: Information is stored in many disparate, heterogeneous systems across the network, but these systems cannot necessarily physically communicate with each other. They may be made by different vendors, employ different technologies on different platforms, or adhere to a different standards or protocols. Additionally, data semantics remain a towering issue: how can one ensure that distributed systems that belong to different organizations but carrying the same name mean the same thing? How can one be sure that the information that is found following a search of the sources on the network is really the information that is being sought?

These technical barriers are common to virtually all enterprises, whether they are working in a network or not. These barriers are present right along with legacy systems that must interact with newer systems, with systems deployed by separate divisions in a corporation, in divisions acquired through acquisition, and in enterprise networks, where each enterprise may be using a system that best meets its own particular internal needs.

In modern enterprises in complex industries, the nature of data itself is changing as well. The data that must be shared and integrated are no longer limited to text and numerical data stored in relational databases—they include a plethora of application data, such as CAD solid models, visualization files, or simulation experiments, and process data, bill-of-materials, and related data residing at different locations and on different platforms. Unless applications and databases adhere to market standards for data exchange, applications cannot be guaranteed to seamlessly exchange data "out of the box." "Wrappers," pieces of middleware written to translate data from one application or database format into that of another, must be written for each possible combination of application or database to allow to the exchange of data. There does not—and probably will not—exist a commercially available wrapper for bilateral communication between any given pair of applications or databases that need to be integrated. This problem grows geometrically for linear increases in the number of applications to be integrated.

In internal enterprise integration, a prevailing wisdom is to standardize as much as possible on systems and protocols: databases and tools should run on common platforms, relational databases should come from the same vendor, etc. This is the wisdom behind Enterprise Resource Planning (ERP) suites—they unite several systems and software packages under a single umbrella, with the promise of ease of data exchange and integration throughout the system without the extensive need for wrappers and middleware. ERP systems are ideal implementations—systems built from scratch based upon newly developed processes, replacing rather than accommodating legacy systems and disparate systems across the enterprise.

In the case of enterprise networks, however, this cannot be the case. The members of enterprise networks are autonomous business units that all have distinct core competencies and contrasting requirements arising from the diversity of their work. It is almost certain that there will be heterogeneous systems across an enterprise network to complement these heterogeneous competencies. Unlike the case of internal integration, it is extremely difficult to convince enterprise network members to adopt common information tools, as there is no central authority with budgetary power providing incentives to do so. In some cases, if the investment is small enough or if the enterprise network is sufficiently long-lived, it may be economically beneficial for all parties in an network to standardize on information technology, especially if there are not compelling reasons why members need distinct systems. This is the exception rather than the rule, however. This forces would-be network integrators to look for other approaches to information integration that do not require standardization on information storage and retrieval technologies.

4.1.3 Knowledge Barriers

Knowledge barriers are problems that involve having the right knowledge in place to perform a task at hand. Often, these issues involve semantics—understanding what data and processes from heterogeneous sources really mean and knowing where they are. This overlaps strongly with many of the connectivity barriers. As an example, a very active knowledge barrier is the disconnect that can exist between product definition, process definition, and knowledge management systems. Many processes require the knowledge contained in all three areas, but these systems have traditionally remain disjointed with little integration between then, forcing users to switch from system to system to have the knowledge necessary to complete a process or task.

Another kind of knowledge barrier is to understand where knowledge resides across many data sources, either internally or across a network. Often, data exists in the network but the barrier to locating it is sufficiently high that it may be easier to replicate it that to find it. While this class of barriers is not unique to enterprise network integration, its difficulty is compounded by the variations that exist in capturing, storing, and searching for knowledge across the network.

4.1.4 Connectivity Barriers

Connectivity barriers exist in two forms: physical connectivity and logical connectivity. Physical connectivity refers to the physical ability to communicate data across a network using hardware, while logical connectivity refers to the ability to logically connect data in meaningful and useful ways in software.

4.1.4.1 Physical Connectivity

While physical connectivity was a major concern as recently as a decade ago, the current information infrastructure in most of the developed world is quite good, and there is currently a large amount of excess capacity in many networks. The key to the decline in physical connectivity barriers has been the phenomenal success of the Internet, and more specifically, the TCP/IP protocol architecture for data exchange over packet switched networks. The TCP/IP Protocol architecture is a layered architecture that addresses transport control and internet addressing of data sent over a packet-switched network. The Internet also embraces several standards for the physical layer (signal conversion and transmission, such as the actual cables used as well as the routers used to relay packets) as well as the network access layer (Ethernet) and application layers(email, HTTP, FTP). Virtually all modern hardware and software support this architecture, which drastically reduces the physical connectivity barriers and costs of the past when coordinating communication between two locations. The protocol can be run over the public Internet, or it can be used on private wide-area networks to increase available bandwidth and security, even using other custom developed application layers. The Internet's TCP/IP protocol and architecture has become the lowest common denominator that almost all people who wish to communicate data embrace.

TCP/IP is not always ideal for every application, however, and it is not without limitations. It does not guarantee latency causing real-time transfer of data such as audio or video to be poor, and the number of available addresses is fixed and the available pool is shrinking, for example. There are new versions of the TCP/IP, such as IPv6 (Internet Protocol, version 6) waiting in the wings, as well as another transmission layer protocol, known as Asynchronous Transmission Mode (ATM) that promise to address many weaknesses of the current Internet transmissions. ATM has already been deployed in many Wide Area Networks by enterprises seeking its low latency and higher transmission rates and is a proven technology. By continuing to embrace these standards, physical connectivity barriers will remain low even in across highly varied enterprise networks.

4.1.4.2 Logical Connectivity

Unlike the rapid advances made in physical connectivity, logical connectivity remains a very large and daunting technical barrier to enterprise network integration. Physical connectivity answers the question "How do I get data from point A to point B?" Logical connectivity answers the questions "What is the data that I need, how does it fit together, and what does it mean?" Logical connectivity includes semantics, data location, query decomposition, and data translation. Logical connectivity barriers are very often highly intertwined with information, knowledge, and interface barriers, and can be the sticking points making the other barrier technically intractable. The keys to overcoming logical barriers to integration are protocols and standards. Often, however, those protocols and standards are either non-existent, they favor one party over others leading to dispute, or there is no clearly defined solution that works well for any party.

One of the first logical connectivity barriers encountered is that of incompatible data formats. This barrier, like many connectivity barriers, is present in many integration efforts. Fortunately, although it can be daunting, it is fairly straightforward barrier and is easily anticipated. Most computer users are familiar with this problem if they have ever received a computer program written for a different version of software they own, or for a different computer platform than the one they are on. In the case of enterprise data, the number of formats used for data exchange can be prohibitively many, requiring companies to have many data filters and versions of software available. Conversions from one data format to another might not always be possible, or may be fraught with semantic difficulties. Upgrading software out of sync can result in incompatible files between two companies that may have good reasons to stand by the version of software that they are using.

The issue of data semantics is a very large barrier to all forms of enterprise and data integration, and its importance only grows as enterprises attempt to share data with ever-increasing complexity. Whenever data is collected from many sources, semantics will be an issue because to date there is no universal, mature technology that ensures semantic compatibility in data that flows across system boundaries. Without semantic resolution, massive amounts of data cannot be efficiently and meaningfully exchanged, unless strict standards are imposed on the enterprise network that increase ease of integration at the expense of innovation and flexibility from network members that can no longer use the tools and processes that are most beneficial to them. Semantic integration offers a way for heterogeneous data to exist in an integrated environment without draconian standardization of tools and processes.

There is no standard way of ensuring that two network members mean the same thing when they use the same tags to define their data or to perform an automatic check to see if the data from all sources are presented in the same units, for example. Further, semantic misunderstandings are difficult to predict a priori without a significant amount of upfront work.

Semantic misunderstandings in data can cause a tremendous amount rework after they are subsequently discovered, and in some cases, can lead to total system failure if not uncovered in time. A key example of a semantic failure leading to a system failure was on the Mars Climate Orbiter program, a $125 million dollar spacecraft that was lost in 1999 because of a semantic issue—one thruster design team worked in metric units, while another collaborating design team worked in English units. The semantic error resulted in the spacecraft entering an unstable orbit and crashing into Mars[2].

The issue of data semantics is the topic of several large research studies, notably the "Semantic Web" being developed by the World Wide Web Consortium (W3C) together with academic and industry partners[3]. Semantic Web seeks to create the framework and tools that will one day allow most things on the World Wide Web to be viewed with context, allowing for seamless integration of all forms of data on the Internet across all boundaries. Context gives data a well-defined meaning that allows computers and humans to interact more meaningfully with data. Although the ambitious project is not yet near its ultimate goal of a fully context-aware world wide web, it has developed several tools to date that have become useful to those trying to integrate data sources, most notably the Extensible Markup Language, (XML), and its framework for semantic integration called the Resource Description Framework (RDL).

4.1.5 Interface Barriers

The last category of technical barriers to integration is interface barriers: how should integrated data from many very different sources be presented to users for meaningful consumption? This, like physical connectivity, is an issue shared by all integrative efforts. Interface barriers include access issues: users should be able to easily

---

[2] CNN.com, "Metric mishap caused loss of NASA orbiter." (September 30, 1999). Accessed from http://www.cnn.com/TECH/space/9909/30/mars.metric.02/ on May 2, 2005.
[3] See "World Wide Web Consortium: Semantic Web," http://www.w3c.org/20001/sw/

access all pertinent information at the location it is needed without having to switch systems of views.

Additionally, interface barriers can include security elements: what data are allowed to be presented to what user? This is an aspect of technical interfaces that is much more relevant to the enterprise network case, because the network consists of autonomous businesses with proprietary knowledge in each project. Internally, companies want this available, but do not want it available to the network, even as the network has access to much of the other project data. As employees are moved around and temporarily collocated with employees of other businesses, they need access to proprietary data, while the next person may not need or may be denied such access. Some of these issues are also present in enterprises that must maintain high security around their projects, whether for competitive advantage or at the request of the customer. In sensitive projects, employees must have access to information on a "need to know" basis, hiding information that they are not authorized to see, limiting the enterprise's vulnerability to security breaches.

5 Chapter 5: The Joint Strike Fighter Program: A Case Study of Integration in a Large, Complex Extended Enterprise

5.1 Introduction

The F-35 Joint Strike Fighter (JSF) and the program enterprise network that is designing and manufacturing it are both often heralded as a prime examples of complex engineering systems due to the myriad dimensions and layers to the complexity and the overwhelming scale of both the aircraft and the program extended network behind it. The JSF, a next-generation fighter aircraft currently under development, is a very ambitious program; it is designed to replace at least six other dedicated fighter and attack aircraft in their specific roles across the US and international armed services. It must do so with increased effectiveness and reduced costs compared to the aircraft it is replacing, while engaging not only the American aerospace industry, but also the aerospace industries of our allies. To date, there have been over 3,000 aircraft ordered at an estimate price around 45 million dollars per aircraft, which would make it the largest and most expensive defense acquisition program in the history of any nation.

While the external appearance of the aircraft seems in line with past and present fighter aircraft designs, the JSF represents a radical departure from traditional fighter aircraft. One of the most technically challenging aspects of this departure was the decision to design the fighter in such a way that would allow it to be built on a common platform into one of three variants: a conventional take-off and landing (CTOL) version, an aircraft carrier based version (CV), or a short take off and vertical landing version

(STOVL). Thus, one basic aircraft design could be used across many services and missions, in theory reducing acquisition and support costs.

The JSF is also being developed in a very new way after a string of troubled aircraft acquisition programs including the A-12, Comanche, and F/A-22, which were all based on arms-length contracts between suppliers and a prime contractor laden with very detailed, specific requirements with limited flexibility. The US Department of Defense is holding the JSF up as its flagship of acquisition reform, throwing away very lengthy requirements documents in favor of performance-based goals that treat cost as an independent variable in the design. Of particular interest, the prime contractor has decided to design this aircraft using a highly-integrated enterprise network consisting of a core of highly-connected, closely coupled partners working side by side on design, with an extended supply chain network that is integrated using information and communication technologies to bring them closer into the design processes and give them more autonomy in the design of their subsystem.

The degree of integration and collaboration across a network of enterprises on a project of the scale of the JSF is a first for the military aerospace industry, and all eyes are squarely on it. The JSF Enterprise Network is forging new ground, and has uncovered new barriers to integration and is working on tomorrow's enablers for enterprise networks in high-clockspeed, complex products. Thanks to the complex array of stakeholders involved, the barriers to integration encountered have covered a broad spectrum, covering technical, strategic, and organizational barriers. For this reason, the JSF Enterprise Network is a prime candidate for a case study into the barriers and enablers to integration in complex enterprise networks. The project is relatively new and is evolving, so the barriers are still fresh in the minds of those working on the project, and many still pose problems. If the JSF program is successful, it will become a textbook example of an advanced complex engineering system that has satisfied the often-conflicting needs of many stakeholders using an enterprise network.

The following chapter details a case study of the F-35 Joint Strike Fighter Enterprise Network, based on multiple site visits and dozens of interviews with people responsible for shaping the enterprise network and working within it. The chapter will begin by placing the JSF aircraft and enterprise network in context, and place it within the taxonomy and frameworks for enterprise architectures from Chapter 2, followed by a stakeholder analysis throughout the program. After exploring the history and creation of the program, we will go through the barriers and enablers to integrating the JSF extended enterprise using the framework developed in Chapter 3.

5.2 System Context

The United States has largely defined its military power since World War II in terms of airpower. In the years immediately following the war, there was a large explosion in the number of aircraft designs, with each aircraft designed to fill a very specific niche, such as high altitude strategic bombing, fighter escort, or close air support. In the following decades, especially as the capability of avionics and mission hardware, increased, there was a reduction in the number of aircraft designed for such narrow missions. This generalization of roles is perhaps most apparent in the evolution of fighter and attack aircraft.

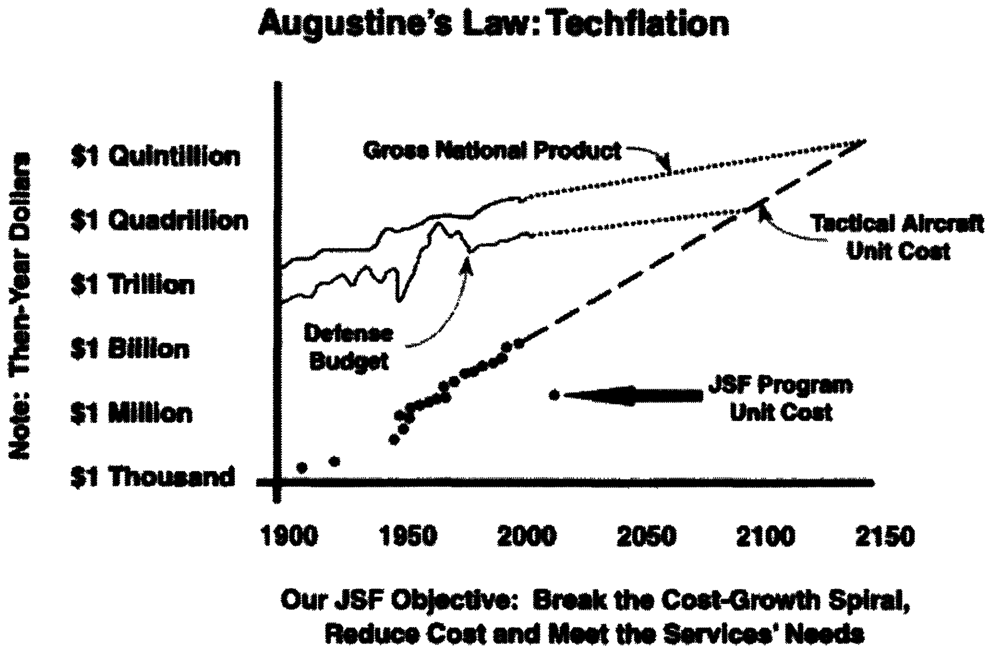

Figure 5.1 – Augustine's Law. Source: (Struth, 2000)

Over this period of time, the cost of developing new fighter aircraft has grown exponentially, in large part due to the ever-increasing complexity of the avionics packages in these aircraft and the onerous requirements placed on the contractors who build these systems. In what has been termed "Augustine's Law," after Norman Augustine, former chairman of Martin Marietta, if trends continue, it will take the entire defense budget to purchase a single fighter aircraft in 2054(Fallows, 2002). See Figure 5.1. As can be seen in the figure, one of the goals of the Joint Strike Fighter is to break Augustine's Law by dramatically reducing the cost of each copy of the aircraft. Taking a lesson from the F-16, one of the ways this cost-reduction will happen is through large economies of scale and use of existing technologies in the design. A way of increasing economies of scale would be to have a single aircraft for all branches of the US armed services that fly fixed-winged aircraft, as well as by selling as many as possible to our allies. The use of existing technologies limits exposure to technical risk, hopefully avoiding both schedule and budget overruns. One other major area for cost reductions could potentially come through an overhaul of the defense requirements process, making the process less of a burden on contractors. To accomplish these goals, the JSF would need to be developed with the needs of many stakeholders in mind, in a highly technical, ICT supported environment.

The 1990s saw the birth of joint operations doctrine in the US, when both technological and political advances allowed the various branches of the armed services to begin working more closely together to provide a seamless military. In the 1996 document Joint Vision 2010 and the subsequent 2001 document Joint Vision 2020, the US DOD laid out its intentions for a high degree of cooperation between the services on the battlefield, involving the fusion of command, control and communications across all of the services and weapons systems. Further, it saw as a goal greater cooperation and communication with allied forces. This would allow, in theory, for pilots to communicate with ground troops and even other allied forces instead of relaying messages back to base. A key element in this vision was commonality across services to reduce confusion, acquisition costs, and coordination costs. The concept of a Joint Strike Fighter fell squarely within this vision—a common platform for all services that would meet their collective need for an effective, affordable strike fighter. If successful, the JSF will fit well into the context of each service's force structure, as well as the DOD's larger vision for the future of joint battlefield operations between services and with other allies.

