AN EXPLORATORY CASE STUDY OF INFORMATION-SHARING AND COLLABORATION WITHIN AIR FORCE SUPPLY CHAIN MANAGEMENT

THESIS

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Abstract

Private industry has proven the advantages of sharing and using information across the supply chain to engage in collaborative decision-making to improve supply chain operations. This research identifies key elements of the Air Force supply chain as it relates to industry, determines how techniques of information-sharing and collaboration are used to make Air Force Supply Chain decisions and how the resulting impacts on operational readiness may be measured. Using cases study methodology the supply chains supporting the PTO shafts on both the F-15 and the T-38 engines were investigated, studying the application of information-sharing and collaboration in two distinct Air Force supply chains. Cross-case comparative analysis evaluated each supply chain's characteristics and the levels of information-sharing and collaboration. The research identified that proactive sharing of information and collaborative decision-making for the T-38 avoiding supply chain failures, while the F-15 supply chain was reactive, failing to collaborate or share information, resulting in a failure of the supply chain, and an increase in the MICAP rate. The F-15 community used information-sharing to recover from this failure. Information-sharing and collaboration seems to positively impact Air Force aircraft availability, but not generally recognized as a necessary supply chain practice. This effort provided insight into the interactions and complexities of the Air Force supply chain, highlighting a need for a more thorough evaluation of the impact of supply chain relationships, information-sharing and collaborative decision-making on operational readiness.

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Wendy S. Kierpiec

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I. Introduction

> "There's a lot of talk about Transformation out there today…it's not just all about technology; it is about relationships."
>
> --Gen John P. Jumper, 2003

Background

Supply chain management describes a cornerstone business process of industry that can "make or break" the effectiveness and efficiency of any company, whether public or private sector. Its complexity is illustrated by the Council of Supply chain management Professionals' (CSCMP) definition as:

> Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, Supply chain management integrates supply and demand management within and across companies. Supply chain management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology (CSCMP, 2005).

Effective supply chain management is an iterative process for many logistics managers which demands constant evaluation of industry "best practices" and innovations to streamline the supply chain, thereby realizing improved customer service/satisfaction levels, shorter lead times and reduced inventory capital (Cooper and Ellram, 1993). As the CSCMP definition indicates, these “best practice” initiatives are applied to like business processes across the supply chain to synergize operations and decision making. Various supply chain management initiatives and research over the past several decades have identified business processes that can benefit better utilization of information and technology. Critical to the success of these initiatives is the expansion of the myopic view of logistics as simply goods movement to the comprehensive approach that considers other functions such as purchasing, inventory movement, relationship management, and above all, information management.

This logistics revolution initially began with production management, which in turn sparked movements in materiel management and physical distribution. Forrester’s model of industrial “flows” and system approach to industrial management provided the seedling for the concept of a supply chain (1958). Donald Bowersox is credited with introducing the concept of integrated logistics and system integration in physical distribution channels beyond a single firm as early as 1969, and has since expanded his research to include impacts of marketing and information technology on supply chain management (Ganeshan *et al.*, 1998; Bowersox *et al.*, 2005). Twenty or so years ago, Material Requirements Planning (MRP) and Manufacturing Resource Planning (MRP II) introduced by Olicky (1975) and Wight (1981), respectively, focused attention on resources flow. This was further revolutionized by Taiichi Ohno’s Kanban philosophy in the Toyota Production System (TPS) and Just in Time (JIT) manufacturing (1984). Positive results in manufacturing resource management shifted the focus to application of similar principles to other links in the supply chain.

Several recent initiatives have addressed various “links” in the supply chain including: Vendor Managed Inventory (VMI), Efficient Customer Response (ECR), Enterprise Resource Planning (ERP) and Collaborative Transportation Management (CTM). Each of these process improvements seeks to streamline product flow by improving the management of relationships, information, processes, and/or physical inventory. Production system improvements have created benefits in the manufacturing arena, while recent supply chain initiatives appear to solely on the Fast-Moving Consumer Goods (FMCG) industry, such as Collaborative Planning Forecasting and Replenishment (CPFR®). First introduced in the early nineties, CPFR® remains one of the more resilient movements in supply chain management, such that it is still evolving into an industry standard. However, even this system has evaded application in a high dollar, investment item environment.

Supply chain management initiatives have not escaped the attention of the Department of Defense. All branches of the military have explored process improvement options to streamline the supply chains. Lean manufacturing has been tested and implemented in production facilities throughout the services. The USAF Spares Campaign initiated by the Deputy Chief of Staff for Installations and Logistics embodies several initiatives such as Purchasing and Supply chain management (PSCM) and eLog21, with the goal of implementing “logistics transformation through Supply Chain integration” (Mansfield, 2002). Additionally, the 2003 Air Force Transformation Plan recently highlighted a need to step up these efforts:

> [To] re-engineer Air Force supply chain processes to incorporate commercial best practices and integrate the purchasing and supply processes into a single end-to-end enterprise process that significantly

> reduces supply chain operating costs and improves warfighter readiness (Department of the Air Force, 2004).

Warfighter readiness as mentioned above may be described as the Air Force's ability to bring maximum capabilities to the fight. This capability is ultimately measured by a Status of Resources and Training System (SORTS) report which identifies the percentage of equipment (including aircraft) and supplies available (College of Aerospace…, 1998). This warfighter readiness demands a responsive and effective supply chain to support training and operational missions around the globe to maintain aircraft availability. This supply chain must be able to respond to demands created by expected parts failures as well as those caused by the harsh operational environments and tempos.

Problem Statement

Senior leadership philosophy indicates that current Air Force supply chain inefficiencies are seriously impacting our effectiveness and are costly. Recent transformation goals set by senior government and military officials site the necessity of Air Force logistics to adopt industry's proven "best practices" in supply chain management. Air Force's Transformation Plans identify the adoption of industry best practices as critical for future Air Force logistics (Department of the Air Force, 2004; Department of the Air Force, 2005d). These best practices have grown out of practical application of theories of supply chain management developed by academia and industry. Integrated application of elements of supply chain management such information-sharing and collaboration may have the potential to improve upon present supply chain shortcomings and improve warfighter readiness.

Research Question

The focus of this research is to answer the following question:

How can the application of information-sharing and collaboration to management of the Air Force supply chain improve operational readiness?

Investigative Questions

To achieve an answer to this research question, the following investigative questions will also be addressed in an Air Force supply chain environment:

1. What are the key elements of an Air Force supply chain?
2. How is information shared across the Air Force supply chain?
3. How is collaboration used to make supply chain decisions?
4. What are key supply chain metrics used by the Air Force to evaluate the effectiveness of the supply chain and its impacts on operational readiness?

Methodology

This research will use a case study methodology to address the research and investigative questions. Two cases will be examined to identify trends in the supply chain management of an aircraft part, specifically to identify the effects of sharing information and collaboration on supply chain effectiveness. Personal interviewing will be the primary data source augmented by the literature and historical documentation, when available. The parts considered for this study represent both reparable and consumable items and are not managed exclusively by Air Force Item Managers. It is important to recognize is that this research intends to show the possible benefits of applying information-sharing and collaboration to the Air Force supply chain environment, assuming the technology, directives and management change environment are in place to improve this process in its entirety.

Scope and Limitations

Given the size and complexity of the overall Air Force supply chain, the research will be limited to addressing supply chain exceptions within a system that surround a small percentage of parts within that supply chain. Literature and research that describes current Air Force supply chain operations is also limited. Additionally, the interviews will be limited to key Air Force players in the selected supply chains and involve personal opinion and second-hand knowledge. While the Air Force supply chain has a definable overarching structure, the nature of the airframe, the customer's mission, and the part's characteristics may impose limitations on the generalizability of the results.

Summary/Preview

This chapter discussed the background and problem statement, presented the research and investigative questions, and briefly described the methodology of the research. Chapter 2 provides an overview of supply chain management in industry, academia and military operations. Key supply chain innovations and their impact on supply chain management evolution will be discussed. Additionally, Chapter 2 also provides an overview of military supply chain management policy, currnent initiatives and metrics. Chapter 3 details the case study methodology, clarifying the research model and addressing the challenges associated with this approach. Chapter 4 provides narrative descriptions of the cases and through within- and cross-case analysis answers each of the research questions. Finally, Chapter 5 provides conclusions and suggests areas for future research.

II. Literature Review

> "What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention, and a need to allocate that attention efficiently among the overabundance of information sources that might consume it."
>
> --Herbert Simon, founder of Artificial Intelligence

Introduction

The first step in attempting any research is of course to define the problem. In order to take this first step, it is equally important to first identify the environment which surrounds the problem. This literature review provides the necessary background for understanding that environment from three vantage points: private industry, academia and military. Initially, it discusses the history and evolution of supply chain information-sharing, supply chain collaboration efforts and supply chain research to understand the foundations upon which they grew. Secondly, an overview of DoD research and supply chain pilot programs provides insight into the military context of the research. Finally, a brief discussion of Air Force supply chain metrics highlights the performance measures used to evaluate the impacts of the supply chain on operational readiness.

Defining Supply chain management

Adoption and success of supply chain management innovations in various contexts such as operations, academia and process improvement depend on many factors. Establishing a definition for "supply chain management" is a critical first step. Scholars agree that many definitions for supply chain management exist and often conflict with one another (Cooper *et al.,* 1997; Mabert, 1998; Lummus and Vokurka, 1999; Mentzer *et al.*, 2001). In fact, research by Lummus *et al.* (2001) indicates that it is less important to define the term than to define the concepts involved. One of the biggest "disconnects" in defining supply chain management is its comparison to logistics. Many researchers comment on the prevalent use of the terms "logistics" and "supply chain management" interchangeably and the ensuing confusion this causes (Cooper *et al.,* 1997; Lummus *et al.,* 2001; Mentzer *et al.*, 2001; Hugos, 2003). Lummus, Krumwiede and Vokurka surveyed materials management professionals including manufacturers, retailer and third-party logistics providers to determine what, if any, agreement exists on definitions of these terms (2001). Their research supported the idea that confusion is prevalent even among logistics professionals. For the purpose of this research it is important to explore and differentiate the two concepts.

It is also important to note that when identifying the differences between the concepts of logistics and supply chain, use of the term "management" with either of these terms simply means oversight. The *management* of logistics or the *management* of the supply chain refers to the collective management of the functions and processes identified within these disciplines. Thus the inclusion of the term "management" is often arbitrary within the literature without creating confusion.

Many scholars credit military culture with popularizing the concept of logistics (Copacino, 1997; Christopher, 1998; Pinkerton, 1999; Lummus *et al.,* 2001). The Lummus *et al.* study indicates a common view that logistics includes "the process of planning and controlling the flow and storage of goods and services from the point of origin to the customer" generally *within* a company, while supply chain management encompasses business processes including logistics *across* companies (2001). For the purpose of this research, logistics is defined based on the CSCMP definition for logistics management:

> Logistics management is that part of supply chain management that plans, implements, and controls the efficient, effective forward and reverse flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements. Logistics management activities typically include inbound and outbound transportation management, fleet management, warehousing, materials handling, order fulfillment, logistics network design, inventory management, supply/demand planning, and management of third party logistics services providers. To varying degrees, the logistics function also includes sourcing and procurement, production planning and scheduling, packaging and assembly, and customer service. It is involved in all levels of planning and execution—strategic, operational, and tactical. Logistics management is an integrating function which coordinates and optimizes all logistics activities, as well as integrates logistics activities with other functions, including marketing, sales, manufacturing, finance, and information technology (2005).

Logistics is therefore, the flow and storage of goods, services and information, from the point of origin to the point of consumption, to meet customer demands.

Experts have defined supply chain management from numerous different view points. Vincent Mabert, Operations Management Professor at Kelley School of Business identified three hierarchical definitions of supply chain (1998). The first definition includes only the relational activities such as direct buying and selling, those relationships directly within a firm's control. The second definition adds "upstream suppliers" for a manufacturing company such as the original equipment manufacturers. Finally, the third definition, the "value chain approach" includes all activities, raw materials to marketplace. In his attempt to "demystify supply chain management," Peter

Metz highlights the “integrated” aspect of the Massachusetts Institute of Technology definition, relaying Integrated Supply chain management (ISCM) as:

> A process-oriented, integrated approach to procuring, producing, and delivering products and services to customers. ISCM has a broad scope that includes sub-suppliers, suppliers, internal operations, trade customers, retail customers, and end users. ISCM covers the management of material, information and funds flows (1998).

Key main ideas behind this definition: process-oriented, procurement, production, users, information and funds flows are prevalent in most professionally accepted definitions of SCM. Dr. Mentzer, Professor at University of Tennessee, and past President of the Council for Logistics Management defines Supply chain management as:

> The systemic, strategic co-ordination of the traditional business functions within a particular company and across businesses within the supply chain, for the purposes of improving the long-term performance of the individual companies and the supply chain as a whole (2001.)

In addition, the key elements of this description are essential for understanding the importance of supply chain management. “Functions within a business” as well as “across supply chain partners” imply consideration for internal and external functions. The concept that performance for “individual firms” compared to the “supply chain as a whole” should be improved, drives a need for a collaborative approach to managing the supply chain.

While academics and professionals, alike continue to “refine” the definition of supply chain management, it appears that the focus should be less on the specific wording of the definition and directed more toward the practitioner’s understanding and application of the concept. Overall, most academics agree that supply chain management is an end-to-end business process that involves a collaborative approach to managing the movement of information and materials which facilitates the most effective use of resources and improved efficiency across the supply chain (Cooper and Ellram, 1993; Mentzer *et al.*, 2001; Hugos 2003). Figure 2-1 illustrates in detail, both the horizontal processes to be collaborated on as well as the level of vertical integration involved in supply chain management (Lambert *et al.*, 1998).

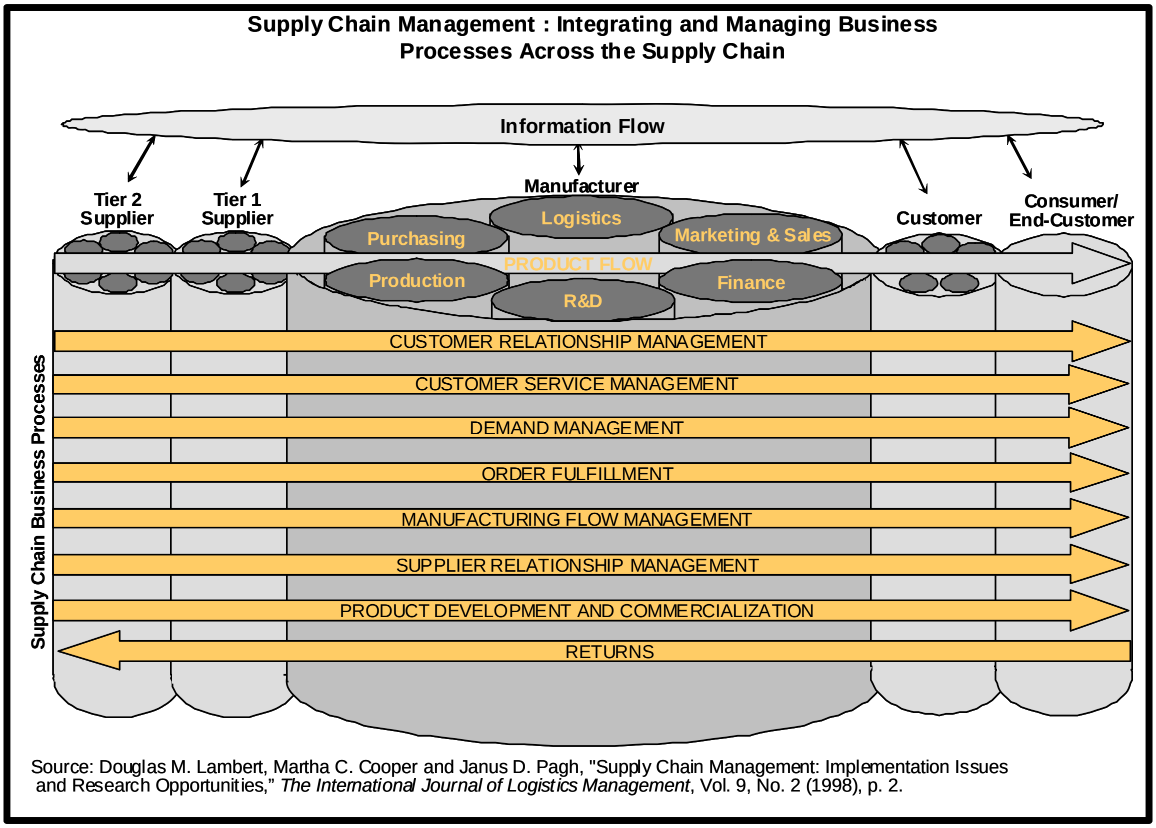


Figure 2-1: Vertical and Horizontal Integration Across the Supply Chain

In the context of this research, the CSCMP definition of supply chain management is used to define SCM as:

> Supply chain management encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence,

> supply chain management integrates supply and demand management within and across companies. Supply chain management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance, and information technology (2005).

Supply Chain History

The evolution of supply chain management has been influenced by several disciplines including operations research, marketing, economics/systems dynamics, and operations management (Ganeshan *et al.*, 1998). Recently, more influence has stemmed from organizational behavior, social behavior, and information technology theory. Researchers are exploring the links between people and technology to understand additional dynamics to the diffusion of innovations in supply chain management (Patterson *et al.*, 2004; Russell and Hoag, 2004). To understand the focus of current and future research, it is first necessary to consider historical influences on the development of the supply chain.

The birth of supply chain management as a concept is often credited to Jay W. Forrester in his 1958 release of *Industrial Dynamics*. Although not named "supply chain management" by Dr. Forrester, his concept of analyzing six systems flows: information, orders, materials, capital equipment, money and personnel identified several cornerstone concepts within what is now known as supply chain management. He illustrated how the interaction of these flows, particularly information, orders and materials can impact one another and suggested a systems management approach to modeling for decision analysis.

Shortly following Forrester's introduction of Industrial Dynamics, Donald Bowersox pioneered research in physical distribution and began his renowned career in logistics and supply chain management research, focusing his attention on integration of processes and the flows of information and materials and touching on what would come to be recognized as the supply chain (1969). Researchers such as Masters and Pohlen, LaLonde and Mentzer have described several evolutionary timelines for logistics, identifying the physical distribution properties and elements of internal and external integration (Ganeshan *et al.*, 1998). Houlihan is credited with the introduction of the term "supply chain management" identifying the importance of incorporating a logistics focus into corporate strategy (Houlihan, 1985; Cooper and Ellram, 1993; Ganeshan *et al.*, 1998).

Operations research has impacted the growth of supply chain management with regard to modeling. Simulation has been used to explore distribution optimization, single and multi-level inventory analysis, and overall supply chain performance. Researchers have evaluated nearly every facet of physical inventory management. Much attention has focused on the complexity and uncertainty of inventory management (Clark and Scarf, 1960; Sherbrooke, 1992; Axsater and Juntti, 1996; Graves, 1996; Axsater, 2001). Inventory optimization policies such as Clark and Scarf's Multi-Echelon model explore various elements and assumptions of inventory modeling including holding and shortage costs and replenishment policies (1960). Axsater *et al.* have done extensive research on various inventory, order and review policies (Axsater and Juntti, 1996; Axsater and Zang, 1999; Axsater, 2001; 2003; 2005b). Additionally, Graves' exploration of demand patterns has provided models for reparables and production management (Graves, 1996; Graves *et al.*, 1998; Graves, 1999).

The focus on inventory modeling research has expanded from the above described service-level optimization to overall process or system optimization with the introduction of the "Bullwhip Effect" concept. Lee *et al.* (1997) define this characteristic of the supply chain as increasing variance of demand up the supply chain, from customer to supplier. This concept, that small distortions in demand throughout a decentralized supply chain can magnify inventory errors further upstream from the consumer, has led to extensive research into its causes and the influences on the supply chain with may affect variability in demand or how that variability is managed. The four causes of the bullwhip effect as described by Lee *et al.* (1997) include:

1. Demand Signal Processing: when past demand data is used in forecasting but the demand is not stationary
2. Order Batching: ordering/producing in more economical batches
3. Rationing/Shortage Game: over-buying/producing to combat a perceived future shortage
4. Price Fluctuations: high-low (wholesale) pricing

Centralized information-sharing throughout the supply chain has been identified as a counter-measure to these phenomena and has attracted increasing attention by logisticians in academia and industry alike. Chen *et al.* (2000) take this concept a step further in their evaluation of the impacts of demand forecasting and information-sharing on the bullwhip effect. They illustrate that even with centralized demand information, identical inventory policies and identical forecasting techniques, the bullwhip effect is still present. However, they conclude that the variability is additive when information is centralized and multiplicative when it is decentralized, thus highlighting the importance of information-sharing when demand is non-stationary (Chen *et al.*, 2000).

As supply chain management has become a more recognized discipline, research in this area has expanded beyond quantitative models and operational theories to the qualitative nature of operations and organizational management. An increasing amount of research has been focused on the more strategic elements of the supply chain which are less directly measurable, yet equally and perhaps increasingly more important. Studies have tried to capture the impacts of process integration, illustrating that greater efficiencies can be realized by shifting from vertical integration to horizontal integration of business processes first with in a firm and ultimately across the supply chain (Cooper and Ellram, 1993; Cooper *et al.*, 1997).

Industry Influences

In addition to academic research as discussed above, the supply chain management environment has also been impacted by changes in the complexity of the economic environment. Historically, the nature of market shifts can be related directly to the advancement of supply chain research and practical application. US economic focus has shifted from raw materials, to manufacturing, to quality, to customer service, to experience-driven demands. The evolution of supply chain management may correlate to this economic transformation.

Until the 1950s, the economic markets were primarily characterized by the raw-materials industry. Competition within industry focused primarily on dominance of the marketplace through providing (mining, harvesting, etc.) the right materials. During this period, prior to the industrial revolution, industry did not require control or even recognition of its supply chain. Of the common elements within today's supply chain, such as distribution, transportation, marketing, sourcing, inventory, etc., the most relevant concern at this point in economic evolution would be selecting the right location and source—to determine what would result in the most materials and the highest profit.

The introduction of industrialization shifted the market environment into one characterized by finished goods. Customer desires for product quality drove firms to focus on both management of raw materials and production capability. The increased influence of manufacturing suggested a need for management of raw materials and production capability. Establishing a balance between production and inventory highlighted a need for research in inventory optimization modeling, perhaps also sparking the emergence of Activity Based Costing in the 1980s.

The market saw a shift of focus from product quality to providing a service. This is best marked by Taichii Ono's Just-in-Time Toyota production model (1994). Ono's concepts of "pull vs. push" inventory and Total Quality Management (TQM) have provided foundation for research into streamlining and "leaning" the supply chain to remove non-value added processes. The lean concept, combined with inventory modeling has driven academics and practitioners to evaluate optimization for other areas of the supply chain.

With the gaining influence of computers and telecommunications throughout the 1990s, customer needs became more service-oriented. Technological innovations reduced or eliminated many market entry barriers, making it tougher to control high market shares. Competitive firms needed to provide not only the right type and quality of goods, but also to provide products at the right time and place while providing the customer with the most accurate product and real-time logistics information. This stressed the importance of additional “links” in the supply chain, specifically logistics disciplines such as distribution and inventory management.