There are no current plans to build any other manned fighter aircraft, so it is likely that the Joint Strike Fighter will be the last manned fighter built in the US, as unmanned combat aerial vehicles (UCAVs) are maturing at a fairly rapid pace, and have already recorded their first kills in combat before the JSF had finished its critical design review. Because it is likely to be the last fighter of its kind, the entire military aerospace industry scrambled to get on board. For many, there was a feeling that if they were not able to get on board the massive JSF program they would be forced to leave the industry, as only a very few aerospace companies have experience with unmanned aerial vehicle design and system development. Additionally, unmanned fighters may require much less engineering and design work because they do not have to take into account the safety of and interaction with the pilot, which drives down profitability. More importantly, unmanned aircraft remain an unknown, with much uncertainty. The industry will shift, and the JSF represents the last opportunity to work on a major program under the known paradigm of manned fighters. Figures 5.2 and 5.3 show the projected budgets for acquisition (Figure 5.2) and for research, development, testing, and evaluation (Figure 5.3) for all military fixed wing aircraft over the next 25 years. The Joint Strike Fighter (F-35) is soon projected to capture the vast majority of all work in the industry.

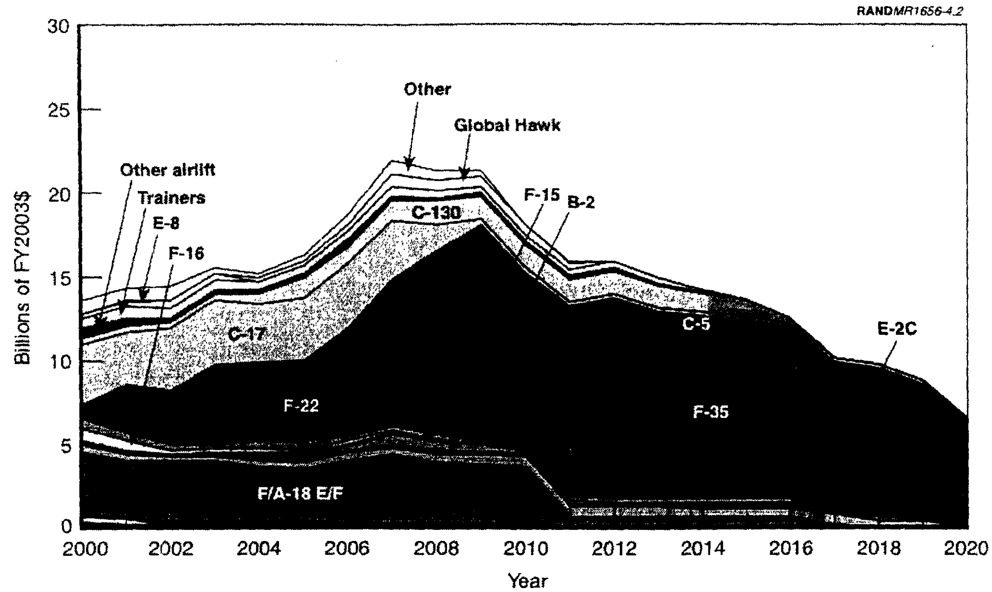

Figure 5.2: Base Case Procurement Obligation Authority

Source: RAND MR1656

5.3 The History of the F-35 Joint Strike Fighter

The origins of the Joint Strike Fighter can be traced back to 1993, when in the wake of the Cold War the Department of Defense under Dick Cheney conducted a very thorough Bottom-Up Review that concluded that the DOD should "continue the ongoing F-22 and F/A-18E/F programs, cancel the Multirole Fighter and the A/F-X programs, curtail F-16 and F/A-18C/D procurement and initiate the JAST Program"(Rand MR1559). The Joint Advanced Strike Technology (JAST) program was designed as a technology incubator to develop technologies for future use in a jointly developed strike fighter, which would serve the strike needs of the services at a much lower cost than that of other cancelled programs. At the earliest stages, the necessary concepts and technologies were developed to further the specific concept of a single fighter that could meet the needs and goals of the joint services through high commonality. Other programs, such as the DARPA/USMC Advanced Short Take Off and Vertical Landing (ASTOVL) study and the Air Force's Common Affordable Lightweight Fighter (CALF) were also rolled into the program the following year.(Rand MR1656).

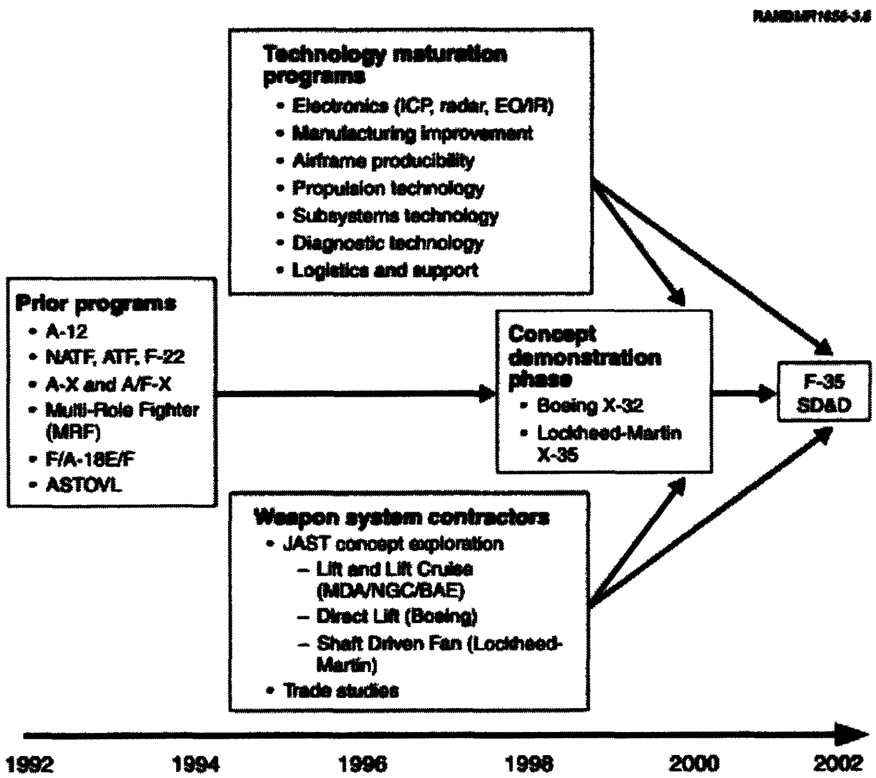

Figure 5.4 – The Evolution of the JSF Program

In 1994, the DoD embarked on a wave of acquisition reforms and decided to make the acquisition of this new aircraft the flagship of the reform initiatives by taking six key steps to increase the affordability of the new aircraft: ensure commonality between variants, change the acquisition cycle to spend more time in "concept development," make the requirements process more iterative, seek out international cooperation in development, create proactive technical and programmatic risk reduction programs, and use competition as a means of selecting a best design. The Concept Development phase was a 5-year period of time when contracts were awarded to four firms to develop their own concepts for how they would meet the JIRD goals (Struth 2000, GAO / T-NSIAD –00-173).

In December 1994, Lockheed Martin, Boeing, McDonnell Douglas, and Northrop Grumman were selected to create conceptual aircraft during a 15 month Concept Definition and Design Research period. McDonnell Douglas and Northup Grumman decided to team their efforts, but soon Boeing acquired McDonnell Douglas, hampering that effort. After several rounds of design reviews in 1996, Lockheed Martin and Boeing were selected as the two prime contractors that would move forward into the next phase, Concept Development (CDP). Beginning with CDP, Lockheed Martin officially teamed with Northrop Grumman and British Aerospace (later renamed BAE Systems). During this time, the project was officially renamed the Joint Strike Fighter(Birkler, 2003).

The Concept Development Phase is perhaps one of the most well-known and exciting aspects of the Joint Strike Fighter Program. Each team developed and demonstrated their own prototype aircraft to prove how their design would meet the goals developed for the aircraft. The Boeing version of the JSF was given the designation the X-32, and the Lockheed Martin version was given X-35(Birkler 2001).

The next four years brought a very bitter rivalry head to head, as each JSF team essentially competed for survival in the market. It was known at the time that this would be the largest contract in military history, and that in all likelihood there would not be another manned fighter built. The outcome of the decision could very possibly determine who would stay in the business, and who may have to bow out. In addition to the large-scale fight between the two dominant prime contractors, many larger suppliers began to soon partner with one of the two, betting on their own future as well.

It is interesting to note that although the actual concept and performance-based requirements of a joint fighter was the same for both entries into the JSF competition, the resulting aircraft, the X-32 and X-35, were surprisingly different. The only major common design component that the designs featured was a Pratt and Whitney F119-derivitive engine, which was successfully used on the F/A-22. Many of the major subsystems, notably the STOVL lift system, employed vastly different technologies and alternative designs. Boeing relied on a direct lift ducted exhaust system, much like an updated, advanced version of the system used by the AV-8B Harrier. Lockheed Martin, in contrast, opted to use a proprietary lift fan system that blew cold air from behind the cockpit, originally developed as part of the DARPA/UMSC ASTOVL program from the early 1990s. The exhaust of the engine is also directed downward via a 3 bearing exhaust nozzle (Beliquva, 2004).

In addition to competition on technical performance, the two teams also had to compete on their support and logistics infrastructures, their manufacturing processes, and their supplier networks and partners. Both teams invested heavily in IT solutions that could coordinate the virtual design of the aircraft, coordinate supplier access to designs and track common parts and variant parts for each design. A significant advantage went to the program that could prove that they had a robust enterprise network, capable of staying on budget, on schedule, and handling technical and programmatic risk. Each enterprise network competed as a team, and had to prove that not only did they posses first rate core competencies spread across the network, but that they also could work effectively together.

Cooperation was not only a technical asset, but also a political one. As this was such as massive military project, many congressmen were keenly interested in getting some part of this program in their district. As with previous large budget government programs, there was pressure to spread the work out geographically, necessitating the use of IT to coordinate design, process, and manufacturing. At the same time, there was pressure from the Joint Program Office to work with international partners in the project. The idea was that in exchange for providing funding for the development phase of the aircraft, international companies within sponsoring countries would be allowed in on several aspects of the design and would be allowed access to some of the technology developed on the program. Lockheed Martin already had an advantage when working with international partners, as they had extensive experience developing the wildly successful F-16 variants for sale to foreign nations, as well as helping other countries develop indigenous aircraft, such as Japan's F-2. It was during this time that each program architected their extended enterprise, which will be studied later in this chapter.

Over 2000 and 2001, there were many publicized tests of the two experimental aircraft. The X-32 was the first to fly. Dubbed the "Flying Frog" or "Monica" by Washington insiders, Boeing developed a highly unusual looking aircraft with a delta wing and a large, downward reaching air intake just under the nose. The X-32 went through its flight tests with minor hiccups. The Lockheed Martin X-35 was second to fly. The X-35, with a much more conventional-looking airframe, demonstrated the merits of its lift fan system by being the first aircraft in history to take off, break the sound barrier, and then land vertically using the same aircraft (Baliquva, 2004).

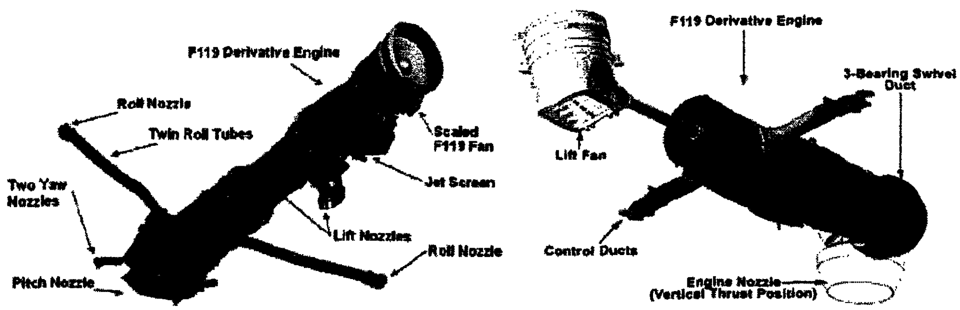

Figure 5.5– The X-32 Propulsion system (left) and the X-35 propulsion System. Source: Brig. Gen. Leslie Keene: "Designing the Joint Strike Fighter" Slide Presentation.

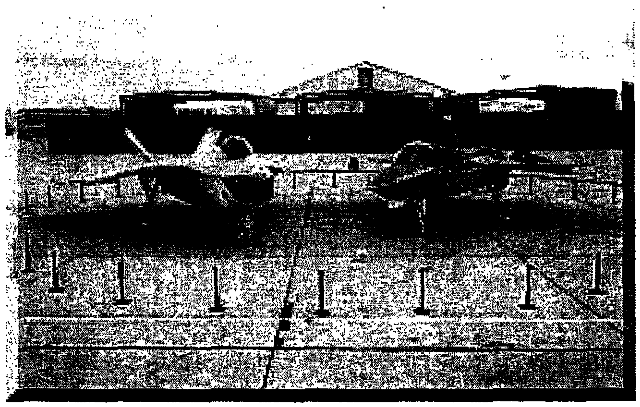

Figure 5.6 - The X-32(l) and X-35(r) Source: JSF System Program Office

On October 26, 2001, the DOD announced that Lockheed Martin had won the contract to continue on to the System Design and Development (SDD) Phase. According to Pete Aldridge, the Secretary of Defense for Acquisitions, the X-35 (to be renamed the

F-35) was the clear winner of the competition on several dimensions. It was widely thought that the largest advantage came from the technical design on the lift fan system. The contract was awarded, and Lockheed Martin began an immediate ramp-up to fully develop their aircraft (Birkler 2003).

In the three years since the SDD contract award, the F-35 has suffered a few setbacks, most notably a weight problem and some dissatisfaction from international participants. It became apparently in 2003 that the STOVL version of the F-35 would be around 6% over its projected weight, decreasing its range and weapons carrying capacity. While many critics panned the program, the Lockheed Martin team worked to alleviate these problems, both by making subsystems lighter but also by pushing back against the customer requirements to see if they could be modified in ways that would allow the team to make weight saving changes to the design. One such change included making the weapons bay slightly smaller, which would prevent the JSF from carrying all ordinances in the inventory, but in the end it was decided that this change would not significantly impact the effectiveness of the aircraft. In August of 2004 it was announced that the STOVL version was now at its desired weight, and that weight reducing efforts on common F-35 parts had resulted in the CTOL and CV versions of the aircraft to come in under their projected weight, increasing their range and performance.

Another setback was that the JSF program decided to postpone the Critical Design Review, originally scheduled for April 2004. Most people at the program felt that the original CDR timeline was unrealistically aggressive, and that the program should have been immediately rebaselined at the start of SDD. It did not appear to surprise many people when the decision came to postpone CDR to allow for the final design to become more stable. This was a lesson learned from the F/A-22, which pressed ahead through a CDR before the design was entirely stable. As a result, the F/A-22 was plagued with problems with its design, which caused a massive amount of re-work and schedule slippage.

The current schedule for the F-35 features a first flight by a CTOL variant in 2006, with aircraft entering service in 2008. Full Rate production of the F-35 will begin in 2012, with a peak production of 206 per year. The last JSF will be ordered by the US and Allied Forces in 2026 (RAND MR 1559).

5.4 Stakeholder Analysis

The Joint Strike Fighter Extended Enterprise is comprised of hundreds of companies working together towards a common goal. This section will examine the major companies within the network, abstractly depicted in Figure 5.7.

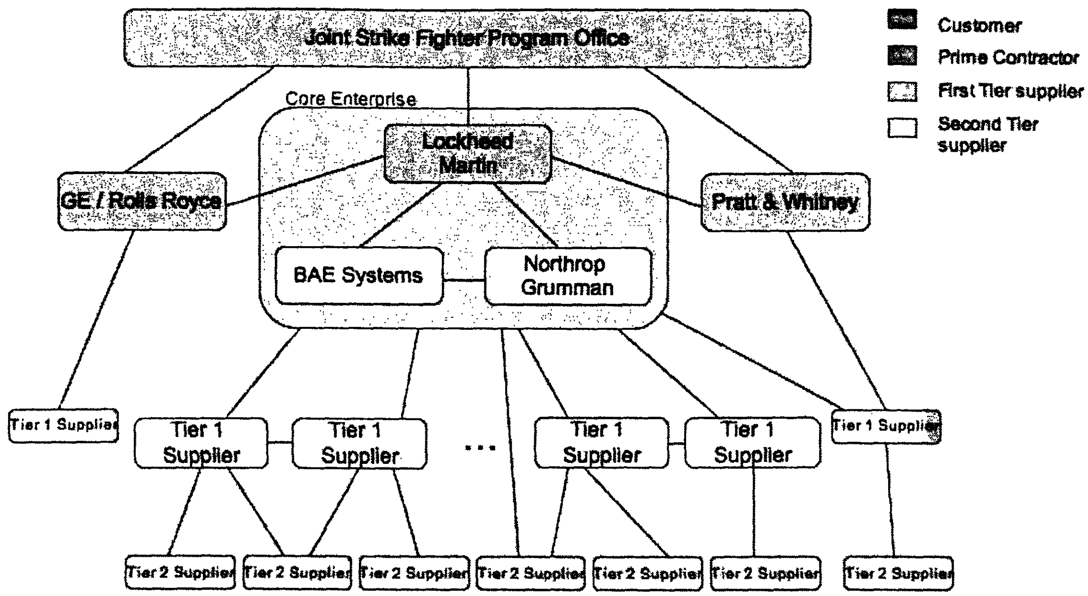

Figure 5.7 – A depiction of the JSF Extended Enterprise. The supply chain continues down at least two more tiers.