The sharp increase in information technology, wide-spread internet connectivity, web-based communications and a global marketplace, has challenged industries with “experience-driven” consumers. Advances in these areas have created “educated” customers who require flexibility, visibility and responsiveness, driving the need for an efficient and effective supply chain. Gaining a competitive market edge requires adoption of improved supply practices such as automated inventory and transportation management, and successful implementation of supply chain tools including management information systems.   Ganashan *et al.* (1998) note eight (*sic*) influences on supply chain planning that are prevalent within the literature:

1. New customer service requirements
2. Competitive pressure
3. Changing [increasing logistics] costs
4. Pressure for improved financial performance
5. (*sic*) need to redesign and improve logistics systems
6. (*sic*) regulatory changes
7. (*sic*) improved communications
8. (*sic*) information technology

Additionally, much supply chain management literature over the past five years has centered on information sharing and technologies that facilitate that sharing (O’Marah, 2001; Bowersox *et al.*, 2005). These influences are also evident in many of the supply chain theories and movements that industry has attempted over the past two decades.

Practical Supply Chain Innovations

Throughout the evolution of Supply chain management, industry and academia have pursued many possibilities for process improvement across the supply chain. Each has made contributions to the body of knowledge, driving current and future decisions for the direction of supply chain management. Some of these efforts have been internal such Materials Requirements Planning (MRP) and Efficient Customer Response (ECR). Others such as Vendor Managed Inventory (VMI) and Collaborative Transportation Management (CTM) have directed efforts to a single function within the supply chain that involves multiple partners. Still other initiatives including Enterprise Resource Planning (ERP) and Collaborative Planning, Forecasting and Replenishment (CPFR) have made attempts to improve processes across functions and across the chain.

MRP & MRPII

The introduction of the Materials Requirements Planning (MRP) system in 1975 by Joseph Orlicky marks the first steps towards automated planning systems in manufacturing. Although initially designed as an internal scheduling and inventory management system, MRP identified a connection between capacity and supply through the Bill of Materials (Chung and Snyder, 1999). This closed-loop system determines what materials and components are needed in what quantities and when, using a master production schedule linked to Bills of Materials for each process (Orlicky, 1975). Less than ten years later, this system was further expanded to the Manufacturing Resource Planning (MRP II) system. MRP II included all the company's primary business processes including manufacturing, marketing, purchasing, engineering and finance under a single system, considering incoming flow of materials and outgoing finished product (Wight, 1981). However, both systems looked only at internal processes, making little improvements for external communications (Pinkerton, 1999).

JIT

While the Americans focused on integrating the business functions of the manufacturing company, the Japanese focused their efforts on streamlining the processes with the introduction and successful implementation of lean production and the Just-In-Time (JIT) philosophy. Eiji Toyoda and Taiichi Ono established the lean production model at the Toyota Motor company in the 1980's. This philosophy is based on quality management ideals; to reduce cost, waste and excess activities, improve the quality and reduce the defects, and led to the JIT inventory management philosophy (Womack *et al.*, 1990). This approach to inventory and production management is based on the Japanese philosophy of Kanban in which inventory replenishment information is communicated directly from production to purchasing (Ohno, 1984). The "signal" to replace inventory is generated at the production level in direct response to consumer demand, thus products are "pulled" to demand rather than "pushed" to the market. The Japanese Kanban philosophy indicates that excess inventory simply hides other problems in production such as bottle necks, forecasting problems, etc., so it seeks to minimize inventory, balancing it with production quantities in order to help managers identify these problems (Christopher, 1998). Ultimately JIT focuses on streamlining, or "leaning" manufacturing processes so that nothing happens to a product that is not "value-added" or absolutely necessary.

QR, ECR, & CRP

The introduction of "pulling" to demand rather than "pushing" to supply highlighted the importance of customer service and information to the supply chain. Progress in JIT manufacturing inventory and production scheduling gave way to customer-service and information-technology supply chain initiatives in the apparel industry and grocery industries. In the early 1980s leaders of the apparel industry commissioned Kurt Salmon Associates to conduct a supply chain analysis which highlighted that products spent over 60% of the supply chain time in transportation (Lummus and Vokurka, 1999). Results of this study lead to the Quick Response (QR) movement defined by Lummus and Vokurka as a "partnership where retailers and suppliers work together to respond more quickly to consumer needs by sharing information" (1999). A follow-on study by Kurt Salmon Associates in 1992, identified large reductions in inventory (37%) within the supply chain through increased information-sharing as part of the Efficient Customer Response (ECR) movement (Lummus and Vokurka, 1999). The industry adopted the grocery industry's UPC concept and implemented Point-of-Sale (POS) scanners to generate real-time customer demand information and make it easily accessible (Hill, 1999). The Quick Response strategy ultimately led to wide-spread adoption of Efficient Customer Response (ECR) and Continuous Replenishment (CRP) in the grocery industry (Lummus and Vokurka, 1999). Research identified several best-practices combined with POS and Electronic Data Interchange (EDI) that could result in large inventory and cost reductions in the grocery supply chain (Lummus *et al.*, 2001). The focus of information-sharing across supply chain partners began to take hold with these movements.

Information-Sharing as an Element of SCM

The shift from process improvements to system improvements created a greater need for improved information-sharing within Supply chain management. Supply chain management literature touts the benefits of sharing information across the supply chain. However, the types of information shared are not clearly defined in much of the literature and in many cases assumed to be general demand information. The best description of the types of information is presented by Lummus and Vokurka (1999) in their discussion of "moments of information." They describe a "moment" of information as "any episode in which the company can gain information from the customer, however remote, and thereby have an opportunity to from a response to customer demand." Information, then comes in one of two forms: "information which allows time to sense that there is a change in demand and information which allows companies to respond to the change" (Lummus and Vokurka, 1999). Lee and Whang (2000) identify six types of shared information in supply chain management:

1. Inventory level (most common)
2. Sales data
3. Order status for tracking/tracing
4. Sales forecast
5. Production/delivery schedule
6. Other (*i.e.* performance metrics, and capacity)

Research supports the idea that sharing the above identified information across the supply chain can improve overall supply chain performance through reduction of system-wide inventory, reduction of the Bullwhip Effect, improved fill rates and better customer service (Lee *et al.*, 1997; Gavirneni *et al.*, 1999; Cachon and Fisher, 2000; Li *et* *al.,* 2001; Zhu and Thoneman, 2004; Auramo *et al.*, 2005). Much effort has been devoted to identifying causes and counter-measures of the bullwhip effect through supply chain models (Sterman, 1989;Lee *et al.*, 1997; Lee and Whang, 1999; Chen *et al.*, 2000). Sterman (1989) illustrates that a decrease in variability can achieved by information-sharing through centralization of customer demand information in his “Beer Game” supply chain model. It is important to note that this research included various unavoidable assumptions regarding capacity, demand distributions, etc. which may have impacted results and limited practical applications. Chen *et al.* (1999) conclude that complete sharing of customer demand information can reduce this increasing demand variability, thus reducing the bullwhip effect. Overall, it is agreed that benefits of sharing customer demand information include: reduced lead-time, lower inventory and inventory costs, improved customer service due to reduced demand variability and improved visibility (Chen *et al.*, 2000; Lee and Whang, 2000; Li *et al.*, 2001; Huang and Gangopadhyay, 2004;). Both industry and academia realize benefits of sharing supply chain information with such initiatives as Electronic Data Interchange (EDI), but also recognize its limitations.

Research by Cachon and Fisher (2000) concludes that reduction in lead time or order processing costs has a greater impact on supply chain costs than information-sharing and that information-sharing is most valuable in a non-capacitated environment which allows for response to that information. Gavirneni *et al.* (1999) indicate that information-sharing is not as beneficial under certain conditions:

1. Demand variance is high because the relevance of the information diminishes

2. Production capacity is low (below demand) because there really is no other choice than to produce at the maximum capacity

3. Retailer order costs are high and supplier capacity may be limited because the cost to carry inventory outweighs the ordering costs or penalty costs.

The literature also presents some disagreement as to what types of supply chain relationships benefit most from information sharing and that other elements of supply chain management which should accompany information-sharing to facilitate success (Bowersox *et al.*, 2000; Gunasekaran and Ngai, 2004). A case study by Fawcett *et al.* (2005) concludes that there are two equally important components of information integration: the connectivity element—technological capability to share information, but also the more human aspect of being *willing* to share that information. Akkermans *et al.* (2004) identify a lack of available research that explores how organizations transition to transparent information-sharing. Bowersox *et al.* (2000) discuss ten paradigm shifts which are key enablers of supply chain logistics including information sharing collaborative relationships, relationship management and implementation of collaborative forecasting techniques such as Collaborative Planning Forecasting and Replenishment (CPFR®), the next step in information-sharing. Some believe that while progress can be made with partnerships, IT initiatives and proven CPFR techniques, collaboration is key to realizing large gains from information-sharing (Sherman, 1998; Sheffi, 2002).

CPFR®

Origins

CPFR® is an integrated closed-loop supply chain approach to forecasting and replenishment supply chain activities that originally grew out of the ECR movement (Hill, 1999; Barratt and Oliveira, 2001; Fliedner, 2003). The first attempt to test CPFR® theory surfaced in a 1996 partnership between Wal-Mart and Warner-Lambert with consulting and IT help from Benchmarking Partners, SAP and Manugistics (Sherman, 1998; Hill, 1999; Aviv, 2001; Smaros, 2003). After a successful test period, resulting in a sales increase of over $8.5 million, and a lead-time reduction from 21 to 11 days, a volunteer organization of manufacturers and retailers, VICS (Voluntary Interindustry Commerce Standards) formed to facilitate further development and adoption of the CPFR concept (Hill, 1999). In 1998, VICS released its first set of guidelines for implementing CPFR® and has gone through several revisions based upon lessons learned from various case studies and implementation efforts throughout various industries (VICS, 2004). Since its inception in the mid 1990's, hundreds of companies have adopted CPFR® philosophies and practices (VICS, 2004).

The Model

VICS has published detailed guidelines to standardize implementation and adoption of this collaborative SCM approach. The CPFR® model in Figure 2-2 presents the basic foundation for the philosophy as it applies to manufacturers, retailers and consumers within the supply chain.

Source: VICS, 2004

Figure 2-2: CPFR® Model

Although the needs of the end-customer is the focus of buyer and supplier as in most end-to-end supply chain models, unique to this supply chain model is that the customer is at the center of the model. The guidelines establish four collaboration tasks which are common to nearly any business plan: Strategy and Planning, Demand and Supply Management, Execution and Analysis. Although listed in logical order, the circular design is most appropriate because the philosophy is based on the idea that most businesses are engaged in more than one of the tasks at any given time (VICS, 2004). These four tasks are subdivided into eight activities which partners should engage in to employ a collaborative business approach. Additionally, the collaboration tasks are customized to retail and manufacturing members of the supply chain to further facilitate collaboration as identified in Figure 2-3.

Retailer Tasks	Collaboration Tasks	Manufacturer Tasks
	Strategy & Planning	
Vendor Management	Collaboration Arrangement	Account Planning
Category Management	Joint Business Plan	Market Planning
	Demand & Supply Management	
POS Forecasting	Sales Forecasting	Market Data Analysis
Replenishment Planning	Order Planning/Forecasting	Demand Planning
	Execution	
Buying/Re-buying	Order Generation	Production & Supply Planning
Logistics/Distribution	Order Fulfillment	Logistics/Distribution
	Analysis	
Store Execution	Exception Management	Execution Monitoring
Supplier Scorecard	Performance Assessment	Customer Scorecard

Source: VICS 2004

Figure 2-3: CPFR® Business Plan Breakout

VICS indicates that while EDI is not a requirement of CPFR®, it will certainly aid in the management of POS forecasting information and exception management (2004). The key to the CPFR philosophy is that members of the supply chain engage in a collaborative approach to forecasting the customer's needs and focus on managing instances where that forecast cannot be met or agreed upon as an exception (Barratt and Oliveira, 2001;Sheffi, 2002).