5.4.1 Joint Program Office

The Joint Program Office, headquartered in Arlington, VA, is the "voice of the customer" in the JSF program, and also serves as a directorate for the entire program, sharing responsibility for the program with the Lockheed Martin. It is staffed with personnel from the Air Force, Navy, and Marines Corps. The Joint Program Office (JPO) is directed by the Program Executive Officer, a flag officer either from the Air Force or the Navy, with this position rotated between the two services. The Program Executive Officer reports to a civilian Service Acquisition Officer from the other service. The JPO is composed of 16 separate integrated program teams (IPTs) that oversee the production and design of the entire system, and interface with the contractors and the public, and ensure that the program is on target to meet expectations. The sixteen IPTs are:

- Air Vehicle
- Autonomous Logistics
- Propulsion
- Air System Integration
- Air System Engineering
- Air System Requirements
- Air System Logistics
- Air Systems Production
- Operations
- Verification and testing
- International
- Contracts
- Business and Finance
- Security
- Public Affairs
- Legal

It is obvious from the list that the JPO sees the JSF as a complete air system, paying special attention to areas that were previously neglected in the design stages, devoting high-level teams to such areas as Autonomous Logistics, Air System Production and Air System Requirements. They also manage the international interface of the program as well as monitoring the security, public relations, and legal aspects of the program as a whole.

The goal of the JPO IPTs is to provide a uniform face to the customer, avoiding many customer and management problems in previous multi-service programs with conflicting opinions from a disjoint customer base, such as the TFX program. Additionally, the JPO sought out international participation in the program, and laid the foundations for international participation. They monitor several metrics required by law, such as contracts awarded to foreign companies and number of contracts awarded to small-businesses, and often interface with lawmakers inquiring about the program.

5.4.2 Prime Contractor – Air Vehicle

After a four-year competition, the Lockheed Martin proposal for the JSF was chosen by the JPO, and a 10-year award for the System Development and Design (SDD) phase was awarded to Lockheed Martin, making them the prime contractor for the air vehicle (the propulsion system is handled via separate contracts from the JPO). As such, Lockheed Martin, together with the JPO, is ultimately responsible for the success of the aircraft and all supporting systems necessary for it. The primary headquarters for the JSF is the Lockheed Martin production facility in Ft. Worth, Texas. The Ft. Worth plant, featuring a mile-long moving production line, is the manufacture facility for the forward fuselage, wings, and leading edges on the aircraft, as well as the site of final fabrication for the aircraft. Additional manufacturing work is done at the Lockheed Martin facility in Marietta, Georgia.

In addition to manufacturing, the Ft. Worth facility is headquarters of the engineering design effort and program management. Ft. Worth hosts many project-wide Integrated Product Teams composed of employees from many across the JSF project. Many partners and suppliers, both domestic and international, have employees co-located in Ft. Worth working on the JSF. Lockheed Martin is involved in some way in the design, manufacture, and support of every major subsystem on the JSF.

Ft. Worth is also the center of IT integration efforts across the entire program, and is home to the master copies of the program databases and the central program servers. Many partners, suppliers, as well as the JPO have dedicated landline connections to these central resources maintained by Lockheed Martin.

5.4.3 Prime Contractors – Propulsion

Pratt & Whitney, based in multiple sites across Connecticut, is the prime contractor for the development of the F-135 engine for the JSF. Pratt & Whitney works directly with the JPO as the primary contractor for the propulsion and interfaces its work with Lockheed Martin. They also must interface their efforts with Rolls Royce, who is developing the lift fan, clutch, roll posts, and three bearing exhaust nozzle for the F-35B

STOVL version of the aircraft developed for the USMC and the UK. They also work closely with Hamilton Sundstrand, who is developing the engine control systems. Pratt & Whitney is responsible for all integrative efforts on the propulsion systems for the JSF.

General Electric (GE) teamed with Rolls Royce and has a prime contract from the JPO as the alternate propulsion supplier for the F-35. In 2002, they formed a limited liability corporation (GE Rolls Royce Fighter Engine Team, LLC) to produce their engine for the JSF, the F-136. Rolls Royce, in addition to development of the common STOVL hardware that will also work with Pratt & Whitney's F-135, is also developing the low-pressure turbines in the F-136. GE is designing and manufacturing the high pressure counter-rotating turbine and afterburner systems.

5.4.4 Major Partners

Lockheed Martin has two principal partners working closely with them on the Joint Strike Fighter: Northrop Grumman and BAE Systems. These three companies had worked together on the JSF proposal for many years previous to the award of the JSF contract, and together they form the nucleus of the Joint Strike Fighter Enterprise Network. They are highly integrated and densely interconnected with respect to this project, having formed several integrated project teams with members from all three companies and sharing in production of the largest subsystems on the JSF.

Northrop Grumman is a company that has developed several notable aircraft, such as the B-2 Stealth bomber, F-14 "Tomcat" naval fighter. They have valuable experience in designing low-observable aircraft, in working closely with the Navy, and with fire control radars, avionics, and mission system software. Northrop Grumman involves four of its seven divisions on the JSF: Integrated Systems, Mission Systems, Electronic

Systems, and Space Technology. Of these, Integrated Systems has the largest share or work designing and manufacturing the mid-fuselage, weapons bay, and missions systems. Another major component is the Fire Control Radar system, a descendant of systems used on the F-16 and F/A-22, which is developed by Electronic Systems. Northrop Grumman is involved in many of the systems of the JSF, often in conjunction with Lockheed Martin, such as on the Electro-Optical Targeting System, or on the Electronic Countermeasures with BAE Systems. Northrop Grumman has facilities involved with the JSF in Baltimore, Maryland, Reston, Virginia, and in El Segundo, Palmdale and Redondo Beach, California.

BAE Systems is an international aerospace company based in Samlesbury in the United Kingdom. They were the developers of the Harrier, the world's most successful vertical takeoff and landing fighter aircraft. They bring extensive experience not only with VTOL, but also in working with European markets and projects that the US firms are not comfortable with or have no experience with.

The aft fuselage and the empennage of the F-35 are designed and built at the production facility in Samlesbury, with additional manufacturing work done at the facility in Wharton. BAE Systems is also taking a lead role in the development of the Electronic Warfare capabilities and the Vehicle Management Computer of the JSF out of its facilities in Nashua, New Hampshire and Rochester, England and Edinburgh, Scotland. Other work includes STOVL testing, autonomic logistics, and preventive health maintenance.

5.4.5 International Partners

There are currently nine countries other than the US that are participating in the System Design and Development stage of the JSF. The goal of their participation, from the point of view of the United States, was to attract investment, lower unit costs through economies of scale, increase interoperability between allies, leverage foreign technologies, and to promote foreign sales of aircraft (JSF Oral Testimony, 7/21/2003).

International participants are organized into three tiers, with different privileges on the program corresponding to the level each country has invested in the program. At the highest tier, Tier I, there is a single country—the United Kingdom. The UK has invested over 2 billion US dollars into the project, and is allowed the deepest access into the program of any foreign country as a result. They have a deputy at the JPO that reports directly to the Program Executive Officer, unlike other countries that must report to a JPO deputy for International Affairs. They are given 10 full time staff positions at the JPO, including the deputy directorship of the Systems Engineering IPT. They are given priority on acquiring aircraft from production, and can share in profits made off sales to non-investing countries.

At the second tier, there are two countries—Italy and the Netherlands, contributing approximately one billion and 800 million US dollars, respectively. They report to the JPO international director, and are given multiple full time staff positions at the JPO (5 and 3). The Tier III countries include Turkey, Canada, Australia, Denmark, and Norway, each contributing between 175 and 125 million dollars. They each receive one full time position at the JPO, must report to the JPO International director, and may receive aircraft in a priority commensurate with their investment(GAO. For a full look at the contributions and expectations of each international participant, see Figure 6.1.

Additionally, there are two countries, Israel and Singapore, that have not invested enough in the program to be considered partners, but do receive the right to some program data for purposes of evaluation for suitability, and will have purchase priority over other countries that have made no investment at all.

5.4.6 Supply Chain

The Joint Strike Fighter, as mentioned earlier, has an international supply chain that is centrally managed by the prime contractors (primarily Lockheed Martin), and selected for providing "best value" to the program. "Best value" is never clearly defined, but it is assumed that many factors can be taken into the value proposition besides monetary value, such as strategic value or political value. The majority of the supply chain is widely distributed across the United States and the partner countries, rather than centrally located near the major manufacturing centers of Ft. Worth, Southern California and Samlesbury, UK.

The US aerospace industry intentionally has distributed itself geographically over the last several decades to shore up political support from local congressmen eager to keep jobs in their districts. While this dispersal makes programs within the industry more robust to political pressures, it also creates higher transaction costs between firms, as both communication and transportation of materials is made more difficult. See Figure 5.8 for a map of major JSF suppliers in the United States to Lockheed Martin.

The supply base of the Joint Strike Fighter is extremely eager to be on board the program, as the JSF is possibly the last manned tactical fighter to be built, providing a "make or break" scenario with respect to the tactical fighter business. This is especially critical for those who are not well diversified with business in other sectors of the industry. Those that make it on board can possibly look forward to up to three decades of contracts and stability in the future.

The JSF program plans on using their supply chain in new ways, involving them more up front in the design work, and also allowing them to add more value to the program by delivering entire subsystems, rather than components designed to specifications. This also provides a further incentive for companies to become part of the JSF Program Supply Chain, as it will give them experience with higher technologies, new design methods, and more advanced tools.

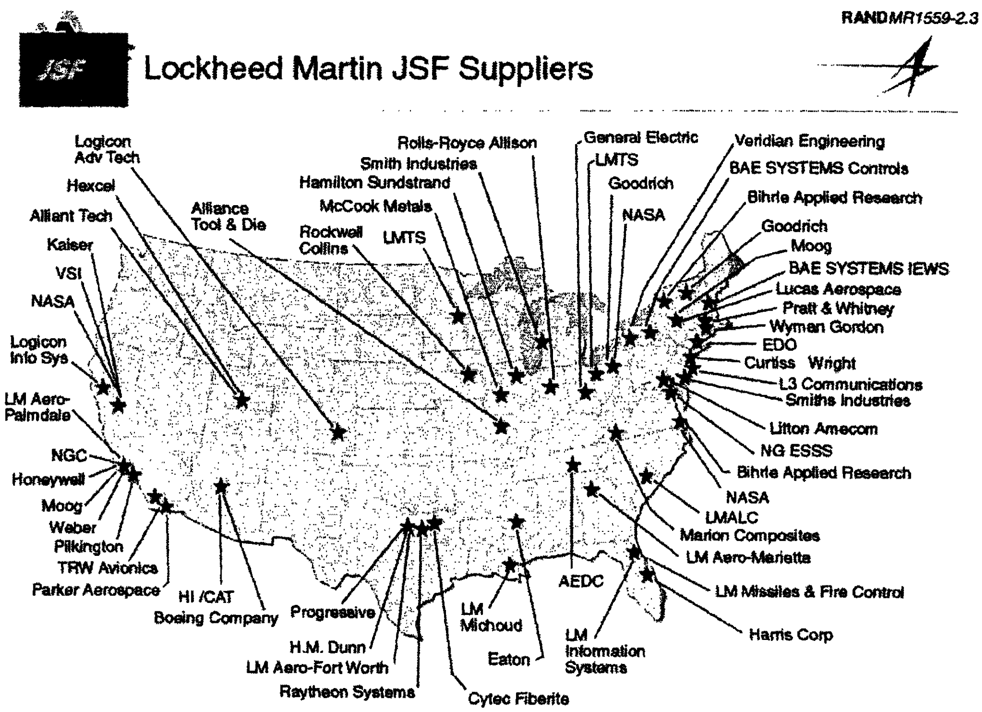

Figure 5.8 – Major Suppliers to Lockheed Martin in Ft. Worth. Source: Rand Report MR 1559, originally from Lockheed Martin.

5.5 Classification of the Joint Strike Fighter Program as An Enterprise Network

The Joint Strike Fighter Program is a prime example of a modern enterprise network in a complex technical environment. Of the various varieties of enterprise networks defined in chapter one, it most resembles an Extended Enterprise, with a closely-held core group of participants composed of the prime contractors and principal partners, and then the extended supply chain and customers, linked into the core enterprise (composed of Lockheed Martin, Northrop Grumman and BAE Systems) via an ICT infrastructure with a high degree of communication and integration along critical paths through the value stream. While normally extended enterprises have a single dominant firm with an integrated, cooperative supply chain, the JSF Extended Enterprise has a nucleus of dominant firms forming the core enterprise, led by Lockheed Martin. This is in contrast to virtual enterprises, which tend to be highly dynamic and more loosely coupled, or alliances, which tend to have very low coupling, very loose governance structure, and involve few participants. The key aspects that make the JSF program enterprise an extended enterprise rather than a traditional enterprise with a coordinated supply chain is the nature of the relationships and the degree of connectivity between suppliers. The relationships are cooperative, and there is a high degree of interaction, both electronic as well as physical between the primes and the lower-tier suppliers. Design is done collaboratively, and suppliers are involved at many levels, from design of components to design of the autonomous logistics required to keep the aircraft operational.

Figure 5.9 provides an idealized graph view of the JSF Extended Enterprise. From a graph theoretic prospective, the JSFEE is a rough hierarchy with the special property that it possess both intra-level and inter-level links between nodes. Nodes on the same level, such as first tier suppliers, may work together on subsystems that are provided to the prime contractor, and many second or lower tier suppliers have visibility extending up through to the primes. This multi-level linking, as opposed to hierarchical dyadic links, is a characteristic of extended enterprises.

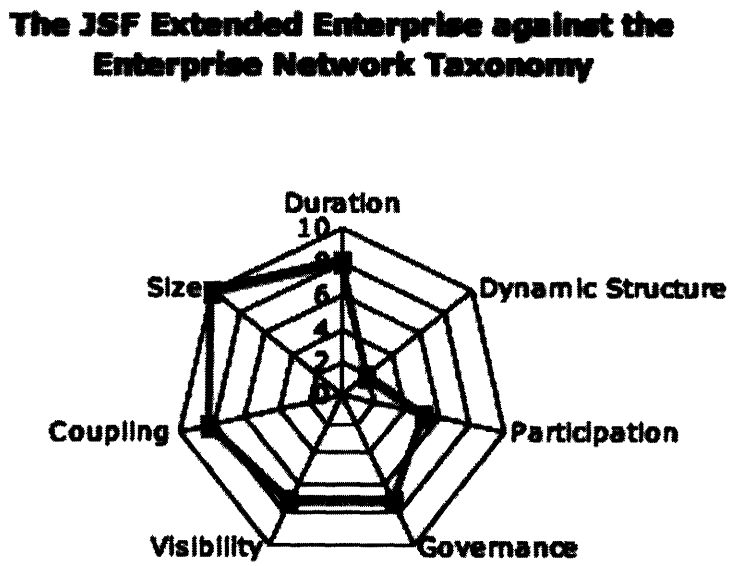

Figure 5.9 – The JSF Extended Enterprise classified using the Enterprise Network Taxonomy developed in Chapter 2.

The JSF Extended Enterprise (JSFEE) can be classified as follows within the taxonomy presented in Chapter 2. Figure 5.9 depicts this classification graphically on a radar chart with these dimensions as the axes.

Duration: The JSFEE is a long-term enterprise network, with a projected lifespan of approximately 30 years. As such, much time can be devoted to network formation and selection of network members. Because of its duration and size, a large amount of resources can be invested in the enterprise network's infrastructure and tools, which will be able to amortized over a long period of time.

Structure: The JSFEE employs a fairly stable structure, without a high degree of dynamism. Contracts are in place to define roles over the life of the program. There is a high degree of trust in the network allowing for strong, stable relationships to be built. It would likely take a gross breach of contract to have a member removed from the network, as others in the network, especially the primes, would likely first try to rectify any problems and get the network member back on track.

Participation: The JSFEE network does not necessarily display exclusivity, but there are exclusive aspects to it. A member of the network is not contractually obligated to avoid work with competing projects, such as one managed by Lockheed Martin's rival, Boeing. The aerospace industry is small enough that this is not possible to do, and most wise companies try to work on several programs concurrently. However, there are exclusivity requirements placed on JSFEE participants forbidding them from taking the knowledge or technology they have gained working on the program and applying it to other programs they may be working on, either individually or as part of another enterprise network.

Governance: The JSFEE displays a hybrid structure when compared to governance structures developed in Chapter 2. It is most like a star-topology structure, with the prime contactor for the airframe, Lockheed Martin, at the center, which makes most large decisions regarding design, sourcing, and strategy. Lockheed Martin, however, is not the only prime contractor—both Pratt & Whitney and the GE/ Rolls Royce team also have prime contracts and manage separate sections of the extended enterprise. Above the three prime contractors is the JSF Program Office, which does monitor the actions of the primes and can direct them to change course, and has ultimate authority on matters. Close to Lockheed Martin are the principal partners, who have a very significant say into the design, and often work very close and in tight collaboration with Lockheed Martin. Below these principal partners are second tier and third tier suppliers, who are also integrated, at varying levels, into the extended enterprise. These lower level network members are consulted on design, and often work together to provide system solutions to the primes and principal partners.

Visibility: There is much more visibility in the JSFEE than many previous aerospace programs. Suppliers often are able to see up several levels to see how their component fits into the larger system, and they are allowed access to much more information than they have been previously in the name of increased visibility to decrease inefficiencies and rework due to poor information.

Coupling: Compared to all previous aerospace programs, the JSFEE is very tightly coupled. The extent to which responsibilities are shared and fates intertwined has never been as high. As such, there is a high need to commonality across the network, and there are fairly stringent requirements for data exchange and tools use.

Size: The JSFEE is a massive enterprise network, composed of hundreds of participating enterprises with up two hundred billion dollars worth of business over the projected lifetime of the program.

5.5.1 Roles within the JSF Extended Enterprise

The JSF Extended Enterprise is a very large enterprise network, and it should not be surprising that there are a number of roles within the network that allow it to function smoothly. The JPO and Lockheed Martin hold the most important roles within the extended enterprise. The JPO serves as the customer, auditor, and performs some of the work of the network coordinator and broker of the network, using the terminology for enterprise network roles developed in Chapter 2. Lockheed Martin Aeronautics, the prime contractor of the air vehicle, holds the majority of positions within the network. In this capacity, Lockheed Martin serves as the network coordinator, broker, and program manager. Both Pratt & Whitney and the GE / Rolls Royce team also perform these functions, but their scope is limited to the area of propulsion. Under the new model of acquisition, Lockheed Martin has a great deal of flexibility and autonomy to run their extended enterprise as they see fit, although the JPO does serve in an oversight and advisory role, and may occasionally step in to make their wishes known. A separate division of Lockheed Martin, Lockheed Martin Information Systems, provides the role of Network Coach, developing the networked infrastructure and specifying how companies across the JSFEE will interact electronically.

5.5.2 Lifecycle of the JSF Extended Enterprise

The JSF Extended Enterprise was formed beginning in 2001, after the contract for the 11-year System Design and Development Phase was awarded to Lockheed Martin. Although at the time of the contract award Lockheed Martin had already formed a close partnership with Northrop Grumman and BAE Systems, the rest of the extended enterprise had not been formed. After contract award in October 2001, there was a flurry of activity around the creation of the extended enterprise, selecting suppliers, defining relationships and processes between suppliers, the primes, and the JPO, as well as rolling out the ICT infrastructure throughout the extended enterprise. The first six months of this process could be considered the creation phase of the extended enterprise.

Although the first six months were the most hectic in terms of creation of the JSFEE, new suppliers continue to be brought into the extended enterprise four years after it was formed, as the entire program continues to operate and evolve as the design matures and prototypes are built. At the present time, there is no set date for the dissolution of the JSFEE. After the F-35 JSF aircraft are delivered to the US and allied forces, other countries are likely to purchase additional aircraft, keeping the production lines open. The JSFEE would like to follow in the footsteps of the F-16, originally designed in the early 1970s, which has had foreign sales push aircraft production forward decades after the US acquisition was finished with new and more advanced designs.

After the final orders for F-35 aircraft are filled, the JSFEE will dissolve, although there will likely be support contracts with foreign militaries after the production lines stop.

The IT infrastructure had not been implemented, most contracts for subsystem and components had not been awarded, and no integration had taken place. As part of the competition for the JSF contract, Lockheed Martin Information Systems had developed an integrated virtual work environment, which integrated tools and data in a central location that would be accessible by the entire extended enterprise. Although the system had been developed, it had not been deployed or field-tested at the time of the contract award. In all past military contracts, there was a period of time, usually about six months, between the award of the contract and the time the contract was funded. Lockheed Martin had planned to use this time to plan the deployment and field testing of the IT infrastructure and selected design tools, debug potential problems, and carefully develop the architecture for their extended enterprise. To the surprise of Lockheed Martin and the rest of the industry, the contract was funded the day after it was awarded, forcing them to immediately begin forming their enterprise network and installing the infrastructure necessary to run it.

6 Chapter 6: JSF Integration: Barriers and Enablers to Integration across the JSF Extended Enterprise

The Joint Strike Fighter extended enterprise has encountered many integration challenges as it has sought to design and manufacture the F-35 fighter using new strategies, many new technologies, and innovative organizational structures. Its massive size and multi-decade duration mean that its enterprise integration strategies for its diverse network of companies will have a very deep and lasting impact on the enterprise integration strategies across the aerospace industry, so it is fitting that this program be studied in greater detail.

This chapter explores the barriers to, and enablers of, integration experienced by the JSF extended enterprise as the program evolved its current enterprise network. The data in this chapter were collected in the course of two rounds of semi-structured, not-for-attribution interviews with key personnel working on the program at Lockheed Martin's Ft. Worth, Texas design and production facility, as well as with individuals via teleconference and telephone interviews at other locations in the JSF extended enterprise. As mentioned in Chapter 1, these interviews were conducted with individuals with very high-level visibility into the JSF extended enterprise, covering the heads of program management, engineering, material management, system architecture, manufacturing, and information systems for the JSF program, focused on the air vehicle platform (this includes all aspects of the program for which Lockheed Martin has responsibility as the prime contractor). These interviews represent the views of specific individuals from across the extended enterprise. Where these views reflected sharp differences on some of the key issues explored, they are noted in the course of the discussion presented below. This chapter will focus on common themes that emerged from these field interviews. These common themes are structured around strategic, technical, and organizational integration issues, based on the framework for common barriers to enterprise integration presented in Chapter 3. Barriers to enterprise integration identified in the literature that have been observed to be present in the JSF program are highlighted. In addition, other challenges that are specific to the JSF enterprise, and by extension to the military aerospace industry, such as restrictions on technical collaboration with international partners, are underscored.. Each section will conclude with enterprise integration "lessons learned," enablers broadly applicable to the section that were brought out in multiple interviews.

6.1 Introduction to Enterprise Integration across the JSF Extended Enterprise

There was a tremendous impetus for enterprise integration throughout the JSF program. During the JSF competition in the Concept Development Phase, Lockheed Martin looked to its extended enterprise as a source of competitive advantage against Boeing's proposal, just as it would look to its technical design of the F-35 as a source of competitive advantage. Both Lockheed Martin and the Joint Program Office (JPO) saw strategic teaming with Northrop Grumman and BAE Systems, as well as the extensive international collaboration on the JSF program, as a great asset. As one interviewee explained, however, such a teaming arrangement can also be perceived as a "teaming penalty": by partnering with a number of major aerospace supplier companies, Lockheed Martin would stand to benefit from the experience and expertise of other programs in which these companies might be involved. However, Lockheed Martin would also pay a price for such a partnering arrangement in the form of having to coordinate the resulting greater complexity of interactions between itself and various members in the network as well as among the various partnering members themselves, in a wide spectrum of areas, ranging from tool interoperability to semantics and security. The benefits of partnering do not come for free. The challenge that Lockheed Martin faced was not just to overcome this "teaming penalty," but to enable the extended enterprise as a whole to perform in a way that is greater than the performance of the sum of its individual parts. The traditional approach to enterprise integration has typically been to use technical integration as a way to simply lower transaction costs across the network by using information technologies and systems within the context of existing structures and processes. Often, this has had a positive short- to medium- term effect, and the overall impact on the performance of the extended enterprise over a longer period has largely been incremental.

Lockheed Martin desired to go beyond simply minimizing transaction costs, and made the decision to view *integration as a strategic capability*. The systems, policies and structures in place for integration had more to do than simply reducing or minimizing transaction costs to ensure that networked structures are economically feasible— these had to enable the extended enterprise to behave in revolutionary new ways that would allow it to operate as a single entity, focusing on its performance over multiple time scales—short-term, medium-term, and long-term. This reflected a new mental model of the entire enterprise network reflecting a new enterprise architecture, helping to evolve a coherent set of strategies and technical, as well as organizational, components working together in concert. This entailed a fundamental redesign of the enterprise network, enabling it to perform much more efficiently and effectively over the longer run than the traditional prime-contractor-sub-contractor relationship. In a way mirroring Venkatraman's framework using information technology for business integration and transformation, (as outlined in Chapter 3), the JSF extended enterprise looked beyond evolutionary gains from information systems integration (Level 2) and instead used enterprise integration as a vehicle for revolutionary change and fundamental *network redesign* (Level 4), closely involving strategy and organizational structures with its technical systems. Many aspects of the way traditional companies within the aerospace industry work together need to change for this approach to come to full fruition, and the undertaking continues to be non-trivial. The following chapters outline these integration challenges for the extended enterprise, divided into categories of strategic, technical, and organizational barriers and enablers.

7 Chapter 7: Strategic Integration on the JSF Program

The primary idea underlying strategic integration in an extended enterprise is to interlink the value chains of organizations within the network, streamlining the value stream from material acquisition to product delivery, allowing product to flow smoothly through the value chain. Interlinking the value chains within the extended enterprise includes aligning stakeholders, building trust, opening up processes, identifying opportunities for elimination of redundant or non-value-added activities, and learning to successfully work within external regulatory environments. The JSF program has faced many of these strategic barriers as it has attempted to guide a very large extended enterprise through rocky relationships, international politics, and a highly restrictive regulatory framework.

7.1 Inter-firm Alliance, Allegiance, and Trust

One of the initial challenges for Lockheed Martin when it sought to assemble an extended enterprise was building allegiance between firms that were often in direct competition. The F/A-22 Raptor, an advanced fighter designed in the 1990s and early 2000s, was originally intended by the US Air Force to be a collaborative program, with work shared between Lockheed Martin, Boeing, and General Dynamics (which Lockheed Martin subsequently acquired). According to those interviewed at the Ft. Worth site where major components of the F/A-22 are designed and built, the reality of the F/A-22 was that the program had low mutual allegiance and trust between its major partners. Lockheed Martin and Boeing did not intimately collaborate on this highly technically integrated aircraft, and were hesitant to share technical or process data. A major driver behind this lack of tight cooperation was the JSF Concept Development Phase competition, in which the two companies were competing head-to-head in for the award of the JSF contract. It is difficult to closely cooperate on one project while ruthlessly competing for another simultaneously, even if efforts are made to erect internal inter-program barriers. The F/A-22 suffered many delays over its development, and several interviewees pointed to the lack of program integration in the project stemming from trust issues between the major partners in the highly technically integrated project.

Lockheed Martin had several advantages on the JSF extended enterprise it did not enjoy on the F/A-22 program. When forming the JSF team, it could pick and choose its partners to ensure compatibility on the program, rather than being forced to collaborate with a major competitor. Additionally, many firms in the industry saw the JSF as a "make or break" proposition. Because the JSF is likely to be the last manned fighter aircraft built in the US, companies were eager to become involved with the project in order to stay in business in the industry. The JSF program is the largest defense program in history, and it has generated many potentially lucrative, long-term contracts. This forces smaller companies to be more amenable to change and new ways of operation if it means that they could be a part of a successful 25-year program. In this sense, perhaps ironically, desperation can be a vehicle for building trust.

To both build trust and to increase the flow and quality of information across the network, Lockheed Martin made the decision to populate the program's Integrated Project Teams (IPTs) with personnel from across the extended enterprise and to have many domestic as well as international partners co-located at its Ft..Worth facility. Lockheed Martin opened leadership roles across the extended enterprise for non-Lockheed Martin employees. As a prominent example, the head of the Air Vehicle IPT, one of the largest and most important IPTs on the program, is a Northrop Grumman employee. One co-located non-Lockheed Martin interviewee acknowledged that these practices greatly influence his daily work, as he felt that he had a very strong allegiance to the JSF program, and often thought of the program's concerns before thinking of his own company's concerns.

The strategies that drive both co-located and intermixed teams have proven to be successful enabling strategies to build trust and allegiance necessary for successful enterprise integration, but they do not come without cost. Intermingling of the IPT workforce, and especially collocation of foreign nationals, bring increased security burdens to the enterprise, and law requires that separate databases and associated networks be installed for the use of these employees and that access by these employees be limited to these particular data sources.. These technical requirements will be further examined in the Chapter 7, which addresses technical integration.

7.2 International Stakeholders

A key feature of the Joint Strike Fighter JSF Program is the presence of international partnerships during aircraft development. Many interviewees pointed out that these international partners were a very necessary aspect of the program. In addition to providing expertise on technologies such as Short Take Off / Vertical Landing (STOVL) and experience with other fighter programs, the countries of these international partners also represent other markets for the F-35 in the future through foreign military sales (FMS) and help to shield the program from political attacks and budget reductions within the US, as the program's international alliances carry additional weight with Congress. From the point of view of the US Government, the involvement of the international partners and its investments in the program mean that the acquisition price per aircraft for the US should be lowered due to foreign investment and economies of scale. Additionally, allied forces with similar weapons systems should be able to fight more effectively alongside US forces in the case of allied campaigns. Although there are many benefits to including international partners on the JSF program for the US, the barriers to integrating these international partners into the program remain high and costly. In particular, there are two large *strategic* obstacles: ensuring value for the international participants to keep them satisfied with the arrangement, and US security regulations on the transfer of sensitive technologies to foreign nations.

7.2.1 The International Value Proposition

The countries that invested in the JSF did so to gain access to technology, have some say in the development of the aircraft, to lower the cost of acquisition, and importantly, to allow companies in their own countries to be considered as potential suppliers for the program. With the exception of a very small number of highly specialized parts, all contracts are awarded on a *value basis* to companies in countries that have invested in the program. Unlike many other international aerospace programs, especially those in Europe, which guarantee that contracts will be awarded in proportion to investment or other offsetting contracts, there are no such guarantees in the JSF's Memorandums of Understandings that have been signed between the US and each partner nation. The prime contractor determines its suppliers based on the apparent value that the supplier brings to the table. In this scenario, it is possible for countries that have made a significant investment in the JSF to receive fewer contracts than they might have expected in return if their businesses cannot provide a persuasive value proposition to the JSF program. The US knows that these countries expect a return on their investment. According to the General Accounting Office, "These countries expect to realize a significant return on their investment in the form of JSF contract awards to their defense industries. To meet these expectations, the JSF program office has encouraged the three JSF prime contractors—Lockheed Martin, Pratt & Whitney, and General Electric—and their suppliers to provide opportunities for companies from partner countries to bid on contracts(GAO-04-554)."

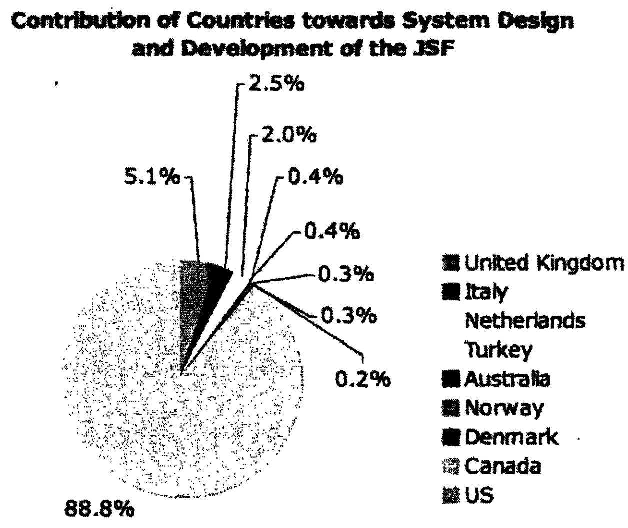

Figure 6.1 – The Contributions of partner nations towards the System Design and Development Phase of the F-35. Data Source: GAO-04-554

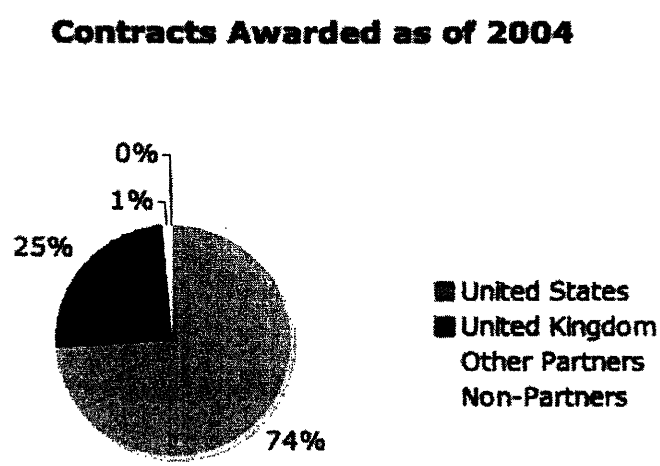

Figure 6.2 – Contracts Awarded during SDD, as of December 31, 2003. (GAO-04-554)

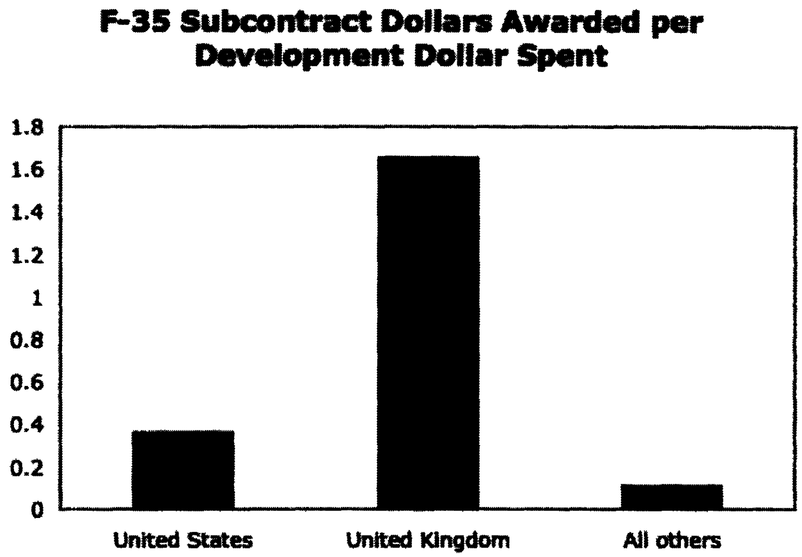

Figure 6.3 – Return on Investment as of December 31, 2003 for the SDD phase. Not all contracts have been awarded under this phase, which will last until 2012. (GAO-04-554)

While the Buy American Act, 41 USC Sections 10a – 10d, stipulates that at least 50 percent of any material acquired by government programs must be acquired through domestic sources, the JPO has applied for a waiver under the public interest exception clause (GAO-04-554), allowing it to let this percentage sink below 50%. Although the primes are actively seeking out international suppliers, many nations are still not seeing a favorable return on investment, although not all contracts have been awarded. This has been a cause of great frustration for many of the international participants, especially in the popular press that sees JSF investment as a waste of money if it does not guarantee jobs at home. Australia and Norway, in particular, dealt with loud opposition in their press in 2004, although much of the uproar died down in Australia as contracts began to materialize in 2005. See Figures 6.1, 6.2, and 6.3.

In recognition of many of the difficulties faced in keeping the international partnership strong and in order to ensure that participants are satisfied with their investment, Lockheed Martin made the decision to redefine the role of the former program manager of the JSF, Tom Burbage, by appointing him to serve in a new role as the Vice President for JSF Program Integration, where he closely works with international partners. Lockheed Martin and Burbage have taken an active role in US and internationally to maintain these strategic partnerships. As an example, in June 2005, Lockheed Martin warned the EU that if it were to follow through on a plan to lift arms embargos on China, there would be repercussions on the JSF program, because the US Government would likely retaliate against European suppliers, which would hurt the JSF partnership.