Academic and Practical "Proof" of Concept

With promises of providing a market edge, the introduction of CPFR® inspired much academic research and industry pilot studies to "prove" the concept. Scholars have researched CPFR® (sometimes also referred to in a limited scope as CFAR--Collaborative Forecasting and Replenishment) identifying benefits, challenges and risks to be considered when implementing this supply chain management approach (Raghunathan, 1999; Aviv, 2001; Boone *et al.*, 2001). Pilot studies have emerged world-wide across varying industries including electronics, clothing and groceries (Hill, 1999; Dangelmaier and Busch, 2001; Lin *et al.,* 2003). One company to test the concept was Hewlett-Packard in their printer division in the 1990s (Callioni and Billington, 2001). For HP, the initial growing pains seemed to outweigh the benefits and the first attempt to implement CPFR® failed due to disconnects between the "collaborated-on" replenishment plan and production planning (Culbertson *et al.,* 2005). However HP revisited it's approach and implementation plan, and by 2001 realized large returns on their investment including in-stock levels of 95% (up from 80%), tripled inventory turns and an increase in sales over the ten-month pilot period from $3.4 million/month to $10.1 million/month (Callioni and Billington, 2001). Further improvements to the program to long-term capital-planning extended the benefits to a 20% decrease in inventory investment and 80% improvement in delivery performance (Culbertson *et al.,* 2005).

Hewlett-Packard's initial dissatisfaction with CPFR implementation is indicative of the doubts common in industry. In fact, academic research has focused on the causes of these less-than-impressive results in practical application (Barratt and Oliveira, 2001; Smaros, 2002; Holweg *et al.,* 2005). Barratt and Oliveira (2001) identify barriers of CPFR implementation as "those factors that limit trading partner's visibility of the supply chain" such as, but not limited to, lack of trust and sharing, difficulties in exception management, and lack of focus on the overall process by partners." They also suggest that trust and technology are critical enablers of CPFR® implementation that will help reduce the barriers. Research by Pallab Saha identified three specific issues which must be addressed by partners participating in large-scale CPFR® adoption:

1. Establishment of a clear statement of expectations
2. Careful selection of participants
3. Shift to a collaborative business relationship

Researchers have also explored the advantages of collaborative techniques such as CPFR®. In a comparison between CPFR® and traditional re-order point (ROP) inventory management, Boone *et al.* (2001) identified several benefits of CPFR® implementation: increased fill rates, decreased supply chain inventories, reduction in cycle time and increased profits. Raghunathan (1999) evaluated the impacts of CFAR (Collaborative Forecasting and Replenishment) on retailer supply chains of participants and non-participants, and found that even non-participants' costs decrease when collaboration is practiced by the manufacturer. Interestingly, this research also showed that the manufacturer's costs actually *increased* when some of its retailers did not participate in collaborative forecasting and while others did. This suggests a motivation for the manufacturer to lead the efforts and assume more initial investment costs to incentivize non-participants to engage (Raghunathan, 1999).

Providing the Spark for Collaboration

Based on case study research, McCarthy and Golicic (2002) identify seven guidelines to implementing collaborative techniques that can result in supply chain efficiency and competitive advantage. These include:

1. Auditing internal processes
2. Senior management support
3. Selecting and training the right people
4. Target key companies first, then expand to lower levels
5. Establish regularly scheduled, customized meetings to support the forecast
6. Determine method of on-going, timely information exchange
7. Develop a single, shared projection of demand between partners

While these seven concepts embody the CPFR® approach, McCarthy and Golicic (2002) suggest them as alternative approaches to the rigorous and costly nature of CPFR®. The pilot studies and academic research summarized above illustrate advantages and challenges of adopting CPFR®. More importantly, they may provide the foundation for supply chain management to take on a more collaborative nature.

Collaboration as an Element of SCM

Scholars agree that CPFR® has provided the initial spark for SCM to migrate to a more collaborative state (Sheffi, 2002; Kracklauer *et al.*, 2004). The concept of supply chain collaboration appears throughout the literature. However, a universal definition of collaboration in the context of Supply chain management has not yet been clearly presented. Dr. Mentzer (2001b) defines supply chain collaboration as, "means by which all companies in the supply chain are actively working together towards common objectives, and is characterized by sharing information, knowledge, risk and profits." Bowersox *et al.* (2003) discuss collaboration from an enterprise view, describing it as "when two or more firms voluntarily agree to integrate human, financial, or technical resources in an effort to create a new, more efficient, or relevant business model." They further describe it in terms of tactical and strategic collaboration. Tactical collaboration is identified as “joint modification of traditional processes to enhance the way in which essential functions are performed” as in CPFR. While strategic collaboration, the less commonly achieved form of collaboration involves “restructuring…core competencies while sharing the risks and rewards associated with successfully executing all other value-adding parts of the process” (Bowersox *et al.*, 2003). Tom Anthony, Supply Chain Collaboration Strategy Manager for PeopleSoft, Inc. describes collaboration as “when two or more companies share the responsibility of exchanging common planning, management, execution, and performance measurement information…[to] drive change to the underlying business processes” (Anthony, 2000). Considering the above definitions, for the purpose of this research, supply chain collaboration is defined by the author as:

> Two or more units continuously working together to share information and knowledge and make decisions in an effort to improve overall supply chain processes.

Dr. Mentzer explains the role of collaboration in supply chain management in a recent interview for *Supply and Demand Chain Executive:*

> A lot of what supply chain management's about is collaboration — collaboration is a management process, it's not a technology system. The technology can augment collaboration, but it doesn't create the willingness for the two of us to collaborate (Reese, 2005).

The element of collaboration is based on both the ability and the willingness to share information and agree upon a supply chain vision. Central to supply chain collaboration, is the concept that all parties should benefit from the effort (O’Marah, 2001; Bowersox *et al.*, 2005). Due to the large investment of time, resources and energy collaboration is best suited for complex and interdependent environments for benefits to be realized (Nix *et al.,* 2004). The CPFR model provides structured guidance for effectively employing collaborative supply chain management to produce benefits for all partners, ultimately delivering a better product to the customer at the right time, place and cost. Kracklauer *et al.* (2004) identify the clear distinction between CPFR® and traditional supply chain management is commonly managed data. However, critics also agree that key organizational and technical barriers must be overcome, such as the time and cost investment associated with new information technologies and mismatched internal processes (Barratt and Oliveira, 2001; Sliwa, 2002; Smaros, 2003). Additionally, research has identified social barriers such as trust and commitment to the overall goal by all partners involved that deserve further attention (Mentzer, 2001b; Kwon and Suh, 2004; Russell and Hoag, 2004). Akkermans *et al.* (2004) suggest that achieving the transparency of data important in collaboration requires trust; trust which can only be achieved primarily through hard work. This hard work may be in the form of collaborating at all levels within the supply chain to develop common goals, metrics and processes. Without agreement in the collaborative goals of the supply chain vision, the supply chain will have difficulties functioning as an integrated chain.

Supply chain management in the DoD

In addition to understanding the evolution of supply chain management initiatives and various directions taken by academics and industry, it is necessary to comprehend the Air Force's supply chain management environment. Policy influences as well as recent and current military supply chain initiatives have molded the development of that environment and are equally critical to understanding the context of the problem addressed by this research.

DoD Supply chain management Inception

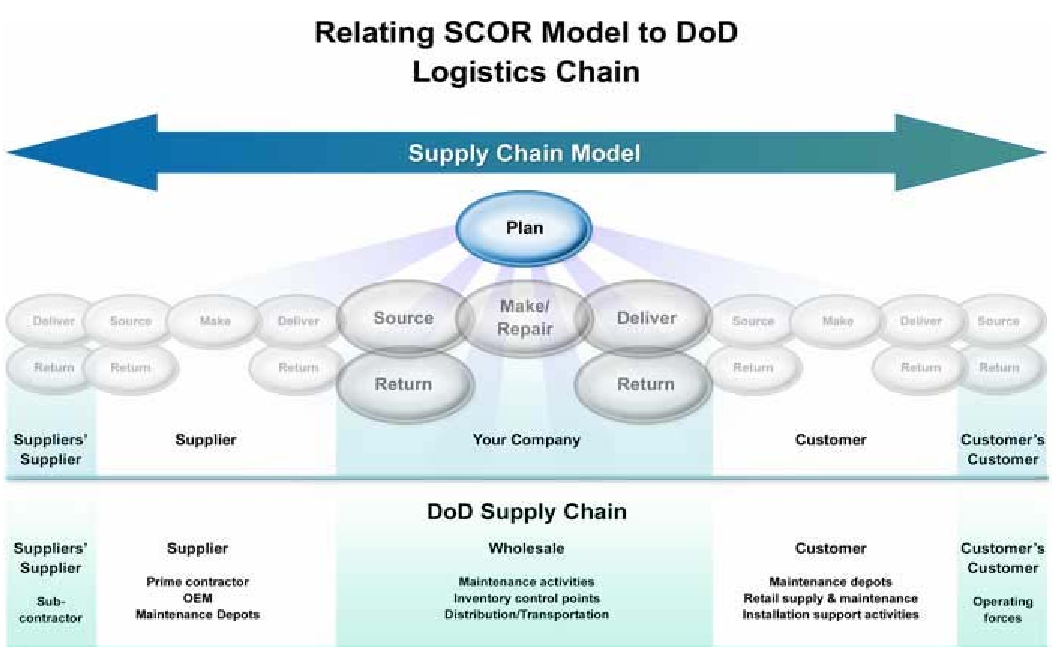
The change in focus of our military objectives as we complete the transition from Cold War Era to Post-Cold War Era drives the need for a transformation of key processes (Department of the Air Force, 2004). To some, it seems the post-Cold War era could be called “the era of reductions.” The shift in mission focus from defense against a nuclear threat through a strong global presence to the current expeditionary state to defend against a variety of threats is referred to the transformation from “threat based” strategy to the “capabilities based” approach to defense planning (Department of Defense, 2001; Rumsfeld, 2002). It has imminently resulted in the “do more with less” mentality. The downsizing of inventory whether in systems, parts or even personnel, throughout the eighties and nineties, introduced new strains to our logistics capabilities. The luxury of large inventory buffers to meet the mission is no longer afforded.

Policy Influences

In addition to a changing mission and inventory position, key policies influenced the evolution of government logistics and supply chain management initiatives. The establishment of the Corporate Information Management (CIM) initiative in 1989 induced close scrutiny of DoD’s material management systems and resulted in a failed attempt to adopt commercial best practices to improve logistics information management (US General Accounting Office, 1996a). Misdirected attempts to redress these early failures at making improvements to logistics information systems quickly changed to migration strategies for system integration that would mirror industry. However, a GAO report indicated that no cost analysis was done to determine why the first attempt failed so miserably (US General Accounting Office, 1996a). At about the same time as the release of the CIM initiative, a series of executive and legislative events resulted in the Clinger-Cohen Act of 1996. Passed with the intent to reengineer the DoD's approach to adopting Information Technology to better complement private industry, one of the primary goals of this Act was to eliminate the "implementation of ineffective information systems resulting in waste, fraud, and abuse" ("Clinger-Cohen Act," 2005).

Recognition of the need for logistics reengineering was also influenced by the establishment of the DoD Logistics Strategic Plan in 1994 and its update in 2000 (Department of Defense, 1999). Additionally, the 1998 DoD Reform Initiative #48 which mandated the adoption of commercial EDI Standards for DoD logistics business transactions reinforced a commitment to adoption of proven commercial technologies. This Initiative was updated two years later by the Electronic Business/Electronic Commerce Program (Department of Defense, 2000). Annual updates of the Logistics Strategic Plan facilitated its evolution, and by 2000 six focus areas for logistics were identified and each DoD component established its initial logistics transformation goals. The Air Force component expected to "adopt best government, commercial and academic initiatives and opportunities to increase performance for the Warfighter" emphasizing the Air Force's intent to seek out Best Practices for improved logistics and supply chain management (Department of Defense, 2000).

The most recent (and perhaps most significant) policy influence was the revision of the 1998 Department of Defense *Supply Chain Materiel Management Regulation, DoD 4140.1R*, in 2003. This policy provided direction and structure for adopting commercial best practices and pursuing "collaborative initiatives" in an effort to shift DoD SCM towards that of the private sector. This regulation identifies the Supply Chain Operational Reference (SCOR) model as the official framework for "developing, improving, and conducting materiel management activities to satisfy customer requirements (Department of Defense, 2003). The SCOR model is a popular supply chain modeling approach used throughout industry and academia to baseline the supply chain for process improvements (Herrmann *et al.,* 2003). Figure 2-4 illustrates the SCOR model within the context of the DoD/Air Force Supply Chain.