7.2.2 Technology Transfer Challenges

A second major strategic integration concern in relation to international partnerships is learning to work successfully within the United States' restrictions on the export of technology to foreign nations. The US export control regime's rules are governed by the International Trade in Arms Regulations (ITAR), US Code Section 2751. The industry has often called these rules onerous and even counterproductive:

> "The purpose of licensing military equipment appears to have gotten lost in the bureaucratic maze and has grown so cumbersome,

complex, and slow that it is generating tensions with allies and degrading the competitiveness of the US defense industry.[4]

ITAR was at the center of recent efforts to overhaul US export control laws by the US Congress (notably Senate Bill 147 in 2001), but these efforts stalled in the wake of the attacks of September 11, 2001[5]. In its place, the current laws in effect "effectively tighten restrictions on high-tech exports to the detriment of US competitiveness abroad *without* enhancing US national security."[6] There is no doubt that export controls export controls are needed by the US; the central point of contention is the bureaucracy and inefficient controls that accompany it.

The current export control regime severely limits international involvement in the development of the JSF, because it places many technical aspects of the aircraft, such as almost any piece of computer code, completely off limits to international sharing, while the JPO is simultaneously pushing for increased international collaboration. The law is very complicated, difficult to understand, and at times ambiguous, further hampering efforts to involve international partners because it often takes a significant amount of time to understand what the law actually requires. The penalties for breaking these export control laws are very severe. Consequently, international collaboration is usually avoided in any remotely questionable "grey" area in order to steer clear of any potential legal troubles with the US Government. An interviewee mentioned that Lockheed Martin

---

[4] "The Export Control Project of the Center for Strategic International Studies." < http://www.csis.org/export/projdescript.htm> (accessed May 9, 2004)

[5] Gary G. Yerkey, "Rep. Drier Says Prospects for Passage of Export Control Legislation Not Good," 20 Int'l trade Rep. (BNA) No. 16, at 664 (Apr. 17, 2003)

[6] Nathan T.H. Lloyd. Rebuilding a Broken Regime: Restructuring the Export Administration Act, 37 Vand.V and J. Transnat'l L. 299 (2004).

has an entire office whose sole job is to interpret ITAR and ensure that the extended enterprise is in compliance with it.

One particular difficultly is that a few international partners, most notably the UK-based partner companies such as BAE Systems, desire access to the technical plans and software code of the aircraft, to allow for the opening of a second manufacturing facility in the UK and also to allow for future maintenance operations to be performed within the UK which would avoid sending the aircraft across the Atlantic for their maintenance in the United States. At the 2005 Paris Air Show, the UK hinted that it may pull out of the JSF program if it does not receive greater access to design data for the F-35 in the future. One option noted by Mike Turner, the head of BAE Systems, was instead to enter into a partnership with France and Sweden on the development of an unmanned combat aircraft known as the Neuron.[7]

General Jeffery Kohler, director of the Department of Defense's Defense Security Cooperation Agency, noted, "A lot of partners don't seem to quite understand that this isn't an old-style airplane program. This is not an offset program or an industrial development program that awards contracts in return for funding." "The US isn't in a position to say you've invested a bit so here you go, here are the blueprints to the Joint Strike Fighter." [8] According to Alexandra Ashbourne, a defense analyst who heads London- based Ashbourne Strategic Consulting Ltd., "There is a huge amount of frustration about the lack of progress on this issue. There is real resentment within the

---

[7] "U.K. shouldn't expect technology access on JSF, officials say." Published June 16, 2005. Bloomberg News Service, Bloomberg.com.
http://www.bloomberg.com/apps/news?pid=10000102&sid=akMVFuWO09vo&refer=uk
Accessed June 17, 2005.
[8] Ibid.

UK government that despite being the most loyal ally in Iraq, we have nothing to show for it."[9]

Lockheed Martin and the JSF extended enterprise have been active politically, lobbying for changes to the law to make it easier to work with while still retaining, if not improving, national security objectives.. In one example, Lockheed Martin has lobbied Congress for an extension to the so-called "Canadian Exemption", which exempts Canadian citizens from many of the requirements of ITAR. The JSF program would like to see these exemptions applied to the UK as well, especially as the US has been increasingly collaborating with the UK in many defense-related areas, notably the recent war in Afghanistan and Iraq, as noted above. The US Congress is hesitant to approve any legislation that could be perceived by the public as relaxing arms export controls in the current political climate and has largely blocked these efforts. Many of those interviewed felt that this situation is not likely to change, and, if anything, the controls will only become tighter in the short- and medium-term future.

The influence of ITAR extends beyond what foreign nationals are allowed to see while working on the program. It governs the work environment, the computing environment, and policies for collocation. Examples of these barriers mentioned in interviews include restricting foreign nationals from entering into buildings to work overtime, requiring a separate computer network that needs to be maintained for their work, and there is now a six-week minimum term for co-located foreign nationals, as any shorter duration makes going through the legal hurdles necessary for collocation not worth the effort. There are often tendencies to want to create "US -only areas" that are

[9] Ibid.

free of the obstacles for integration. Taken together, interviewees have pointed out that the job description for many foreign nationals is often "fuzzy and ambiguous," as their roles within this structure are still evolving. This has led to what one person termed "successful ambiguity," because to date they seem to have seemed to found ways to make this work.

The legal environment created by ITAR has led to a phenomenon known as "information hiding" within the program. Often, foreign nationals are not outwardly denied requests for information or data—instead, nothing appears to them when searching or making inquiries. This has the effect of telling a foreign national that there is no information, leading them to possibly re-do the work or re-acquire information that has already been assembled, creating wasted rework leading to schedule oscillations known as "design churn, " which makes many of the efforts of international employees especially inefficient. The problem is exacerbated when design documents incorporate information that foreign nationals can and should be able to see with some that they are not, which restricts the entire document.

The phenomenon of information hiding has been observed in many complex product development processes, even within a single enterprise without these restrictions. In these situations, most often information hiding is not intentional and is instead the result of asynchronous information exchange(Yassine, 2003). In the case of ITAR restrictions on the JSF program, information hiding is intentional, exacerbating the problems of design churn, leading to a great deal of waste with international partners. At least one of the non-American interviewees pointed out that this was a problem that he and other foreign employees faced.

An effective strategy that those in the JSF Extended Enterprise have found to work within ITAR while avoiding design churn and the inefficiencies of information hiding has been to rigorously separate technical, restricted data from its non-technical, unrestricted parts. By having design documents issued as a bundle of restricted and non-restricted parts, foreign nationals can search for and access information they can see, such as schedule, change orders or non-sensitive design and process data, while still adhering to the letter and spirit of the law dictated in ITAR. This solution took time to institutionalize, because it represented a change to the normal way of doing work. When this new process was not followed, it created noticeable information hiding problems with international participants that helped to reinforce the importance of data separation. Today, it works most of the time, and some of those interviewed mentioned that the situation is much better than in the past.

The issue of technology transfer is a thorny issue that must be negotiated between the armed forces of partner nations, with dramatic consequences for the program. Obviously, the larger companies in the extended enterprise, such as BAE Systems and Lockheed Martin, are very actively working with their governments to overcome these barriers to strategic integration. There are still open issues and must be resolved in the coming years before the F-35 enters production if the current structure of the JSF program and future international collaborative efforts like it are to be successful.

ITAR is a strategic barrier that influences all areas of integration, including technical and organizational integration. Many of the solutions developed for working within the confines of ITAR are indeed technical and organizational, and these. These issues will resurface in those sections of this chapter.

7.3 Supplier-Partners

The Joint Strike Fighter Program envisioned a large change in the traditional role that suppliers played in past aerospace programs in an effort to drastically reduce costs on the aircraft. In the past, there has been what some called "a PO mentality" within the industry: the prime contractor would draft a very specific contract with detailed requirements and designs, and then the suppliers would manufacture the piece exactly to specifications. Suppliers could then expect the prime contractors to force them to lower prices or face losing a contract. Even though price reductions were being routinely forced on them in an older system, suppliers had little say in the design to effect real cost savings, had little share of the risk, and could not integrate subsystems of their own or provide value to the program in other ways. Programs with such traditional supply chains showed little integration beyond possibly the top tiers into the smaller suppliers, and could not be seriously considered an "extended enterprise," as the suppliers were not true members of the enterprise network with real bilateral links, but rather exogenous entities that had to be "handled" by the prime contractors. As a result, there were often problems in the supply base that caused delays and technical problems that affected the entire program, necessitating a change in the prime-supplier relationship.

Today, this relationship is changing, and the JSF Program Office hopes that the JSF Program will be a model of this change in the military aerospace industry. The military customer has gone through changes of its own to encourage this behavior, moving away from hard specifications and requirements in its contracts to performance-based requirements that contractors can meet in ways they believe are optimal. These changes have been codified in the Department of Defense Directive 5000 with subsequent revisions. Color-of-money issues, where sources of money dictate where it can be spent, have been reduced, creating more of a "single pot of money" environment that is much more conducive to flexible allocation of resources to achieve desired outcomes. The customer would like to move towards a more participatory supplier base that is active in design and can take on more responsibility, providing increased value to the program and heading off upstream problems before they make their way farther downstream and causing very costly rework cycles.

These supplier-partners collaborate on lower-cost and more manufacturable designs that will benefit everyone in the extended enterprise. These supplier relationships are more long-term, leading to more trust in the network and allowing greater network flexibility. For their part, suppliers are eager for many of these changes, as greater responsibility often means greater financial rewards and brings freedom from the relentless pressure to reduce prices while having no control over the design or specifications.

Currently, interviewees described that Lockheed Martin is trying very hard to get away from the old "PO (Purchase Order) mentality" towards suppliers as replaceable sources of low-cost fabrication and to treat them more as partners on the program with added responsibilities, although this has been a hard thing for the company to do. One person mentioned that he prefers using the term "extended team" rather than "suppliers" to help foster this mindset. There will always be a "my idea is better than your idea" attitude when comparing similar ideas between a large prime and a smaller supplier that is hard to avoid. Everyone involved, however, acknowledges that the real cost savings in future aircraft must come from the supplier base, and beating up suppliers for lower prices has limited utility over the long run, especially if suppliers have little control over design and subsystem integration. If costs are to be drastically reduced, suppliers and primes must work together on new designs and processes that allow for more drastic cost reductions without eliminating the profitability of the suppliers. It is through partnership with creative incentive structures that costs can be dramatically reduced through a "win-win" arrangement —not through strong-arm tactics forcing suppliers to reduce price without little guidance or influence over the design.

Lockheed Martin has taken partnering in its supplier base very seriously, as the supplier network will account for between 70 and 80 percent of the total value of the aircraft[10]. When determining supplier-partners, Lockheed Martin performs a risk assessment of the partnership with multiple levels of fidelity, projecting the outcome of possible scenarios on the partnership and the ability of the supplier-partner to deliver on its promised capabilities. Detailed business plans with long term, multi-year projections are considered, and partnerships are only approved if it can be determined that the partnership will be mutually beneficial with a certain likelihood.

Some mentioned that there was concern in the industry after the defense acquisition reforms that the prime contractors in the industry would take the performance-based requirements from the customer and simply turn them into detailed specifications for the suppliers, doing little to allow these reforms to impact the supply chain. To combat this, Lockheed Martin has made the decision on the JSF to buy at the

---

[10] Barlas, Demir. "Lockheed's Virtual Workspace." Line56. February 20, 2002. Accessed online at http://www.line56.com/articles/default.asp?articleID=3393&TopicID=2 on August 4, 2005.

systems-level as much as possible, which means that suppliers will be responsible for more integration and design. Suppliers are often encouraged to work together on systems. Lockheed Martin will intentionally pair suppliers with complementary core competencies together in an effort to get a single best design rather than two competing designs with different weaknesses. Contracts can be given to groups of suppliers for a system, and Lockheed Martin lets the suppliers decide how to best split the contract among themselves, hopefully leading to a more optimal allocation. The idea is that if the team is rewarded, as opposed to individual suppliers, there will be more incentive for supplier-partners to help each other. This must be handled carefully, however; just as Lockheed Martin learned on the F/A-22 Raptor program with Boeing, rivals are not known for their open and collaborative approaches on programs that they are forced to share. Although the supply chain design and management practices on the JSF program contain many features of lean supply chain management, it remains to be seen how deeply the basic lean principles have been actually adopted by observing the program outcomes in the future in terms of affordability and other targets.

7.4 Strategic Lessons Learned

- It is difficult keeping international partners satisfied with a non-traditional partnering arrangement. Although contracts do not specify returns on investment, there is a minimum level that is expected. This disconnect must be resolved.
- In order to have a significant impact on program cost, suppliers of systems need to be involved in the design process to give them the power to significantly affect designed-in cost.
- It is very valuable to have a single customer voice (the JPO), instead of answering to many customers as on previous joint programs
- Traditional industry supply chain incentives should be changed to reward cooperative team behavior
- A challenge ahead is to understand how to reward suppliers for intellectual contributions
- Both colocation and site visits with critical suppliers are very effective at building trust, establishing connections, and improving communication between members of the extended enterprise.
- The structure of information is key to working within ITAR restrictions on export of technical information and avoiding information hiding and design churn.

8 Chapter 8: Technical Integration on the JSF Program

The technical integration strategies taken by Lockheed Martin on the Joint Strike Fighter JSF have caught the attention of industry and others in the information systems industry for its new uses of technology to integrate such a large and complex extended enterprise as well as to design and manufacture the technologically advanced F-35 JSF aircraft. Although the technical integration strategies of the JSF program have received the most attention from those outside the program, the extended enterprise as a whole realizes that technical integration strategy alone is but one leg of the overall integration approach. It sees this as a critical enabler that facilitates collaborative, integrated work, and which also complements the strategic and organizational integration approaches that are also being pursued concurrently.

Technical integration consists of design integration, handled by a design process for the entire extended enterprise, and a technical infrastructure for collaboration. The design integration process is centrally controlled by the system architecture to minimize misunderstandings and rework as people from across the extended enterprise seek to design and build parts of the aircraft with a high degree of interaction. The technical infrastructure is the hardware and software in place to allow partners from across the extended enterprise to work on the system collaboratively. It was designed and implemented by Lockheed Martin Aeronautics' Information Systems & Technology division, independently of other partners in the extended enterprise. When designing the system, the goal was to design "an architecture that would promote a team environment, rather than emphasizing a prime/contractor role."

Technical integration is important during many phases of the program's lifecycle, ranging from design, where the emphases are on an integrated design space and integrated processes, to manufacturing and support, where the emphasis is on having the right information at the right place at the right time in a clearly digestable format. Technology was used as a tool to fundamentally redesign the character of the enterprise network and its methods of operation, in a way quite similar to what is outlined in the fifth level (*network redesign*) of Venkatraman's framework for technology-enabled transformation of business, (addressed in Chapter 3). To date, although there have been growing pains and many lessons learned, the system is providing value to the extended enterprise. This section will outline the challenges faced when implementing and operating the processes and systems put in place for technical integration of the extended enterprise, and identify enablers and lessons learned from the experience.

8.1 Technical Design Integration

The ultimate authority for all technical design integration issues lies with the Office of the Chief Engineer of the JSF, which ultimately controls the Work Breakdown Structure (WBS) of the aircraft. The WBS is a set of design documents describing specific system boundaries for the aircraft that are owned by an organization within the extended enterprise. Whoever owns the WBS for a section of the aircraft has authority over integration within that area, as well as at the interfaces of its internal system. WBS is described in greater detail in Section 9.1.

The Chief Engineer's "watchdog" for system integration issues on software and missions systems (avionics), one of the most complex systems on the aircraft, is the system architect. The system architect creates and maintains the system architecture and interfaces for these systems, watches over all technical integration issues, and enforces design policy. The system architecture of the avionics is a very critical component of the aircraft, as it determines everything from its ultimate performance to the designability, testability, and feasibility of the system.

In addition to the creation and maintenance of the system architecture, the system architect is responsible for signing off on all Requirements Work Packages (RWPs) that are produced by the system engineers on the design integration teams in avionics. RWPs set performance goals, specify interfaces, perform error analysis for specific subsystems. Additionally, both the US Air Force and the Navy have sent in teams to examine the integration work on the JSF and make recommendations to the system architect.

A further look into the task of the system architect and the integration of avionics on the JSF will yield a very good example of technical design integration challenges in the JSF program and will be explored in greater depth.

8.1.1.1 Avionics Integration Challenges

Avionics architectures have been steadily evolving in the past three decades, and have swung between loosely coupled federated systems to highly integrated systems and back over this time period. The most recently designed fighter, the F/A-22, has the most integrated avionics architecture of any aircraft developed, and it ran into many, many problems during development, stemming from its technical feasibility and from mismatches between its technical architecture and the organizational architecture of the team that designed it. One particular problem of note was that the mission system software was highly unstable after it was initially developed and released. Due to the highly integrated nature of the system and the demands it made on its hardware, it was extremely difficult to debug, and required a great deal of attention from many high - profile experts to finally get it to an acceptably workable state. These problems caused very significant delays in the delivery of the F/A-22, and greatly contributed to higher development costs.

When developing the avionics architecture for the JSF, the system architect chose a more "hybrid" approach for the system architecture than the F/A-22 used, incorporating more federated, modular systems together with some specific integrated systems to specifically avoid the problems that plagued the F/A-22. The reasoning for this was that it made business sense: this hybrid architecture would be easier to debug, manage, and control. It allowed the use of more inexpensive processors and makes fewer demands on the computational infrastructure as a whole. The decision on whether to go with a federated or integrated system was made on a case-by-case basis, analyzing the function and critical interfaces of the component before making a decision. Central processing, for example, remained integrated, because it was easier to upgrade this capability with a single source, as opposed to many distributed processors. Over time, the feeling held by several of those interviewed has been that the trend in avionics architectures will swing back towards integrated architectures as processing power, communication speeds, and tools to work with highly integrated systems become more mature.

8.2 Physical Network

One of the least problematic aspects of integration has been development of the physical communications network. Lockheed Martin laid dedicated communication lines to over 150 supplier-partners to include them in a dedicated, high-speed, secure, wide-area network infrastructure, at a rate of 50 lines per year, using a highly flexible, agile deployment team. The entire network uses commercially available components, albeit in conformance with DoD requirements for secure communication at the physical layer. There are parallel, firewalled computer networks where required by DoD security restrictions. There are multiple physical computer and communication networks, including one internal to Lockheed Martin employees, one for American work on the JSF external to Lockheed Martin (the primary network for the extended enterprise) and a third, separate network for foreign nationals working on the program. Although maintaining separate networks is an added burden, it is a security requirement from the customer intended to keep sensitive data in "safe" areas.

Lockheed Martin Information Systems & Technology is constantly upgrading hardware, monitoring performance, and reviewing the system at approximately six-month intervals. These reviews are driven by the condition of the network rather than by a set schedule. The entire infrastructure is on a three-year upgrade cycle, and each part is monitored and replaced before it fails. In the opinion of those in Information Systems & Technology, this is the easy part—they have done it for years, and the hardware in use is fairly well understood. Problems do occasionally appear, but are usually quickly resolved by experienced teams.

Above the physical network on the transmission layer, the wide-area network uses standard TCP/IP for communication, with added encryption technologies specified by the

DoD where necessary. The expertise necessary for such systems already was resident at Lockheed Martin, and it was able to install this very large network in fairly short order, considering the size, security considerations and the number of sites included in the network.

The true technical challenge for integrating the extended enterprise is not the physical layer—it is the application layer, the myriad tools that must work together to design, manage, and build a very complex aircraft with many radically different systems. The next section will move into exploring the challenges to integrating this aspect of the networked infrastructure.

8.3 Logical Network

The "logical network" refers to the parts of the network that provide *logical connectivity*—ensuring that one part of the network can logically interoperate with each other part. This includes standardization or interoperation of file formats, databases, and tools necessary for the design, management, fabrication, and maintenance of the JSF. It is the integration of the logical network where the real challenges lie in the technical integration of a complex extended enterprise such as the JSF. Typically, each member of the extended enterprise has traditionally used its own tools, processes and policies to design its own components in a way it has been comfortable with on past aircraft programs, thus making collaborative work with others who have different tools, processes and policies extremely difficult on new programs. Logically integrating tools and processes requires changes in the technology, specific applications and procedures used, which are usually met with stiff cultural resistance from people who must work with these changes.

An effective strategy for successful technical integration of enterprise networks should understand that integration in and of itself is not the ultimate goal. The ultimate goal should be overall network performance. The central task should be to understand how to integrate resources across the extended enterprise just enough to allow people effectively get their job done—eliminating waste and redundancy throughout the enterprise's computer and information network—without creating a new process that is so integrated that it diminishes the effectiveness of the previously diverse and specialized tools and processes. Ultimately, a decision must be made to determine which systems should be standardized and tightly integrated, and which systems should be left de-coupled or federated.

As more tools and processes are integrated, the program becomes easier to manage and will run smoother, but a uniform environment that promotes a "one size fits all" approach will hamper the creativity and capabilities of individual systems, according to one of those interviewed. The JSF program initially attempted to integrate information, design, and manufacturing systems as much as possible, as it saw technical integration as one of the cornerstones of the program. Over time, it identified portions that could deal with less integration, and has either decreased its integration efforts in these areas or has decided to build systems differently on future programs. The challenge in integrating such a complex environment is to understand the tradeoffs that occur when integrating and knowing where the marginal benefits from integration lie.

There are three large information systems that serve as logical connectivity across the air vehicle portion of the JSF extended enterprise. The first, and most difficult to implement, is the Virtual Processing Center (VPC), the massive collection of integrated tools centered on a Product Data Management (PDM) system that also features security and document control. In addition to the VPC, the JSF Data Library (JDL) serves as an integrated repository of all business and process data for the aircraft, and the Integrated Management Framework (IMF) serves as the integrated management portal used by program management, supplier-partners, and the JPO. The following sections will outline each of these logical integration systems, and the challenges encountered in design, implementation, and operation of them.

8.4 The Virtual Processing Center

The Virtual Processing Center is a massive suite of design tools centered on a PDM system that allows engineers from across the extended enterprise to collaboratively design the JSF, even from remote locations. Lockheed Martin developed the Virtual Processing Center working with existing commercial design tools and their vendors to incorporate these tools into a central suite of tools. It wanted to avoid custom-made, in-house solutions wherever possible to save the expense of independent development and to benefit from the expertise of companies who operate in niche markets. These tools were modified from their original form to work seamlessly with other tools as part of an integrated system that could be used to easily share, store, and control design data from a single source. Ideally, the system should help people understand how the design decisions they make interact with the decisions of others around them, and help identify conflicts early in the design and manufacturing process. Lockheed Martin went to its engineers, as well as those of its primary partners, Northrop Grumman and BAE Systems, to identify the tools that they desired to use and identified more than 400 tools to be integrated into the VPC. Mapping them together, ensuring interoperability and then validating such a large array of tools into a single platform that users could log into from a single source proved to be a tremendous challenge for Lockheed Martin's Information Systems & Technology division.

The goal of the VPC was to create a highly integrated design environment that would enforce common processes with standard tools that everyone across the enterprise could use, while controlling access to sensitive documents and maintaining version control of documents. In reality, this proved very difficult, as there were a number of challenges that developers faced along the way: users' choice of tools or design platform often conflicted; they disliked standardized processes; the VPC (and especially the PDM component) did not allow people to work in the way they were accustomed to; it was difficult to get input from users when the system was being designed; and there was resistance to the system once it was initially implemented.

8.4.1 VPC Development

Work on the VPC began during the Concept Development Phase, when the prototype X-35 and Boeing's X-32 were in competition for the JSF contract. This was a very busy, turbulent time during the program's history, and the X-35 development team had many difficulties gathering the information that it needed. One of the first challenges came when the team tried to map out engineering design processes, which would become embedded into the VPC's architecture. This task required experienced engineers to stop work momentarily and think very critically about how they do their job, asking questions such as "what information do I produce," "how do I produce information," and "where does the information go when I am through with it?" These data would allow VPC designers to tailor the VPC to make doing a job easier by codifying the work required for it into standard processes. Getting engineers on the program during this crucial time to slow down long enough to describe their work in the detail that IS&T desired was very difficult, and the engineers often tried to push the task back onto the VPC design team. As a result, IS&T often had to make best guesses as to process using the data at hand. As one person noted, "although it takes a while, it's relatively easy to develop the tools, but it's much harder to understand the process."

Tool selection for the VPC did not always go smoothly. Lockheed Martin involved its close partners in the tool selection, but ultimately, it made the final decision. One notable point of contention centered on one of the largest tools in the VPC—CATIA, an integrated suite of Computer Aided Design (CAD), Computer Aided Engineering (CAE), and Computer Aided Manufacturing (CAM) applications. Although most companies throughout the industry use CATIA, there are divisions that exist based on the version of the software in use. Lockheed Martin desired to standardize on Version 4.6 on Unix platforms for the JSF program. Northrop Grumman had previously standardized its entire company on Version 5 using Windows NT, which was not backwards compatible with the older version. Each company had legitimate reasons for standing by its version (primarily based on leveraging resources in other programs the companies had) and adamantly refused to migrate to the other system. In the end, this problem was not resolved, and each company continued to use its own version, causing large inefficiencies in the system due to undetected version conflicts. A middleware solution was developed to help translate between the two file formats, but this process was not always successful.

The software architecture for the VPC was centered on a PDM system from Metaphase with a large number of integrated design and manufacturing tools (such as CATIA) feeding design data into the PDM for storage, analysis and collaboration. An interviewee said that this architecture "evolved" as the need for it became apparent. The lead system architect for the VPC relied loosely on the Zachmann Framework and another reference architecture from the Metagroup when designing the VPC architecture, but the concept was largely developed in-house and would be a new experiment in PDM implementation.

As the center of the VPC, the PDM was the first area of the VPC to receive attention from the VPC team and continued to be a key area of development throughout the VPC's implementation. After successfully identifying the tools to be used on the VPC, the next task was mapping the exchange of information between all of these tools, identifying interfaces, and developing middleware that would allow the translation of data into mutually comprehensible formats. This process was tedious, but fairly straight forward in the opinion of those interviewed.

8.4.1.1 Security in the VPC

Security was a critical element of the Virtual Processing Center. The VPC was tasked with controlling access to the design data for a very advanced fighter with many highly sensitive capabilities, such as stealth and advanced avionics. Many of these technologies are highly restricted by ITAR. Therefore, the VPC had to ensure security across both corporate and international boundaries.

A key question while securing the VPC was whether to harden the applications and tools, the network, or some combination of the two. There are DoD standards for securing classified computer networks that provide security for all levels of digital communication from the physical layer up to the application layer. While some aspects of the JSF are classified and must be handled under these government guidelines for security, many aspects of the program are not. New guidelines had to be drafted for technical security in these industry-sensitive areas that met the security needs of the program and all of its participants while remaining flexible enough not to impede work across company boundaries.

One person said that in future projects such as the VPC, much more attention will be paid to the area of security earlier in the design process to understand how to best use applications with firewalls. The observation was that security on a large program in an extended enterprise is different from security on smaller, self-contained programs, and that few people today, including security experts, have a good understanding of how to secure computing infrastructures across extended enterprises. In these programs, security has become intertwined with all aspects of the program, and cannot be added to the network as an afterthought after the system's architecture has already been established.

8.4.1.2 The Product Data Management System

The PDM is the center of the VPC because it acts as the universal gatekeeper of all design data for the JSF. All designs are stored on a central server in Ft. Worth, with linked servers in El Segundo, California and Salmesbury, UK. The PDM system controls access to this database by requiring permissions granted to the user, tracks versions of changes to all files created in any of the many tools integrated into the VPC, controls the flow of data between users, and allows users to remotely collaborate in real time on designs. Additionally, it tracks common and non-common components across the three versions of the aircraft. The system allows data to be easily classifiable and searchable, making it much easier to track changes across the system and identify potential problems before they emerge, in theory. These capabilities require that data is appropriately marked and labeled using metadata when it is created and submitted to the system.

The VPC team worked closely with the Lockheed Martin office devoted to ITAR compliance to ensure that the system accurately controlled access to all documents and designs as required by ITAR. PDM systems enforce a more disciplined design processes, as users must frequently commit their designs to the system so that others can see them and potentially collaborate.

8.4.1.3 Pilot Programs on the PDM

The VPC team developed a pilot program for the PDM system that worked with structural engineers in order to address potential problems with the system long before it was deployed. The pilot program went very well in the eyes of its designers, and all involved felt that they had successfully vetted the system. However, many problems emerged with the PDM when users from other design disciplines—especially those users who dealt with non-structural aspects of design—began to use the system. It had not been developed with the needs of these more abstract disciplines in mind, and was biased towards systems that could be easily visualized. In the case of software or electronics, for example, although documents could be committed to the system and tracked, its users use the PDM in a different way than a structures user would.

The pilot program had been overly narrow in scope, focused on a "best case" discipline. While this may be effective in situations where the system needed to be "sold," in this case the opposite problem occurred: the difficulties encountered by some disciplines led to limited buy-in, and resistance to a system that many people saw as forcing them to work in a way they did not like, although many of these people had been asked for input on their work processes earlier.

8.4.1.4 Post-Implementation and Non-technical Obstacles to Technical Integration

At the time that Lockheed Martin won the Concept Design Phase competition, allowing it to move forward with the detailed design of the F-35, the VPC was not finished, and was missing a few tools. This was not a major concern, initially. Lockheed Martin had expected to have several months after the announcement of the contract award to prepare for the program and the sudden loading of the system before the contract was awarded, as was the case in all previous military aerospace acquisition programs on which Lockheed Martin had worked. Instead, no such time became available immediately after the contract was awarded to Lockheed Martin and the entire program scrambled to get up to speed. As a result, the VPC went into operation before it was as fully developed as planned, which inevitably led to criticism of the system and resistance from its users. The system could not handle the shock of so many new users and encountered growing pains. This led to many data and process ownership challenges that are detailed in Section 9.3, including the creation of localized parallel systems to circumvent the PDM's data storage capabilities and process management capabilities.

8.4.1.5 Reflections on the PDM and the VPC

In retrospect, the system designers felt that there were many lessons learned to make such systems easier to implement in the future. Technically, future projects will employ a federated architecture, and will not be centered on a single application as heavily as the VPC was dependent on the PDM. There are two primary reasons for this: first, the designers interviewed have expressed the feeling that a federated system without a single overwhelming application is more scaleable and not as prone to crashing under heavy loading, and second, security experts are more comfortable securing federated systems. Perhaps with future advancements in PDM technology and increased security experience with centralized systems this may change, but this is the current feeling at the program.

The VPC designers feel that there was a lot of planning that went into the design of the system, but that it was at the wrong level. Instead of focusing as heavily on tool selection and verification, which turned out to be fairly straightforward, more effort should have been directed towards understanding the *processes* that would be captured by the system, understanding and incorporating the role of security earlier in the design of the technical system, and spending much more time getting stakeholder (particularly engineering) buy-in on the project, thus easing adoption. The immediate project ramp-up after contract award was completely unanticipated. Nevertheless, the system should have been much more thoroughly tested before being made ready for use. After the initial release, it was impossible to keep people from breaking away from standard processes and using other systems, because the PDM had many open technical issues at the time.

Additionally, the pilot programs developed for any new system must be piloted in all of the various environments it will operate in, rather than only the most likely to succeed or understand. None of the pilot programs that the VPC design team used were broad enough to encounter all of the problems that were eventually encountered. Had these problems been identified earlier, much of the early resistance to the system could have been defeated faster.

8.4.2 JSF Data Library

The VPC is the largest of the three primary technical information systems deployed across the JSF extended enterprise. The other two are the JSF Data Library (JDL) and the Internal Management Framework (IMF). While the PDM system in the VPC contains all of the design data for the aircraft in a build-to-print format, the JDL is a database that contains all of the process and business data required to build the aircraft from the data in the PDM. As an analogy, if the PDM contained the blueprints for the aircraft, the JDL would contain the instructions to build it, as well as the history of how the design would actually have evolved and how common mistakes could be avoided. Unlike previous programs that had such data scattered across the enterprise, the JDL is a single, unified repository for all programmatic data across the extended enterprise. It has proven to be an exceptional tool for the program, and has enabled knowledge transfer throughout the extended enterprise. Lockheed Martin took the same idea and transferred it to the older F/A-22 Raptor program after seeing how well the JDL worked for the JSF program, where it has also has met with success.

The JDL was described as an unfolding bulletin board, with ideas and lessons learned posted in pertinent areas for others who follow to see. This was found to be more useful than other knowledge management systems that are in effect searchable databases, because rather than having to search for a lesson learned or for design decision history, the information a user would need would be right there on the computer screen as the user would look at each pertinent section of the aircraft in the JDL. Many of those interviewed said that while the JDL is a useful system now, its real value lies in the years ahead, as changes and upgrades are made to the aircraft by future engineers who will refer back to the original development notes to see what had been tried and what was problematic. All of those interviewed universally had a favorable opinion of the JDL.

8.4.3 The Internal Management Framework

The last major technical information system is the Integrated Management System (IMF). The IMF can be seen as a program manager's portal into the program, allowing management to look at live updates on cost, schedule, risk management, and other program management metrics. Access to this "dashboard" system is not limited to program management only, however. Access is open to members across the extended enterprise from customers to suppliers, allowing small- and medium-sized partners or the JPO to have the same integrated view of the extended enterprise as program managers at Lockheed Martin have. The idea is to give everyone across the JSF insight into the larger picture of how the extended enterprise is doing, allowing all the participants to orient themselves on how best they can benefit the extended enterprise. The intention was that the IMF would be a heavily used system to access continually updated metrics.

After implementation, however, the widespread usage did not materialize, even though the IMF worked as promised to give insight into the performance of the JSF program. Today, several hundred people regularly access IMF on a weekly basis to track the program. It has been discovered that people from different parts of the extended enterprise use it in different ways—a 4th tier supplier uses it primarily for scheduling, while the JPO closely tracks many aspects in addition to schedule, such as cost or risk. In light of this, in the future there may be more customization of the IMF for groups of stakeholders to allow them to make better use of the system. Although the massive use envisioned for the IMF did not materialize, the system is still considered a success and continues to receive updates and improvements to make it more useful.

8.4.4 Semantics and Data Exchange

A final major concern encountered in the technical integration of the JSF was the issue of semantics and the related topic of data exchange. When many companies come together within a large industry to collaborate on a project, or even with divisions within a single large company come together, semantics are frequently an issue, as engineers from different companies work together with similar but slightly differing vocabularies and methods for communicating data. For the most part, many traditional semantic issues due to miscommunication have been resolved by using the VPC as a common set of tools and processes for design. By forcing everyone to use the same system, semantic misunderstandings have been reduced. Differences still arise, especially with international partners who are not used to American industry. Due to the unified nature of the system, however, semantic misunderstandings are usually quickly caught and become annoyances rather than disasters. Very few of those interviewed who worked with Lockheed Martin using the VPC and JDL mentioned that semantic issues remained a major problem in their own work.

There was one example of a semantic problem on the program that an interviewee mentioned that occurred on the development of the F-119 engine by Pratt & Whitney. Pratt & Whitney, as prime contractor for the F-119 engine, uses its own systems for design and collaboration on the propulsion system, and is not a part of the Lockheed Martin-led air vehicle network that uses the VPC. While working on the F-119 with one of its partners, Pratt & Whitney encountered a significant delay with an engine component. After many integration meetings between management and lead engineers, it was discovered that the two companies had slightly different definitions for a particular measure of engine performance, leading to a technical discrepancy that was the source of the delay. This delay cost several thousand dollars as a result of a slight undetected disagreement on the meaning of a specific term. Such a semantic problem as this may not be always prevented by a unified system such as the VPC and JDL, but the increased visibility such a system, if the two companies in fact used it, might have allowed them to identify the semantic mismatch much earlier.

One other area that has received attention is the issue of data exchange. Although the VPC uses standard formats for relaying data between any of its many applications and the PDM system, the designers of the VPC and the JDL want to ensure that the technical data are easily readable even when removed from the current environment, as in the case of a system upgrade. On previous projects, there have been issues with highly proprietary EDI data formats and their ability to handle system upgrades and modifications, leading to many headaches during system upgrades. The current trend has gone towards adopting open XML-based industry standards for all data exchange between applications in the VPC as well as the JDL. The open format ensures that the data will be easily transferable and readable by all who follow the standard, making system upgrades much less painful.