Source: Defense Acquisition University, 2006.

Figure 2-4: DoD SCOR Model

This model was developed by the Supply Chain Council as a process reference model for evaluating and improving supply chain operations, combining business process reengineering, benchmarking, best practices and process measurement into a single framework (Supply Chain Council, 2005). The goal is to capture relationships and management processes, identify metrics and align features and functionality of the supply chain. While the SCOR model does not explicitly capture all functions such as sales and marketing or IT, it is based on evaluation and analysis of five distinct management processes: Plan, Source, Make/Repair, Deliver and Return (Department of the Army, 2006b; Supply Chain Council, 2005). Figure 2-4 illustrates how these processes translate to key links in the supply chain, with each link capable of exhibiting varying levels of each of the five processes. The DoD *Supply Chain Materiel Management Regulation* outlines the use of this model as follows:

> C1.4.1.2.1. Under the Plan process, conduct demand and supply planning that optimizes supply chain resources to meet established support strategies and employs, to the furthest extent, collaboration between support providers and their customers.
>
> C1.4.1.2.2. Under the Source process, perform materiel sourcing and acquisition and manage their sourcing infrastructure applying total life-cycle support management where applicable.
>
> C1.4.1.2.3. Under the Maintain/Make process, seek to optimize the relationships between materiel managers and commercial sources of supply and between materiel managers and activities performing production, manufacturing, repair, modification, overhaul, and testing functions at organic or private sector facilities or through public and private partnerships at those facilities.
>
> C1.4.1.2.4. Under the Deliver process, manage orders, distribution depots and other storage locations, transportation networks, and other delivery infrastructure.
>
> C1.4.1.2.5. Under the Return process, administer customer returns of

> defective materiel, excess materiel, and materiel requiring maintenance, repair, or overhaul (Department of Defense, 2003).

The regulation also details the specific requirements and procedures for each process. Essentially, the SCOR model uses a cause and effect logic to identify collaborative relationships throughout the supply chain, making it a logical choice as a basis for improving the military supply chain and pursuing transformation goals that were under development.

DoD Supply Chain Transformation

At the onset of the 21st Century, "Transformation" became one of the hottest buzzwords in the public sector, with new offices and initiatives emerging throughout DoD. Vice Admiral (ret.) Arthur K. Cebrowski, Founder of the Office of Force Transformation, defined Transformation as:

> A continuing process. It does not have an end point. Transformation is meant to create or anticipate the future. Transformation is meant to deal with the co-evolution of concepts, processes, organizations and technology. Change in any one of these areas necessitates change in all. Transformation is meant to create new competitive areas and new competencies. Transformation is meant to identify, leverage and even create new underlying principles for the way things are done. Transformation is meant to identify and leverage new sources of power. The overall objective of these changes is simply—sustained American competitive advantage in warfare (2006).

Efforts to "transform" Air Force logistics and supply chain operations were fueled by several GAO investigations, reporting the shortcomings of the many logistics systems in use. One evaluation of Air Force re-engineering efforts in 1996 recommended adoption of commercial inventory tracking systems, VMI practices and third-party logistics to ensure re-engineering efforts succeeded (US General Accounting Office, 1996b).

Despite recommendations for adoption of industry supply chain innovations and improvements to logistics information systems from consulting organizations such as GAO, RAND and LMI, actual progress across the Air Force, even DoD-wide has been slow (Moore *et al.,* 2002; Bickel, 2003). The mere size of the Air Force supply chain and its dependence on legacy data systems developed over 40 years ago presents huge challenges to tackling supply chain improvements. A recent GAO report of business systems modernization efforts throughout the DoD identified a lack of control over business system investments within each department, citing a 255% *increase* in logistics systems alone across the DoD from April 2003 to February 2005 (US Governement Accountability Office, 2005). With technology and resources focused primarily on system development for warfighting capabilities throughout the 20th century, the Air Force has essentially taken a "wait and see" approach to technological innovations, allowing the private sector to work out growing pains of management data systems before adopting proven technology. While this approach has monetary advantages, the nature of the legacy-based demand information and the multitude of unique information-management systems put the Air Force at a disadvantage with industry. One GAO report identified 107 logistics and inventory systems within the Air Force, most of which are not integrated and require manual data inputs and maintenance (US Government Accountability Office, 2004). This also negatively impacts the private industries that are engaging in technological supply chain management such as VMI, EDI and CPFR® with other private partners but must revert to outdated/legacy practices or workarounds when dealing with the government as a supply chain partner.

DoD Supply Chain Initiatives

It is impossible to identify all the Supply chain management "pilots" in the Air Force, let alone DoD-wide, due to the reasons mentioned above. However, in response to private industry advancements and changes in military information management policy, several key initiatives have emerged and helped shape the direction of Air Force supply chain management and information sharing. Only a few are identified here from several departments within the DoD including DLA, the US Army and the Air Force. However, with the transformation goals established by Secretary of Defense, Donald Rumsfeld in 2002, all branches have established offices and are transforming logistics and supply chain operations. In 2000, Assistant Secretary of Defense, Arthur Money released the DoD's Enterprise Software Initiative (ESI) which essentially reduced some of the "red tape" of software acquisition and leveraged DoD buying power by creating an enterprise-wide Blanket Purchase Agreement that all services could use to purchase integration software. This may have driven the focus of supply chain initiatives toward adoption and implementation of commercial ERP systems throughout the Department of Defense.

Defense Logistics Agency Business Modernization

The Defense Logistics Agency (DLA) provides worldwide logistics support to all branches of the armed forces, providing nearly every consumable item needed to operate, as indicated by its motto: "If America's forces eat it, wear it, maintain equipment with it, or burn it as fuel…DLA probably provides it" (Defense Logistics Agency, 2005). DLA manages 5.2 million items, valued at $89.2 billion. Over the past decade or so, DLA has developed several business process improvements that have influenced government supply chains, including web-based asset visibility, supplier relationship management and implementation of an ERP system.

In the 1990s DLA established a web-based information system, WebCATS, for its Air Force customers to access order information, much like FedEx's tracking website. Currently the WebCATS system is evolving into the DoD EMALL system, which provides internet-based shopping for Military and Federal purchasers to buy "off the shelf finished goods, items from the commercial marketplace and government sources" much like amazon.com (Defense Logistics Agency, 2006c).

DLA's largest supply chain management transformation initiative is its current Business System Modernization (BSM) plan. One of 13 transformation initiatives outlined in its 2006 Transformation Plan, DLA describes Business Systems Modernization (BSM) as:

> DLA's project to replace the agency's 1960 vintage legacy systems (i.e., Standard Automated Material Management System (SAMMS) and Defense Integrated Subsistence Management Systems (DISMs)) with commercial-off-the-shelf (COTs) software and state of the art technologies. DLA's new Enterprise Resource Planning (ERP) System will replace the agency's legacy supply system with a state-of-the-art system linking the entire supply chain from customer to supplier. This major re-engineering effort crosses all agency commodities (e.g. subsistence, construction, medical, etc.) to provide end-to-end materiel, financial and procurement management (Defense Logistics Agency, 2006b).

BSM has been evolving since its inception in 1998 and is projected to be complete by the end of 2006. To date, DLA has seen a 16% improvement in logistic response time and anticipates a 700 million dollar reduction in inventory as a result of BSM (Cottrill, 2004; Defense Logistics Agency, 2006a).

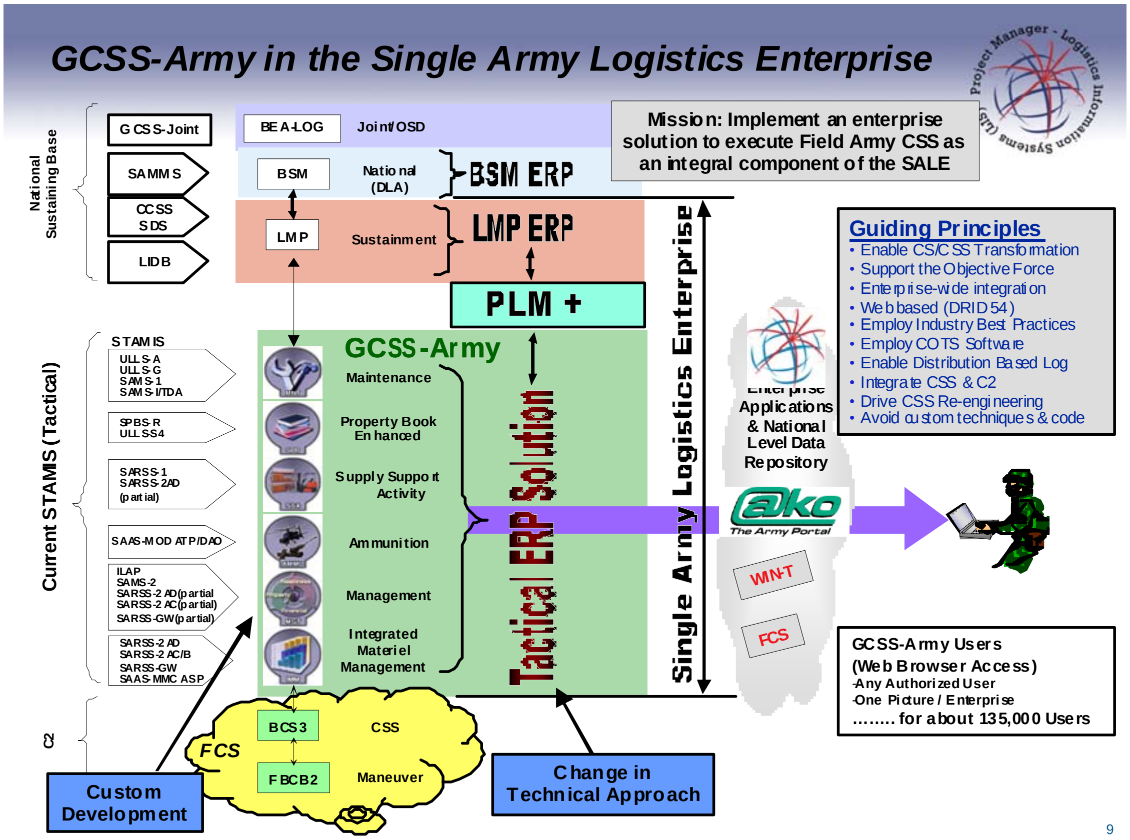
Army Logistics Transformation

As the grandfather of military logistics, the US Army is no doubt a notable leader in supply chain improvements. Its self-named “Revolution in Military Logistics” of the 1990s fit well with the call for logistics strategic plans for all DoD components (Department of Defense, 1999). The Army’s focus on Total Asset Visibility, “from factory to foxhole” was a primary motivation for its Movement Tracking System (MTS) a satellite-based location tracking system that uses Global Positioning Satellites (GPS) to identify locations of vehicles carrying supplies in a wartime environment (Buxbaum, 2005). Army Materiel Command (AMC) has sponsored many integration efforts evolving into its current transformation vision known as Single Army Logistics Enterprise (SALE):

> Fully integrated knowledge environment that builds, sustains and generates warfighting capability through an end-to-end logistics enterprise based upon collaborative planning, knowledge management and best business practices (Department of the Army G-4, 2004).

A 2003 whitepaper released by the Army Office of the Deputy Chief of Staff for Logistics (G-4) identified the four focus areas for logistics transformation as: connect Army Logisticians, modernize theater distribution, improve force reception and integrate the supply chain (Department of the Army G-4, 2003).

One of the primary initiatives within the SALE concept is the Global Combat Support System (GCSS), the Army’s ERP system. Figure 2-5 illustrates the Army’s vision for adoption and implementation of the GCSS system within the SALE vision and in connection with DLA’s BSM ERP.