8.5 Technical Lessons Learned

- Highly integrated technical designs are very difficult to debug, manage, and control as the complexity rises. Hybrid systems are more manageable at the present time, given the structure of most development organizations
- The physical network for integrating an extended enterprise is the easier part; the software, protocols and standards it requires are much harder and should receive more attention in the network creation phase
- Invest as much time as possible in understanding the actual processes that workers use. This is more important than many technical concerns, because if done poorly, it will lead to an ineffective system that will be resisted by those who must use it
- A centralized repository of design data integrated with design tools can overcome many common technical and organizational integration challenges, integrating processes, semantic differences and tools, but the technology will present its own challenges
- From the point of view of security and scalability, a federated structure with a centralized repository is superior to a highly integrated structure for enterprise-wide systems for design like the VPC
- Only make processes common that absolutely must be to allow for flexibility. It is unrealistic to make everyone on all programs use exactly the same processes.
- Design tools must be identical and speak a common language
- Pilot programs for systems that will be applied across many disciplines should have pilots in all of those programs to avoid surprises later after implementation.
- A unified data library of all process and business data such as the JDL is highly valuable resource for an extended enterprise
- The extended enterprise should use open, flexible standards for data transfer to ensure that systems will be easily upgradeable
- Technical collaboration is most important in the design phase—it is less important later
- Systems may not always be used as they were originally intended; the designers should be flexible and allow the system to morph in the direction its users desire as long as this is beneficial to the program
- Avoid implementing a large, process-altering system before it is proven and mature
- Middleware should be used to were possible to reuse robust legacy systems that have been proven and validated on other programs
- Beware of information overload from technical sources. There is a limit to how much information can be "pushed" to users. Technical information systems cannot entirely replace "face time"

9 Chapter 9: Organizational Integration on the JSF Program

Organizational Integration is the last of the three aspects of enterprise integration addressed in the framework proposed in Chapter 4 to look at the JSF Program. The JSF extended enterprise learned fairly early in the life of the program that it must address several organizational challenges before its strategic and technical strategies for enterprise integration could have their intended impact. The integration strategy for the JSF program was largely driven earlier by strategy and technology, missing the organizational dimension. In some cases, these organizational barriers to integration were initially overlooked or neglected in the face of more pressing technical and strategic concerns, only later to be addressed once their influence was felt, as this chapter will show. By pursuing strategies for integrating organizations' cultures and structures concurrently with technical and strategic integration strategies, system deployment and operation will proceed much more smoothly.

There have been several challenges in organizational integration that the JSF program has faced to date. One of the earliest challenges faced was how to integrate many different cultures owing allegiance to many sources into a single, coherent program with a clear direction, which requires more than just technical connectivity. It also must also address issues that arise in organizational rivalries, especially in light of data ownership and management. Finally, from the point of view of architecture, the JSF program must ensure that its organizational structures are properly aligned with the technical system architectures that they are involved with to ensure a proper fit, and that there are organizational structures in place to ensure technical and strategic integration is accomplished. Not surprisingly, many of these organizational barriers to integration are closely linked with the implementation of the VPC, discussed in Section 8.4.

9.1 Control Structures

As mentioned in Chapter 4, one of the unique aspects of integration of enterprise networks is the need for adequate control structures and centralized authority. Perhaps this is a problem in comparatively smaller, dynamic virtual enterprises where there is no single dominant partner. However, similar, questions of authority—and especially funding—would be expected to appear in extended enterprises as well.

Lockheed Martin, as the prime contractor, has ultimate authority over the air vehicle (although the JPO can issue requirements and make its wishes known). While prime contractors have always had authority over their supplier networks, the difference on the JSF program is that there is a large amount of collaborative work and there are much greater resources devoted to the network for integration and coordination. This empowers the supplier network and involves them in the program more directly and at a higher level. To maintain the spirit of teamwork and a real sense of partnership, as well as to receive valuable input from its partners, Lockheed Martin consults with its partners across the extended enterprise before making decisions that would impact the extended enterprise, although, as one person who was interviewed mentioned, it also occasionally unintentionally "slips" and makes an internal decision that impacts others without consultation Although there is a process set up for consultation and advising, such as the Strategic Suppliers Advisory Council mentioned below, Lockheed Martin ultimately makes the final call, allowing for a fairly quick, decisive process.

The primary reason that Lockheed Martin makes the final call is that it is the owner of the prime contract, and as a result, it controls the budget. Capital investments for network-wide tools and integration are paid for by Lockheed Martin's internal funds, not by the program. Before the JSF contract award, much of the original design of the VPC was paid for through Lockheed Martin's corporate funding for internal research and development. Because it is the prime contractor and it has made this investment, and continues to be the main funding source for the entire system, Lockheed Martin has the final word on decisions in the network.

Another important source of authority on the JSF is the breakdown of technical work on the program. The Work Breakdown Structure (WBS) clearly specifies who has authority over which aspects of the aircraft. The owner of the WBS for each section of the aircraft is, in effect, "the prime contractor for that section," and controls most aspects of that section, including management of supplier-partners and manufacturing. Northrop Grumman holds the WBS for the mid-fuselage, BAE Systems holds the WBS for the aft-fuselage and tail surfaces, and Lockheed Martin holds one for the forward fuselage and another for the integration of the entire aircraft. Defining the boundaries of the WBS between major subsystems is a major challenge for the chief engineer and his staff, as this will specify the inter-company interfaces on the project as well as the technical interfaces. It is a critical boundary between technical and organizational designs, and ultimately has a significant impact on the difficulty and success of integration on the aircraft. A large amount of time was spent defining the WBS before the contract award, and there continues to be a great amount of time devoted to engineering integration and systems engineering. Design Integration Teams, groups of system engineers who focus on the technical integration challenges, tackle many of the engineering integration issues. Their organizational structure is designed to closely correspond to the actual structure of the WBS to promote a better match between technical and organizational architectures. They make sure that there are no mismatches between the division of work defined by the WBS itself and organizational structure, within Lockheed Martin as well as across the supplier network, responsible for performing the work on the aircraft.

9.2 Integrating Organizations and Cultures across the JSF Extended Enterprise

One of the earliest challenges to organizational integration that the JSF program faced was learning how to integrate the many members of the JSF extended enterprise in such a way to engender a "team spirit" and foster increased communication and collaboration across the network, while ensuring clear, established lines of authority and control for the network where necessary and desirable. This includes supplier-partner collocation, site visits, and specific organizational structures designed to ensure collaboration and integration. The JSF extended enterprise is trying to break out of traditional supplier-contractor relationships and move towards a more collaborative approach.

To foster a sense of camaraderie on the program, both the JPO and Lockheed Martin have spent a significant amount of resources on both public and internal relations to promote the idea of a single JSF Program Team. The international diversity of the program is often celebrated on insignia, logos, press conferences, and newsletters. There is an extended enterprise-wide newsletter published by Lockheed Martin, which fosters this team spirit by featuring the partner nations and smaller suppliers across the network to give those working on the program in many companies a sense of membership in the program in addition to helping to elevate their visibility within their own companies. For many in the network, working in this way as part of a larger team has taken some adjustment. BAE Systems and Northrop Grumman both have traditionally been prime contractors in their own right, and they are used to having ultimate authority in their respective spheres. According to one person interviewed, this was the source of some initial frustration. Also, for many other suppliers, especially non-North American suppliers, there seems to be a great deal of shock associated with working in a foreign environment, causing frustrations. To address such frustrations, an integrated decision making process has been put in place, where decisions are discussed with many stakeholders to ensure that their views are heard and taken into account. Ultimately, however, Lockheed Martin has the final word, allowing for decisions to be made quickly. The speed of decision making is especially quick judged by European standards, as one person interviewed from a European supplier noted.

A critical component to the organizational integration strategy of the JSF extended enterprise has been collocation of supplier-partners and exchanges of engineers. This is critical, because despite many advances made in information technology enabling close collaboration during the design process, the person-to-person interface is still critical to building trust and teamwork, as well as for design work requiring a high degree of personal interactions among the design team members.

As the head of the extended enterprise, Lockheed Martin realizes this, and sends its own engineers to work with its supplier-partners at its facilities on interface and design issues, as well as temporarily collocating many engineers from supplier-partners in Ft.

Worth to get them up to speed and become familiar with the program. According to one person interviewed representing one of the supplier organizations, suppliers and partners usually send their best people to Ft. Worth in an effort to make a good impression and lay down the roots of a strong partnership that will last for many years over the life of the program. They are directing much effort and many assets into building this kind of trust, including investment in specialized tooling and facilities, in the expectation that their relationships with Lockheed Martin will prove to be long-lasting.

Collocation is a critical part of both organizational and strategic integration strategies on the JSF program, because there is a limit to technology-enabled distance collaborative work, especially in the early design stages, which really does require face-to-face contact. Collocation of foreign nationals, in particular, presents many work integration challenges in order to meet ITAR regulations. Many people interviewed, however, felt that having such people on site is critical for collaboration and communication and worth the added legal hurdles of ITAR.

Interviewees have also stated that there is an "information overload" throughout the program, and that "technology should not be used as a crutch for integration." "Face time is still important" was a common theme heard across the various interviews. Although one interviewee who worked with supplier-partners thought that having a "village" of supplier-partners close by would be highly advantageous, there have not been any partners to date that have built dedicated facilities near the Lockheed Martin plant in Ft. Worth. Given the history of the troubled F/A-22 program which saw its total acquisition numbers shrink by more than 200 percent, perhaps suppliers that have so far chosen not to make such program-specific investments on the JSF may be waiting to see if Congress' attitude towards the aircraft will change before the end of the decade, when production is scheduled to begin in earnest.

Examples of organizational structures supporting supplier involvement in the design stages include the Joint Product Assessment Team (JPATs), Supplier Integrated Product Development (SIPD), and the Strategic Supplier Advisory Council. (SSAC). JPATs are gatherings of suppliers to discuss ideas for systems on the program, which those at Lockheed Martin cite as promoting versatility among the supplier-partners. SIPDs are concurrent engineering sessions were many potential suppliers collaboratively work on designs, together developing potential designs. Lockheed Martin then selects the best design and a supplier to produce it, while rewarding other suppliers for their contributions. Rewarding suppliers for their intellectual contributions is not easy, and is still a point of contention with some, especially for those who have advanced design capabilities but do not have low-cost production facilities. In such a situation, such a firm would contribute greatly to the final design, but the ultimate contract may be awarded to a low-cost firm without such design capabilities. If this becomes a standard method of design and sourcing among suppliers in the industry, it may lead to a bifurcation of the supply base into independent design firms and the more traditional "build-only" firms, which would not significantly change the original supplier-contractor relationships perhaps apart from adding-in design "consultants."

The Strategic Supplier Advisory Council (SSAC) is a collection of the top 80% percent (by cost) of suppliers, and meets to consider strategic planning of the extended enterprise. Lockheed Martin will often draft policies for the extended enterprise and present them to the SSAC for comments and feedback, which are usually taken and incorporated into final policies established for the extended enterprise. This builds trust across the enterprise by involving suppliers in the decision-making process, and gives Lockheed Martin much wider array of ideas to consider when making decisions that affect the extended enterprise.

9.3 Managing Data/Process Ownership Barriers

Some of the more common barriers to organizational integration, especially involving technical systems, are data and process ownership barriers. The JSF faced several barriers related to data and process ownership, primarily stemming from the introduction of the VPC and its PDM system. The new system introduced single-point data storage, open access, and standardized processes across the extended enterprise. Although this was highly desirable from a top-level perspective, it upset the balance of power with respect to data and process ownership across the extended enterprise.

Many groups across the extended enterprise did not embrace the PDM component of the VPC when it was initially deployed. Rather, they saw it as a challenge to the way they traditionally worked, their established power structures, and their creativity. In the words of one person, "very little was done to ease the cultural shock of a new system." When the VPC system was first introduced, it contained several weaknesses because it had not yet been thoroughly tested and evaluated due to the compressed schedule after the contract award, and its detractors were quick to point those weaknesses out.

The ideal of one large database for all program data proved unrealistic in the face of the PDM's shortcomings after contract award. During this time, many groups across the extended enterprise set up their own proprietary databases in addition to the PDM to handle design using processes they were accustomed to and had control over, and only committed the final design files to the PDM system after the designs were approaching completion, defeating the purpose and utility of the PDM's concurrent versioning capabilities for collaborative development. This maintained the status quo in regards to processes and data.

Although there was expected resistance from engineers who had spent many years working at Lockheed Martin and were committed to the processes they were accustomed to, there was also resistance from newer hires. This was primarily because many of the older engineers served as supervisors and actively sought to persuade younger engineers to use the older processes within their group rather than using the unproven PDM. People were not comfortable with the new, rigorous methods prescribed by the PDM system and actively circumvented them, allowing for irregular, heterogeneous processes to continue. This dynamic did not persist, however. Eventually, the large volume of new hires went through Lockheed Martin's "onboarding" training in the company and the new system had an impact on the acceptance of the PDM software, as newer hires became more comfortable with the PDM than with the older processes. This, in combination with improvements in the system, allowed the PDM to prove itself in the eyes of most of the engineering design team.

In the three and a half years since the program award, the PDM has matured and it has been accepted and used by almost everyone across the extended enterprise. The attitude of those in the "trenches" has progressed from "Stop! It's killing us!" to "We get it, it works," as one interviewee noted. The parallel systems that many groups developed alongside the PDM have gradually disappeared as users grew to appreciate what the

PDM could offer. It took time to mature the application and to make changes to the system that users requested after the system was initially deployed, as well as for people to realize that the PDM system did have its benefits and was not going to disappear or loose support from management. In some cases, management simply had to issue an edict and migrate the older systems over to the new one. The journey was rocky, but the system is running today close to how it was originally envisioned, linking engineers from across the extended enterprise, and will soon involve a wider reach into the supplier base as manufacturing begins. The system has already performed well during one of the program's early challenges, the much-publicized effort to reduce the weight of the STOVL version of the JSF.

9.4 Organizational Structures for Integration

Several people interviewed mentioned the desire to closely match the design of the organizational structures within the extended enterprise with the actual technical architecture of the system(s) that organization would work with, in accordance with "Conway's Law." Conway's Law, which is not law in the strict sense, states "organizations which design systems are constrained to produce systems which are copies of the communication structures of these organizations(Conway, 1968)." Although it has proven difficult in the literature to find convincing evidence that linking organizational architecture with technical architecture will yield increased efficiency, it has been considered a good heuristic by the many in the enterprise architecting and software fields, and followed wherever possible. The impacts of this heuristic, while anecdotal, have been positive to date.

One of the examples of this is in the architecture of the avionics system on the F-35. There were many lessons learned for the JSF program from the problems encountered on the F/A-22's avionics platform, as described in Section 8.1.1.1. The challenges on the F/A-22 led some in Lockheed Martin to pay closer attention to the issue of technical and organizational matching. Those looking back on the F/A-22 program described the mismatch between the architecture of the organization that designed the avionics system and the avionics system architecture itself. The avionics system was very highly integrated with dense communication channels, while the organization was not nearly as integrated and had more hierarchical communications pathways. Some suggested that this mismatch, together with critical hardware limitations, could have led to many of the technical challenges, as the dense information pathways called for in the technical design were not present in the organizational architecture. The JSF program embraced this lesson, and moved away from such an integrated technical architecture in favor of a more federated approach, as it would not be easy to integrate the organization to the degree necessary for what would have become a highly integrated technical system. For a system as technically integrated as the F/A-22's avionics, the design organization would ideally be a single, omnipotent person. The current JSF avionics architecture more closely matches the organizational architecture that is in place. One person interviewed noted "The two programs used the same team structure [organizational architectures], even though the [technical] architectures are pretty different. It's obvious that one has done better than the other."

The avionics system is not the only JSF system that has heeded Conway's Law. The entire organization is divided according to the WBS mentioned in Sections 8.1 and

9.1, such that interfaces within the system match interfaces between groups working on the program. The Design Integration Team, which advises the Office of the Chief Engineer, is designed specifically to match the technical design, and divides its authority based on technical system boundaries. Additionally, the PDM was designed to mirror the structure of the program's IPTs. Although the JSF program cannot point to quantifiable benefits from this matching of designs, it appears that many people in the program are aware of this design heuristic first posited thirty years ago, and have heeded the advice. It is currently too early to see the effects on the program.

9.5 Utilizing Network Knowledge: A Barrier on the PDM

Although the PDM system is at the center of the VPC and is its most critical component, Lockheed Martin did not have experience with PDM systems before the implementation, and it predictably ran into challenges. Both BAE Systems and Northrop Grumman had previous experience implementing PDM systems on programs of their own, but were not active participants in the development and implementation of the PDM or VPC system on the JSF. The reason cited for this during interviews given by Lockheed Martin employees was that financial incentives were not in place for them to participate. The capital for the computing information infrastructure came from Lockheed Martin, and the other two primary partners were not ready to work on the system without funding in place to do so, and the funding was not made available.

As a result, many of the lessons and the experience of the other two companies were not available as Lockheed Martin implemented the VPC on its own. Even though the two partners would have benefited in the long run by having a capable system up and running faster on the program, they did not want to commit resources without having capital funding in place. Both partners had a smoother experience with their own PDM implementation in comparison with JSF's PDM, and according to one Lockheed Martin interviewee, they were not completely happy with Lockheed Martin's final implementation. It would have benefited the entire extended enterprise, and perhaps saved the program money, had there been financial incentives in place to have developed the PDM system collaboratively. In addition to gaining the experience and expertise of the partners on the program, Lockheed Martin could have had increased buy-in from its partners on the system, as it would have been a product of the larger team, rather than a tool developed by a single member that others were obligated to use.

A contributing factor to this problem goes back to the roles that are defined in enterprise networks, detailed in Chapter 2. The role of assigning the task of working on the network infrastructure would have likely gone to the Competence Manager in the enterprise. The competence manager, tasked with assigning network members to tasks based on their core competencies or prior experience, should ideally be an impartial party. There is no clear role of a competence manager on the JSF program, and if there were, that role is occupied by Lockheed Martin, as it awards contracts in the network. The problem with this arrangement is that there is a natural tendency to internally award contracts (and realize the associated profits), especially in cases where the core company making the decisions might want to become more proficient. From the point of view of Lockheed Martin, there is nothing wrong with this arrangement. It is the prime contractor, and according to the contract, this decision is its own to make. Strategically, it would not be likely to award a contract knowingly to a potential future competitor. If, however, the customer wanted to ensure that there was a "best" allocation of resources, it should request that the network use an independent competency manager, and perhaps insist on independent agents or organizations in the other roles mentioned in Chapter 2 to ensure a less biased allocation of resources towards the objective of running the virtual extended enterprise more efficiently and effectively.

9.6 Organizational Integration Lessons Learned

- There should be clear lines of authority, funding, and control structures in enterprise networks
- Collocation and site visits are important not only for increased flows of communication, but also for social cohesion of the network and establishing cross-network links.
- International partnerships need a large amount of resources
- Organizations should be designed so that information flows in a way very similar to the flow of information in the technical design
- Proper funding structures should be in place to encourage the network to have its best resources working on a given task.
- A large amount of resources must be devoted to easing the barriers associated with data ownership.
- One must ensure that any new system is fully functional before deploying it and that there is a very rigorous training program to ease the shock of the transition.
- A massive influx of newly hired, newly trained employees help overcome institutional resistance.

10 Chapter 10: Conclusions

Virtual extended enterprises are poised to become a more common business structure in the future, especially in complex, project-based industries such as aerospace. The Joint Strike Fighter's virtual extended enterprise is one of the first in its industry, and certainly the flagship for this organizational structure in the military aerospace community. As such, all eyes in the industry are fixed firmly on it, eager to learn from its challenges and mimic its successes. From its inception, the JSF Program sought to identify opportunities for integration and to establish strategies to overcome barriers to integration for their enterprise. While the program has encountered several obstacles outlined in the case study, most agree that it is now on track to perform close to the original high expectations. For these reasons, the lessons learned from the JSF Program's experience integrating their network is worthy of careful study for those that will follow in its path.

Despite setbacks, integration efforts on the JSF Program have ultimately been successful in large part because the program spent a large amount of resources during the creation phase to carefully identify strategic integration goals, and match them closely with available, maturing technologies for integration. Strategic goals on the JSF Program included involvement of international partners, high security standards with several levels of access control, design version control, centralized exchange of data and collaborative design. Work began on the technical systems years before they were deployed, and focused on adapting fairly mature, commercially available tools to meet the needs of the network, rather than developing tools, processes, and infrastructures in-house. This proved to be a successful strategy and allowed the JSF Program to develop its infrastructure fairly quickly.

Another key for successful integration identified on the JSF Program was to match the extent of integration present in the organizational architecture with the extent of integration found in the product system architecture in accordance with Conway's Law. Where possible, organizations that interacted with design and development of technical systems were designed to mirror the structure of their subsystem. The Design Integration Teams and Joint Product Assessment Teams are two examples of organizations designed to match the technical design on the systems on which they work. In cases where the organization cannot be made to reflect the technical architecture, it may be a wise idea to change the technical architecture to prevent problems during development. Many knowledgeable people have accused the F/A-22 of having an overly integrated technical architecture, making design a very difficult task even for modern organizations integrated to the fullest extent possible. Learning from the mismatch on the F/A-22, the system architects of the JSF moved the avionics architecture towards a more federated structure, which happens to more closely resemble the structure of the organization that designs it.

Another key lesson to be drawn from the JSF Program is that integration strategies must take into account not just technology and strategy, but also organizational and socio-technical concerns from the inception. The JSF Program based much of its strategy on the implementation of several technical systems, such as the Virtual Processing Center, the JSF Data Library, and the Integrated Management Framework. A significant amount of resources were invested in the technical aspects of these systems, but little was invested with the intention of understanding the organizational and socio-technical impacts that these systems have on people and organizations when implemented. The VPC in particular encountered fierce resistance initially from its user base. Despite its advanced technical design, it did not perform as its users expected. This was due in part to apathy from its user base during the design of the system when feedback was requested, lack of sufficient training on the system during deployment, and limited production testing before deployment. These barriers delayed the wide-spread adoption of these critical integrated technologies many months, hindering early design efforts. Had more resources been devoted to dealing with these organizational barriers, the technical system could have become operational much sooner.

10.1 Policy Concerns

The JSF virtual extended enterprise operates on behalf of the US Department of Defense, and is directed by the Joint Program Office with input from its international partners. The JSF Program is a key component of a larger effort by the DoD to reform military acquisition to become less prone to waste and cost and schedule overruns. The program was given much more freedom to innovate and dictate its structure and management than past programs. Despite this newfound flexibility, the primary goal of the network from the perspective of the DoD should be to provide value to the taxpayers, rather than to profit the core enterprise.

The structure of the prime contract that guides the creation of the virtual extended enterprise empowers the prime contractor to develop the network as it sees fit, rather than imposing rigid guidelines that could prove stifling. While most observers would view this positively, it does open up the possibility that the network will not be arranged to perform optimally.

One example of how this can occur that was observed during the case study was the assignment of network roles and responsibilities. In extended enterprises, it is often the case that the core enterprise takes on many of the administrative roles in the network, often to their benefit. Usually, the network could benefit from a more independent administrator for many roles such as that of a competence coordinator or a network coach. These roles allocate tasks and resources in the network. It was observed in Chapter 9 that the prime contractor took on a major task that others in the network had more experience with, resulting in delays and setbacks to the successful deployment of the computer infrastructure for collaborative design and design data storage. This decision likely had a significant financial impact on the network.

This dilemma could be ameliorated if the JPO decided to make changes to its policies for awarding contracts. Wording could be included to encourage networks to seek the services of an unbiased, third party for such roles. It may be possible that a government agency, similar to the Defense Contract Management Agency, could serve as this independent broker. Alternatively, the JPO may find it preferable to take a hands off approach, and allow the prime contractor to structure the network as it sees fit even if it means some inefficiencies will occur. Regardless, this is a policy choice that must be studied and made.

Other major policy choices that must be made by the DoD and the US Government on behalf of the JSF Program include a re-examination of export control laws and of the international partnerships on the JSF Program. US export control laws, as described in

Chapter 7, have been shown to be stifling to international cooperation on the development of weapons platforms without yielding a positive benefit to US national security. The barriers imposed by ITAR compliance have blocked a major partner, as well as many secondary tier suppliers, from fully participating in the program, and has led to "design churn," as waste associated with incomplete knowledge in a design organization. If the US wishes to continue to collaboratively develop major weapons platforms with another country, it must seriously consider amending its export control laws to allow meaningful collaboration. A key step in this process would be to extend the "Canadian Exemption" to ITAR to the UK, the US' staunch ally. This would significantly expand the ability of companies such as BAE Systems and Rolls Royce to contribute to the JSF Program, and would have minimal impact to US national security.

International partnerships on the JSF Program must also go through a careful re-examination. Many of the international partners on the program, including partners at all levels of membership, has expressed their frustrations with the current arrangement. Many of these frustrations stem from US export control laws which restrict how they can collaborate and what information they may view. Beyond this, however, there is an architectural disconnect in the program that often leads to frustration. The memorandums of understanding signed by international participants were bilateral agreements between each nation and the US government, and not agreements signed between the prime contractor and international suppliers. There was not a clear mapping between the MOUs signed between nations and expectations of contract awards on the program. This disconnect has frustrated many nations that assumed contracts would be awarded in a manner they were accustomed to (proportional to investment), rather than in the manner they have been (best value basis). The US Government needs to restructure these international relationships to either make clear the separation between contract awards and development investment, or to directly involve the prime contractor in the MOUs.

10.2 Recommendations fo Further Research

This research has been a very broad overview of integration strategies and the barriers and enablers faced when forming them for application to virtual extended enterprises. Due to the breath of this research, there are many opportunities available for further research in this area. This research was constrained to a single, detailed case study to elucidate principals and lessons for other virtual extended enterprises in complex, project-based industries. Future work should seek to include a survey of distinct virtual extended enterprises in order to compare and contrast integration strategies and develop more general principals that might guide integration. These networks should be compared both within a single industry, as well as across industries.

One area worthy of study is the further analysis of the relationship between integration of technical architectures and organizational architectures. This relationship, often governed by what has been termed "Conway's Law," is largely anecdotal and has not received a rigorous academic treatment. Statistical correlations proving increased performance when architectures are in alignment would prove to be persuasive for networks undergoing an enterprise architecting processes.

Another study of interest would be an analysis of the network attributes of integration in a virtual extended enterprise. Virtual extended enterprises are networks that can be studied using tools developed for use in graph theory to understand the properties of networks. It may prove valuable to be able correlate the attributes of integration in the network, such as average path length between network members, the percentage of horizontal integrating relationships, and the percentage of multi-layer vertical integrating relationships to network performance. Such a study will also prove invaluable to enterprise networks seeking to architect integrative relationships across their networks.

The virtual extended enterprise is a very new and promising enterprise form that will likely make great large strides towards becoming a more common business structure in the future. A large amount of work remains to be accomplished so that industries can be better prepared to understand how these unique structures can deliver sustainable competitive advantage in the future.

References

The NIIIP Reference Architecture; January 12, 2005, 2005.

Afsarmanesh, H., Garita, C., Ugur, Y., Frenkel, A., and Hertzberger, L. O. 1999. Design of the Federated Information Management Architecture for Prodnet. In L. Camarinha-Matos (Ed.), Infrastructures for Virtual Enterprises: 209-218. Boston: Kluwer Academic Publishers.

Afuah, A. 2001. Dynamic Boundaries of the Firm: Are Firms Better off Being Vertically Integrated in the Face of Technological Change? Academy of Management Journal, 44(6): 1211-1228.

Ahuja, M. K., and Carley, Kathleen M. 1999. Network Structure in Virtual Organizations. Organizational Science, 10(6): 741-757.

Birkler, J.. 2003. Competition and Innovation in the U.S. Fixed Wing Military Aircraft Industry: RAND Corporation.

Borgatti, S. P. a. F., Pacey C. 2003. The Network Paradigm in Orgaizational Research: A Review and Typology. Journal of Management, 26(6): 991-1013.

Bozdogan, K. 2004. Enterprise Architecting Knowledge Area Research Agenda: Massachusetts Institute of Technology, Lean Aerospace Initiative.

Camarinha-Matos, L. a. A., Hamideh. 1999a. The Virtual Enterprise Concept. In L. a. A. Camarinha-Matos, Hamideh (Ed.), Infrastructures for Virtual Enterprises: Networking Industrial Enterprises: 3-14. Boston: Kluwer Academic Publishers.

Camarinha-Matos, L. a. H. A. (Ed.). 1999b. Infrastructures for Virtual Enterprises: Networking Industrial Enterprises. Boston: Kluwer Academic Publishers.

Camarinha-Matos, L. a. H. A. (Ed.). 2004. Collaborative Networked Organizations: A Research Agenda for Emerging Business Models. Boston: Kluwer Academic Publishers.

Camarinha-Matos, L. M., and Afsarmanesh, Hamideh. 1999c. The Virtual Enterprise Concept. In L. a. H. A. Camarinha-Matos (Ed.), Infrastructures for Virtual Enterprises: 209-218. Boston: Kluwer Academic Publishers.

Camarinha-Matos, L. M., and Lima, C.P. 1999d. Coordination and Configuration Requirements in a Virtual Enterprise. In L. M. Camarinha-Matos, and Afsarmanesh, Hamideh (Ed.), Infrastructures for Virtual Enterprises: Networking Industrial Enterprises: 49-65. Boston: Kluwer Academic Publishers.

Child, J., and McGrath, Rita Gunther. 2001. Organizations Unfettered: Organizational Form in an Information-Intensive Economy. Academy of Management Journal, 44(6): 1135-1148.

Coase, R. H. 1937. The Nature of the Firm. Economica, 4(16): 386-404.

Conway, M. E. 1968. How do Committees Invent? Datamation, 14(4): 29-33.

Cordella, A. 2001. Does Information Technology Always Lead to Lower Transaction Costs? Paper presented at the The 9th European Conference on Information Systems, Bled, Slovenia.

Cummins, F. A. 2002. Enterprise Integration. New York: OMG Press.

Drucker, P. 1988. The Coming of the New Organization. Harvard Business Review, 66(1): 45-53.

Dyer, J. H. 2000. Collaborative Advantage: Winning through Extended Enterprise Networks. New York: Oxford University Press.

Dyer, J. H., Kale, Prashant, Singh, Harbir. 2001. How to Make Strategic Alliances Work. Sloan Management Review, 42(4).

Field, S., and Hoffner, Yigal. 2002. In Search of the Right Partner. In M. C.-M. Luis (Ed.), Collaborative Business Ecosystems and Virtual Enterprises: 55-63. Boston: Kluwer Academic Publishers.

Gibon, P., Clavier, J.-F., Loison, S.{Schreiber, 1999 #93}. 1999. Support for Electronic Data Interchange. In L. Camarinha-Matos (Ed.), Infrastructures for Virtual Enterprises: 209-218. Boston: Kluwer Academic Publishers.

Goranson, H. 1999. The Agile Virtual Enterprise. Westport, Conn.: Quorum Books.

Katzy, B., and Obozinski, V. 1999. Designing the Virtual Enterprise. Paper presented at the ICE '99 5th International Conference on Concurrent Engineering, The Hauge.

Lackenby, C., and Seddighi, Hamid. 2002. A Dynamic Model of Virtual Organizations: Formation and Development. In M. C.-M. Luis (Ed.), Collaborative Business Ecosystems and Virtual Enterprises: 55-63. Boston: Kluwer Academic Publishers.

Laubacher, R., Malone, Thomas W, and the MIT Scenarios Working Group. 2003. Two Scenarios for 21st Century Organizations: Shifting Networks of Small Firms of All-Encompassing "Virtual Companies"? In T. W. Malone, Laubacher, Robert, and Morton, Michael S. Scott Morton (Ed.), Inventing Organizations of the 21st Century. Cambridge: MIT Press.

Laudon, K. C., and Jane P. Laudon. 2004. Management Information Systems: Managing the Digital Firm (8th ed.): Prentice Hall.

Malone, T. W., and Rockart, John F. 1991. Computers, Networks, and the Corporation, Scientific American, Vol. 265: 128-136.

Mejia, R., and Molina, Arturo. 2002. Virtual Enterprise Broker: Processes, Methods, and Tools. In M. C.-M. Luis (Ed.), Collaborative Business Ecosystems and Virtual Enterprises: 55-63. Boston: Kluwer Academic Publishers.

Murman, E., et al. 2002. Lean Enterprise Value: Insights from MIT's Lean Aerospace Initative. New York: Palgrave.

Ouzounis, E. K. 2001. An Agent-Based Platform of the Management of Dynamic Virtual Enterprises. TU Berlin, Berlin.

Piore, M. J., and Sabel, Charles F. 1984. The Second Industrial Divide: Possibilities for Posperity. New York: Basic Books, Inc.

Porter, M. 2001. Strategy and the Internet. Harvard Business Review, 79(3): 62-78.

Rayport, J. F. a. S., John J. 1999. Exploiting the virtual value chain: Harvard Business School Press.

Schilling, M. A. a. S., H. Kevin. 2001. The Use of Modular Organizational Forms: An Industry-Level Analysis. The Academy of Management Journal, 44(6): 1149-1168.

Schreiber, A. 1999. Step Support for Virtual Enterprises. In L. Camarinha-Matos (Ed.), Infrastructures for Virtual Enterprises: 209-218. Boston: Kluwer Academic Publishers.

Spinosa, L. M., Rabelo, R. J., Klen, A. P., Ferreira, A.C. 1998. An oriented Decsion Support System model fo Virtual Enterprise coordination. Paper presented at the 10th International IFIP WG 5.2/5.3 Conference, Prolamat '98, Trento, Italy.

Venkatraman, N. 1994. IT-Enabled Business Transformation: From Automation to Business Scope Redefinition. Sloan Management Review, Winter 1994: 73-87.

Williamson, O. E. 1975. Markets and Heiracrchies: Analysis and Anti-Trust Implications: A study in the economics of internal organization: Free Press.

Yassine, A., Joglekar, N., Braha, D., Eppinger, S., and Whitney, D. 2003. Information hiding in product development: the design churn effect. Research in Engineering Design, 14: 145-161.

List of Acronyms

ASTOVL – Advanced Short Take Off and Vertical Landing
CAD – Computer Aided Design
CAE – Computer Aided Engineering
CALF – Common Advanced Light Fighter
CAM – Computer Aided Manufacturing
CDR – Critical Design Review
CRM – Customer Resource Management
DARPA – Defense Advanced Research Projects Agency
DIT – Design Integration Team
DoD – Department of Defense
EDI – Electronic Document Interchange
EI – Enterprise Integration
ERP – Enterprise Resource Planning
FMS – Foreign Military Sales
IPT – Integrated Product Team
IT – Information Technology
ITAR – International Trade in Arms Regulations
IMF – Integrated Management Framework
JAST – Joint Advanced Strike Technology
JDL – JDF Data Library
JIT – Just in Time
JSF – Joint Strike Fighter
JSFEE – Joint Strike Fighter Extended Enterprise
JPAT – Joint Product Assessment Team
JPO – Joint Program Office
LAI – Lean Aerospace Initiative
MIT – Massachusetts Institute of Technology
MOU – Memorandum of Understanding
PDM – Product Data Management
PDR – Preliminary Design Review
RWP – Requirements Work Package
SDD – System Development and Design
SIPD – Supplier Integrated Product Development
SSAC – Strategic Supplier Advisory Council
STOVL – Short Takeoff / Vertical Landing
UK – United Kingdom
US – United States
USMC – United States Marine Corps
WBS – Work Breakdown Structure
VEE – Virtual Extended Enterprise
VPC – Virtual Processing Center