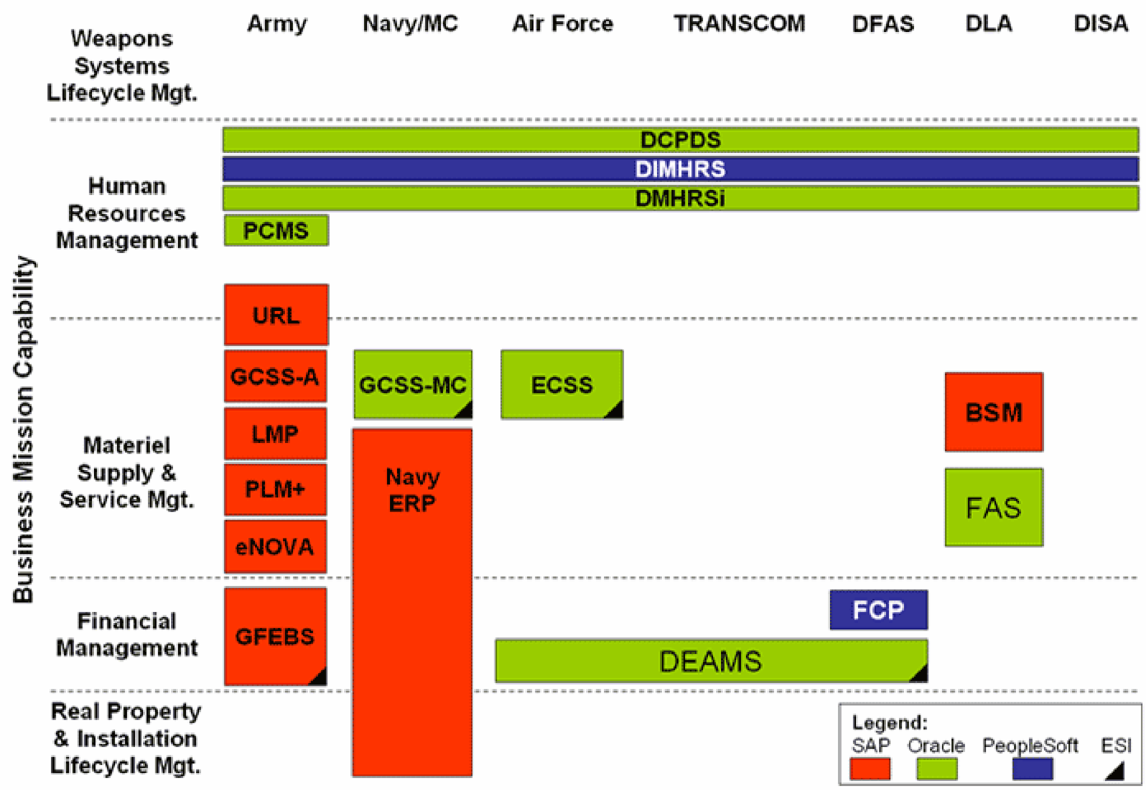


Source: Zoppa, Robert. "GCSS Army Program Overview," 2003.

Figure 2-5: Army GCSS Overview

The complexity of the systems to be incorporated into the GCSS as illustrated above, is one of the challenges facing all military ERP implementation efforts, in addition to the stove-piped nature of military Legacy data systems. The GCSS is projected to be fully operational by the second quarter FY09 (Department of the Army, 2006a)

Other departments such as the Navy DFAS also saw the opportunity to embark down the ERP road at a slightly lesser cost with the inception of DoD's ESI. Figure 2-6 summarizes some of the other ERP initiatives and their vendors that are currently underway across the DoD.



SOURCE: Department of the Army, 2006c

Figure 2-6: DoD ERP Landscape

Many smaller-scale initiatives are not included in this illustration, especially from the Air Force perspective. The successes and failures of these smaller initiatives may be molding the future of Air Force supply chain management and should be considered when trying to understand the Air Force supply chain management environment.

SCM: Air Force Style

There are several "pilot" programs within Air Force Supply chain management that despite slow progress, have given way to larger-scale initiatives. Some of those worth noting are the Enterprise Data Warehouse (now the Air Force Knowledge Service, AFKS), Customer-Oriented Leveling Technique (COLT), and Advanced Planning and Scheduling. On a larger scale, Air Force Logistics Transformation efforts have evolved into Expeditionary Logistics for the 21st Century (eLog21) in response to Mr. Rumsfeld's 2002 call to transform how we do business.

The COLT initiative has improved supply chain operations in the production support arena, from an inventory leveling approach. COLT was developed with the intent to improve availability of DLA-provided consumable parts for Depot maintenance activities (Vinson and Gaudette, 2003). Essentially, this initiative resulted in a dramatic change in setting Depot inventory levels for DLA consummables from the traditional Economic Order Quantity approach to one based on marginal analysis, similar to the process used in management of higher-priced reparable items. The initiative resulted in a 60-65% reduction in customer wait time, one of the Air Force's key supply chain performance measures (Moore, 2003; Vinson and Gaudette, 2003). The COLT model is currently being evaluated for application to base stock levels (Boone, 2003).

The Enterprise Data Warehouse (EDW) program is the first Air Force enterprise-wide data warehousing initiative, providing a web-based integrated database ("BearingPoint and…," 2003). EDW began in 2001 with efforts to consolidate 26 legacy systems spanning maintenance, supply, transportation and financial data into an automated aggregated warehouse. It was brought online in 2002 and renamed the Air Force Knowledge Service in May 2004 ("BearingPoint and…," 2003; Jackson, 2004). While originally designed to consolidate legacy systems, enabling cross-functional queries and reports, the AFKS has evolved over the past several years into a near real-time supply chain analysis tool (Webb, 2003; Jackson 2004).

On a much larger scale, eLog21 is the Air Force Transformation initiative that provides guidance for future logistics transformations. Aimed at "transforming warfighter sustainment operations by leveraging information and process improvements across the Air Force Enterprise," it was initially broken out into two initiatives: Purchasing and Supply chain management Transformation and Depot Maintenance Transformation (Leatham, 2003). The eLog21 Campaign Plan published in 2004 describes its impact on force transformation in four "effects" that expeditionary logistics must operate within: enterprise view, integrated processes, optimized resources and integrated technology (Department of the Air Force, 2005d). Within each of these effects, are numerous objectives, some more specific than others, which establish requirements for logistics innovation. There are 22 initiatives outlined in the eLog21 campaign, all of which have varying degrees of influence on Air Force supply chain philosophy and operations.

Of the 22 eLog21 initiatives, eight will most directly affect how information is shared and collaboration is applied across the Air Force supply chain. Figure 2-7 summarizes the objectives of these eight. In the spirit of commercial supply chain practices, eLog21 is founded on an enterprise view in which "...the supply chain processes transition away from the organizational stovepipes of commodity-focused processes to a non-commodity specific based system," (Department of the Air Force, 2005b).

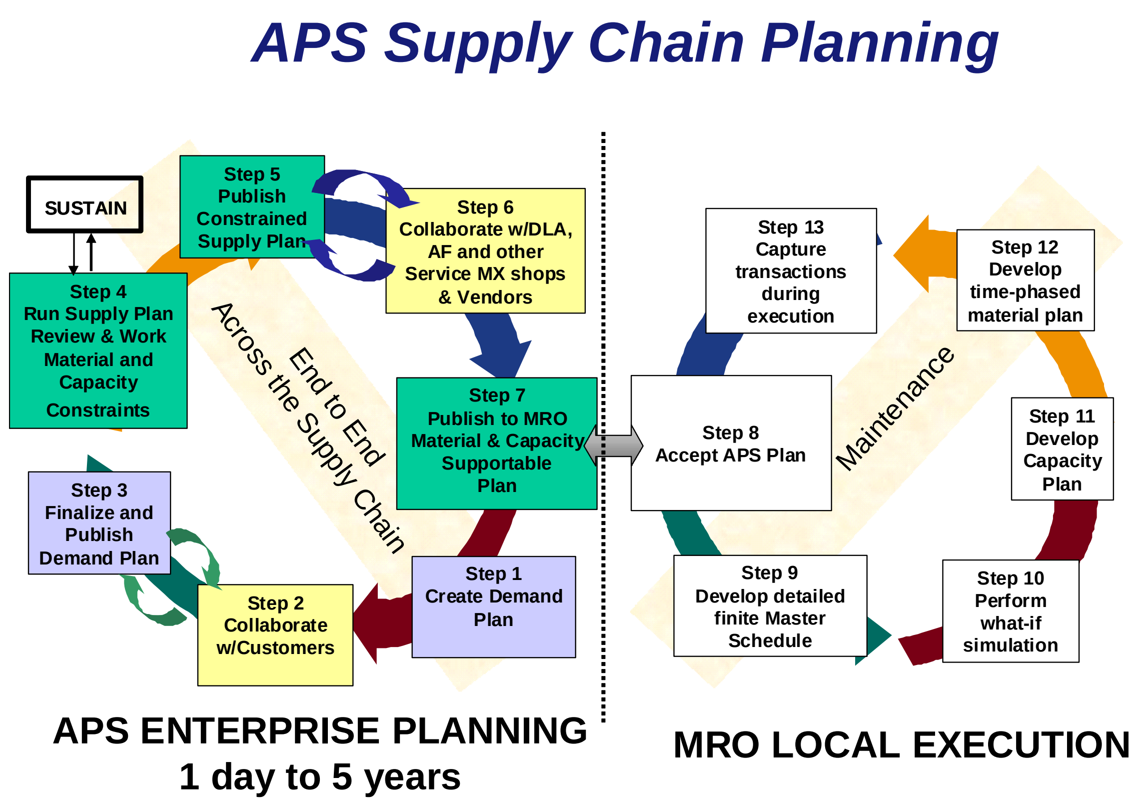
Initiative	Objectives
Logistics Enterprise Architecture (LogEA)	...a single authoritative source to define both operational and systems approach for Air Force logistics supply chain
Installations and Logistics Information Requirements (ILIR)	...a shared environment to supply cross-service and cross-domain users and applications with on-demand access to authoritative, relevant, and sufficient data for decision-making
Air Force Knowledge Service	...a process for identifying, prioritizing, and de-conflicting data warehouse requiremens and establish the source for logistics data (in conjunction with ECSS)
Asset Management Tracking (AMT)	...better visibility of serialized components using existing and emerging standards and technologies including Universal IDs (UIDs), Serial Number Tracking (SNT), and Radio Frequency IDs (RFIDs)
Advanced Planning and Scheduling (APS)	...implementing a COTS APS tool within the Air Force. Develop the processes, procedures, and business rules...and deploy the tool throughout the Air Force
Weapon System Supply Chain Manager (WS SCM)	...a holistic focus on supply chain performance and relate supply chain input (money) to supply chain output (weapon system availability) to optimize spare parts availabiltiy…establish a manager responsible for linking processes and inputs to weapon system targets and goals
Regional Supply Squadron (RSS)	...standard supply structure with RSSs and establish fleet-level advocate for spares Command and Control (C2). Improved spares C2 and weapon system availabilty through increased integration with suppliers, enhanced total asset visibiltiy and operational fleet level of focus
Expeditionary Combat Support System (ECSS)	1) Acquire and implement a modern suite of COTS-based IT solutions to enable the future logistics vision defined in eLog21
	2) retire the current legacy systems across the logistics domain

Adapted from: Department of the Air Force, *Expeditionary Logistics for the 21st Century Campaign Plan*, 2005.

Figure 2-7: Supply Chain eLog 21 Initiatives

One of the more developed Air Force supply chain initiatives under eLog21, is the Advanced Planning and Scheduling (APS) initiative. It was originally one of eight supply chain initiatives of Air Staff's "Spares Campaign" in 2001, the predecessor to eLog21. APS goals include: improved forecasting accuracy, reduced inventory costs and reduced cycle time, very similar to expected industry supply chain management improvements (Kaczmarek *et al.*, 2002). The APS pilot program was conducted on management of F101 engine parts for the B-1 Bomber aircraft and was initially supported by a small team of logisticians including a retail and wholesale item manager, equipment specialist, maintenance planner, computer programmer and BearningPoint contractor support (Oklahoma City…, 2003; Department of the Air Force, 2005a). The Air Force recognized the commercial use of APS systems to integrate forecasting, inventory, production and distribution planning activities across organizations and identified the APS Pathfinder as a way to evaluate the functional benefits and applicability of this system to the Air Force maintenance, repair and overhaul environment (Kaczmarek, 2002).

The Pathfinder was tested using the Supply Chain Reference (SCOR) model to identify areas and processes for improvement under guidance of eLog21 (Leatham, 2003). Essentially, the APS program is COTS technology that enables collaborative supply chain management of fragmented daily activities spanning forecasting, inventory distribution, maintenance and production planning through an automated alerts-based (exception management) tool (Department of the Air Force, 2005a; Kaczmarek, *et al.*,2002). Figure 2-8 provides a graphical overview of the APS system and indicates the Enterprise-wide integration it creates across the supply chain.



Adapted from: Downey, Robert, “USAF Logistics Transformation Briefing: Advanced Planning and Scheduling (APS)”, 2005.

Figure 2-8: APS Enterprise Planning

In addition to establishing a central, prioritized plan which is collaborated on with the customer, DLA and ultimately the Maintenance Repair Organization (MRO), APS is a tool that provides the Air Force enterprise decision-makers with integrated information such as:

1. Difference(s) between planned and actual performance in the supply chain
2. Real-time visibility of changes in the spares pipeline
3. Ability to see and evaluate the impact of adjusted inventory levels
4. Simultaneous assessment of both *buy* and *repair* requirements
5. Ability to identify sources of requirements from various

operational customers

6. Ability to compare both depot-level repair and DLA requirements to funding needs (Kaczmarek *et al.*, 2002).

Early successes of the F101 APS Pathfinder initiative at Oklahoma City Air Logistics Center (ALC) led to larger-scale implementation tests at each of the three Air Force Depots in different commodity areas including Landing Gear at the Ogden ALC and Avionics at Warner-Robins ALC. The four-year "proof of concept" at Oak City has ultimately led to transcendence beyond "pilot" status. The APS system is currently in contract negotiations as part of the Air Force ERP system, the ECSS (Expeditionary Combat Support System). The ECSS is currently still under refinement (not yet in contract negotiations) and slated for Air Force-wide implementation over the next 5-10 years (Westervelt, 2005).

Combining the Elements

Academic research and industry initiatives have contributed to the development of supply chain management theories and practices. Information-sharing and collaboration have been identified as key elements to be adopted as part of SCM. Progress in each of these areas has highlighted the importance of infusing both collaboration and information-sharing into a Supply chain management approach which provides benefits from each discipline and allows challenges of each to be managed collectively. The interactions of collaboration and information-sharing within supply chain management are illustrated by Figure 2-9.

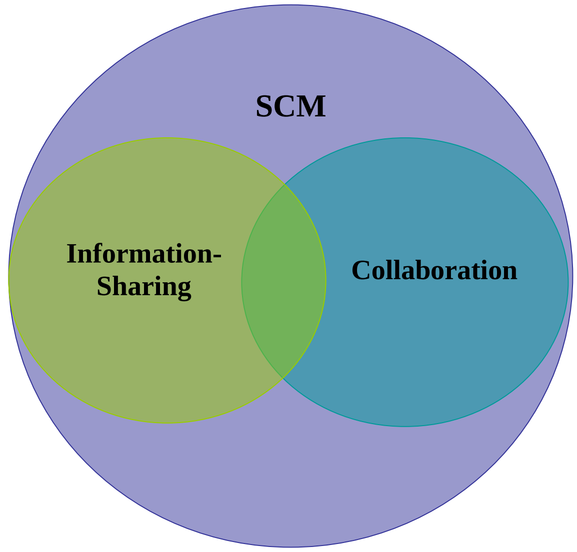


Figure 2-9: SCM, Information-Sharing and Collaboration

This diagram illustrates the combination of the elements of supply chain management previously discussed and their interrelationships. When applied to supply chain management, information-sharing and collaboration can capture elements can produce an effective and efficient supply chain. Akkermans *et al.* (2004) describe supply chain "transparency" as "sharing data regarding current order and production statuses as well as plans and forecasts with the various supply chain partners." In this regard, demand and forecasting data can be considered "shared information" but if that information is not integrated into the supply chain management practices of each partner, it has little impact on improving the performance of the supply chain. Furthermore, the trust factor that may exist among supply chain partners with the intent to collaborate on supply chain goals cannot be put into practice without that trust including the open sharing of information. Finally, the integration of information-sharing and collaboration may be improved by a digital business transformation in which partners transform business processes with improved information technology. This transformation is most effective if supply chain goals and strategy are collaborated on by all members of the supply chain (Bowersox, *et al.*, 2005).

Air Force Metrics

An in-depth discussion of supply chain metrics is beyond the scope of this research effort. However, in order to consider the impacts of information-sharing and collaboration on supply chain management within the Air Force some attention must be given to measuring those impacts. Lambert and Pohlen's discussion of supply chain metrics proposes that most supply chain metrics actually measure "internal logistics operations rather than supply chain management" supporting the previously identified confusion between supply chain and logistics management (2001). They also admit that the complexity of the supply chain makes it difficult to develop accurate metrics. Too many metrics may add more complexity and misguided information due to redundancies in what is measured, revealing "symptoms" of a problem, rather than the problem itself, or lack of consistency across the supply chain (Lambert and Pohlen, 2001; Hofman, 2004; Taylor, 2004). These concerns are shared by both industry and Air Force supply chain managers.

A study by the Air Force Logistics Management Agency cited the need for a customer-focused set of supply chain metrics to address the "disconnect" between operational goals and Air Force metrics that "drive independent and suboptimal behavior" (Manship, 2001). Their research revealed a set of 26 metrics which indicate the general "health" of the Air Force Supply System. These metrics were divided into several categories which described supply core processes, ultimately affecting Aircraft Availability (AA) referenced to as the "Output." Aircraft Availability is defined as the percentage of aircraft not grounded because of parts shortages, and is used to compute inventory requirements (Manship, 2001). Figure 2-10 summarizes the categories and their corresponding metrics.

Performance Metrics

<u>Output</u>
Aircraft Availability (AAactual/AAtarget)
Aircraft Availability (C-Rating)
<u>Repair Effectiveness</u>
Current Repair Asset Position
Keep Up
Catch Up and Time to Catch Up
Draw Down and Time to Draw Down
Depot Repair Time
Supply Chain Responsiveness
<u>Buy Effectiveness</u>
Asset Position By Weapon System
Asset Position (Buy Point)
Items In Buy or On Order
Items In Buy or On Order($)
Procurement Lead Time Effectiveness
<u>Stockage Distribution Effectiveness</u>
Redistribution Excess
Depot Stock Above Requirement
Customer Wait Time
Customer Wait Time (Not Meeting Expectations)
<u>System Effectiveness (Information Management)</u>
Significant Problem Items
<u>Manning Effectiveness (Personnel)</u>
Enlisted Manning By Skill Level
Officer Manning By Grade
<u>Sales Effectiveness</u>
<u>Funding Effectiveness</u>
<u>DLA Responsiveness</u>
IE/SE
MICAP Incidents and Hours

Source: Manship, 2001.

Figure 2-10: AFLMA Recommended Supply Chain Metrics

Headquarters, Air Force Materiel Command (HQ AFMC) refined this list in 2003, focusing on a smaller number of metrics that fall into one of two categories: performance and process. A summary of these metrics can be found in Appendix 1. Consistent with AFLMA's research, HQ AFMC identifies Aircraft Availability as the driver which "provides a mathematical and analytical link between process, performance and customer" (Headquarters, Air Force Material Command, 2003). Taking recommendations from the American Production and Inventory Control Society (APICS) to consider 3 to 7 metrics to avoid "metric-overload" AFMC has divided the Air Force supply chain into seven "perspectives" aligned with elements of the supply chain and has developed a small number of metrics for each perspective. Figure 2-11 summarizes those metrics where the bold measure performance and the non-bold measure process.

Supply Chain Perspective	Most Relevant Metrics
Item Manager	**MICAP Hours** **CWT** MICAP Incidents TRV TRV
Supply Chain Manager (SCM)	**MICAP Hours** **CWT** Backorders MICAP Incidents
Weapon System Supply Chain Manager (WSSCM)	**Aircraft Availability** **MICAP Hours** **CWT** MICAP Incidents TRV *(Requires WS-NIIN relationship)
ALC	**Aircraft Availability** **MICAP Hours** **CWT** **NOR** MICAP Incidents TRV
AFMC	**Aircraft Availability** **MICAP Hours** **CWT** **NOR** MICAP Incidents TRV
Air Staff	**Aircraft Availability** **MICAP Hours** **CWT** **NOR**
MAJCOM	**Aircraft Availability** **MICAP Hours** **CWT**

Source: AFMC Supply Chain Metrics Guide, 2003.

Figure 2-11: AFMC Recommended Primary Metrics

The *AFMC Supply Chain Metrics Guide* (2003) provides a thorough discussion of the data used in each of these metrics, how they are calculated, who is responsible for the calculations and how often. Overall, however, the Air Force has agreed with industry and academia in that metrics are the link to core business processes and by evaluating the most relevant indicators, the Air Force gets "the right part, to the right place, at the right time, at the right price" (Headquarters, Air Force Material Command, 2003).

Summary

This chapter summarized the evolution of supply chain management as influenced by industry and academia, identified DoD and Air Force supply chain management initiatives and discussed metrics. While there remains disagreement on the definitions of logistics and supply chain management, some main concepts are consistent among popular definitions including "end-to-end," "movement of information and materiels," "efficiency and effectiveness," and "across all supply chain partners." This research defines SCM in the spirit of the CSCMP definition as:

> The planning and management of all logistics, procurement, sourcing and manufacturing activities across the end-to-end supply chain, from customer's customer to supplier's supplier, accomplished through collaboration with channel partners across marketing, sales, product design, finance, and information technology processes.

Several key initiatives such as MRP, ECR and CPFR that have impacted this evolution have been identified and described. Both academics and private industry identified the importance of information and sharing of information to improve supply chain performance as illustrated by the Bullwhip Effect (Lee *et al.*, 1997). Table 2-1 identifies the six types of shared information as described by Lee and Whang (2000):

Table 2-1: Types of Shared Information

Inventory Levels
Sales Data
Order Status for Tracking/Tracing
Sales Forecast
Production/Delivery Schedule
Other (performance metrics, etc.)

. As the importance of information-sharing gained momentum, collaborative theory and methods for managing the supply chain such as CPFR emerged. For the purpose of this research, collaboration is defined as:

> Two or more units continuously working together to share information and knowledge and make decisions in an effort to improve overall supply chain processes

Public sector supply chain management was also summarized including policy influences and transformation efforts. Key supply chain initiatives within several departments of the DoD were summarized, culminating in current Air Force logistics Transformation efforts. The ensuing chapters describe the methodology to evaluate the Air Force supply chain within the context a few aircraft parts and the results of this research. Conclusions about the application of supply chain management, information-sharing and collaboration will be drawn based upon these results and recommendations for future research to better understand the Air Force supply chain environment will be suggested.

III. Methodology

"If we knew what we were doing, it wouldn't be research."
--Albert Einstein

Chapter Overview

This research employs a case study methodology to collect the necessary data for understanding the application of information-sharing, collaboration and supply chain theory to the management of Air Force parts. This chapter addresses why the case study methodology was selected for the research, provides an overview of case study methodology including definitions, types and approach and discusses the analysis plan.

Qualitative vs. Quantitative

The debate over whether or not qualitative research can stand alone is an argument that has plagued scholars for some time. Common arguments against qualitative techniques include results that may not be replicable or generalizable to a population and concerns over reliability and validity (Lee, 1989; Numagami, 1998; Leedy and Ormrod, 2001). However, qualitative research such as the case study provides a structured platform for topic exploration and theory generation (Eisenhardt, 1989; Yin, 2003). It also serves as a good tool for theory testing and extension/refinement in a dynamic field such as operations management (Voss *et al.*, 2002). Operations management, like supply chain management, often requires consideration for human factors in research. Drawing from Popper's 1934 discussion of inductive and deductive reasoning, the more "social" setting of the case study provides an opportunity to draw complex conclusions that a quantitative environment cannot provide un-falsifiable evidence for or against (Popper, 1985; Lee, 1989). The case study is often the preferred type of research appropriate for explanation and theory-building of a complex subject, such as the supply chain (Eisenhardt, 1989). It is important to consider the nature of research and research questions when determining the appropriate research method.

Yin identifies three things to consider when evaluating the research method: the type of research, the investigator's control over the behavior, and the focus of the study—historical or contemporary events (2003). Case study research tends to be more explanatory, descriptive and exploratory in nature, addressing "how?" and "why?" questions while the experimental nature of quantitative research strives to determine more direct cause/effect relationships (Yin, 2003). Additionally, a case study methodology is appropriate when the researcher has little or no control over the behaviors and events being studied or when research is desired is a natural setting. Often theories of social and organizational behavior can only be developed in a case study environment. Finally, if the research focus is on historical events, an archival or historical analysis may be used. For current, more contemporary events, the only approach available is likely to be a case study or even a mixed method using both case study and an experimental design (Creswell, 2003; Yin, 2003).

Other research identifies additional criteria which indicate a case study method is appropriate. Eisenhardt (1989) suggests that case study research for theory building is ideal when a phenomenon is not well understood or supported by empirical evidence, or when a more established concept is supported by conflicting theories and evidence and needs a new perspective. Additionally, Robert Creswell (2003) describes the selection of the research method based on three elements: knowledge claims, strategies and methods. The qualitative research approach outlined by Creswell that employs a narrative design using open-ended interviewing to explore emancipatory assumptions (not guided by specific laws) describes a case-study method. His theory is summarized in Figure 3-1.

Research Approach	**Knowledge Claims**	**Strategy of Inquiry**	**Methods**
Quantitative	Postpositivist	Experimental design	Measuring attitudes, rating behaviors
Qualitative	Constructivist assumptions	Ethnographic design	Field observations
Qualitative	Emancipatory assumptions	Narrative design	Open-ended interviewing
Mixed methods	Pragmatic assumptions	Mixed methods design	Closed-ended measures, open-ended observations

Source: Creswell, 2003.

Figure 3-1: Types of Research and Selection Criteria

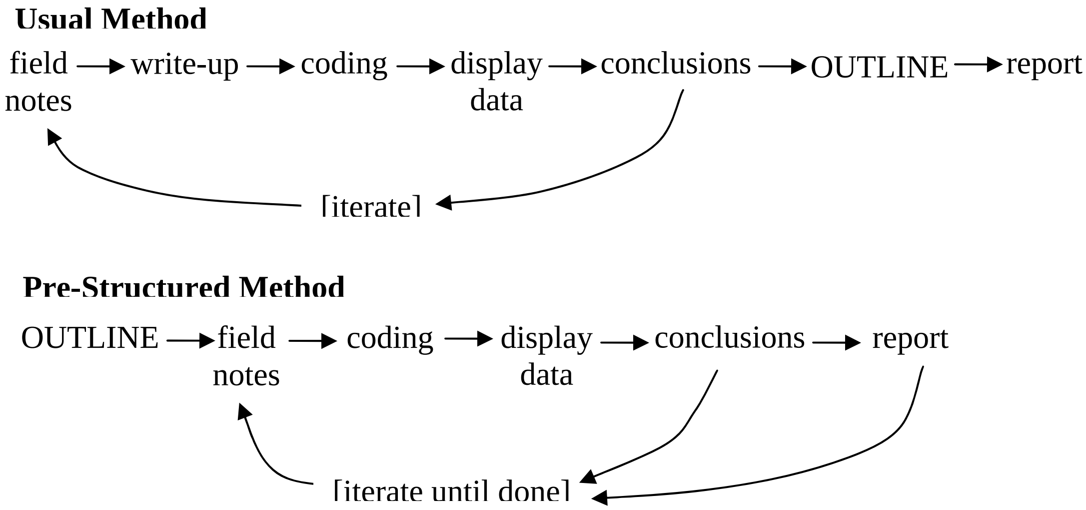
The criteria for research methodology offered by Yin, Creswell and others, as applied to this research converge on a qualitative research approach in several ways. First, the research problem, "*How can the application of information-sharing and collaboration to management of the Air Force supply chain improve operational readiness?*" is exploratory in nature. The research is attempting to understand how each of these elements are applied to and can impact the Air Force supply chain. There is no opportunity for manipulation or control of behaviors or events and with the transforming nature of the Air Force supply chain, the research will evaluate current contemporary events. Considering Creswell's theory on selection of an appropriate research method presented in Figure 3-1, this research will employ open-ended interviewing in a narrative design to explore the elements of supply chain management, rather than to empirically "prove" their benefit.

Considering the measurement of the impacts of information-sharing and collaboration on supply chain management and operational readiness may be more elusive. While the amount of influence the supply chain exerts on mission effectiveness can be quantitatively measured by the many metrics and performance indicators used at various points in the Air Force supply chain, the extent to which collaboration and information-sharing impact the mission is not well understood. These ideas are new to the Air Force environment and to date no metrics have been developed to directly measure the degree to which collaboration and information-sharing occur across the Air Force supply chain. To determine exactly which metrics capture this phenomenon most accurately, is beyond the scope of this research. However, decision-making depends on information provided, and the source and accuracy of that information can be related to the level of collaboration involved in acquiring that information. In order to consider how operational performance measures are impacted by collaboration and information-sharing, intimate knowledge and understanding of Air Force supply chain processes in the dynamic context of parts and information flow must be acquired. This involves research in a contemporary environment to evaluate the events and attitudes which impact the information that is shared within and across links of the Air Force supply chain. A case study approach would be the most appropriate research tool to evaluate the nature of collaboration and information-sharing in the Air Force supply chain environment.

General Limitations/Challenges of the Case Study Method

The preceding discussion illustrates different approaches to using the qualitative case study methodology and various characteristics of the research that should be considered when selecting a case study method. It is equally important to understand the challenges and limitations of this methodology and to follow a research design that combats some of those limitations.

One notable challenge to case study research is the element of time. Depending on the type of case study (single, multiple, embedded or holistic) and the nature of the research questions, the case study may require extensive time. In fact, many longitudinal case studies are executed over years, such as Allison and Zelikow's case study of the Cuban missile crisis in order to explore the case thoroughly and in depth (1999; Yin, 2003). To expedite the process for this research, a technique described by Miles and Huberman (1994) as the Pre-structured Case will be adopted. Figure 3-2 illustrates the difference between this approach and the more traditional (and lengthy) method.



Adapted from: Miles and Huberman, 1994.

Figure 3-2: Traditional vs. Pre-Structured Case Study

The pre-structured method is based on the precise set of research questions set forth in Chapter 1 and the case outline for this research can be found in Appendix 3. One of the major weaknesses of this general approach is that conclusions may be drawn too early in the research process but can be combated by triangulating with other data sources and consulting with colleagues (Miles and Huberman, 1994). Open communication and critique by faculty thesis advisor and a triangulated approach to data collection using anecdotal evidence (emails, briefings, etc.) regulations and local policy and interviewing will be used to address this concern.

Validity of qualitative research is often critiqued and challenged due to the nature of sampling and data collection methods (Miles and Huberman, 1994; Voss *et al*., 2002; Yin, 2003). Validity is defined as “the extent to which the instrument measures what it is supposed to measure” by Leedy and Ormrod (2001). However, types of validity are classified differently by various authors. While Leedy and Ormrod identify two types:

internal (extent to which cause-and-effect relationships within the data can be determined) and external (generalizability to other situations). Miles and Huberman (1994) identify three types: internal, external and predictive. Further, Creswell (2003) considers the three "traditional forms" of validity to be content, predictive and construct. Finally, Yin (2003) identifies internal validity as, "establishing a causal relationship…as distinguished from spurious relationships," external validity as generalizability of the research and construct validity as using the right set of measures to objectively collect the data. Figure 3-3 summarizes some techniques and appropriate point of application to address three types of validity identified by Yin: internal, external, and construct, as well as reliability.

Tests	**Case Study Tactic**	**Phase of research in which tactic occurs**
Construct validity	• Use multiple sources of evidence • Establish chain of evidence • Have key informants review draft case study report	Data collection Data collection composition
Internal validity	• Do pattern-matching • Do explanation-building • Address rival explanations • Use logic models	Data analysis Data analysis Data analysis Data analysis
External validity	• Use theory in single-case studies • Use replication logic in multiple-case studies	Research design Research design
Reliability	• Use case study protocol • Develop case study database	Data collection Data collection

Adapted from: Yin, 2003.

Figure 3-3: Reliability and Validity Tactics

Other tactics for addressing validity include triangulation of data sources, prolonged time in the field, and thick and detailed case descriptions (Miles and Huberman, 1994; Leedy and Ormrod, 2001; Creswell, 2003). Overall validity of this research will be addressed in several ways: using a multiple case design, triangulation of data sources, and informant/peer review/validation of the cases. Yin (2003) indicates that internal validity is not a primary concern in exploratory case studies, the multiple case design addresses this concern with some replication logic, but due to the small number of cases being analyzed will not be addressed further.

A third area for concern in case study research is reliability. Yin (2003) describes reliability essentially as “How well can another researcher draw the same conclusions about *the same* case?” Biases often influence research reliability but are unavoidable (from both the researcher and the subject) when using subject data such as interview data from a targeted “sample” as is common in case study research. Numagami (1998) argues that in case study research, reliability/replicability is only necessary if the research intends to identify an “invariant and universal law,” which Popper (1985) attests, cannot be obtained. Although not seeking an “invariant law,” reliability for this research will be strengthened by the case study protocol in Appendix 2.

Research design

The research questions outlined in the previous chapter suggest an illustrative or exploratory research design. A multiple case study approach will be used to attempt to capture some consistent and representative characteristics of the Air Force supply chain and the nature of information-sharing and collaboration across the supply chain. Yin (2003) indicates that to achieve literal replication or prediction of similar results across similar cases, examination of 2-3 cases is suggested, while prediction of contrasting results to introduce theoretical replication, usually requires at least 6-10 cases. In the interest of time and based on the fact that Air Force regulations establish consistencies for many of the operational supply chain procedures, two cases will be evaluated for literal replication to determine similarities and differences in supply chain management of Air Force parts and the information-sharing and collaboration within the supply chain. Pilot studies and site surveys of several different bases and airframes will be used to determine the best choice for this analysis based on similarities and differences, information availability and variety in an attempt to capture a cross-sectional sample of Air Force supply chain anagement.

Sources of data to address the exploratory research questions will include: on-site observation, informal interviews and follow-up structured telephone and e-mail interviews guided by the supply chain questionnaire in Appendix 4, as outlined in the protocol in Appendix 2. When available, documentary evidence such as slide presentations, meeting minutes, talking papers, etc. will also be considered. Archival information such as Air Force and MAJCOM regulations, metrics and item records will be used to validate collected data. Due to limitations of the Human Subjects Research exemption granted for this research, all interview responses and correspondence must remain confidential and will not be included in the report.

Analysis will accomplished through classification and categorization of data based on the Comparative Data Analysis Matrix in Appendix 5. Each case will be evaluated on its application of supply chain management and for elements that do (or do not) illustrate information-sharing and collaboration. Additionally, analysis across the cases will include identification of similarities and differences in Supply chain management, sharing of information and collaboration.

Summary

The five components of research design described by Yin (2003) provide an outline for the case study methodology of the research:

1. a study's questions
2. its propositions (rationale for the study)
3. unit of analysis
4. logic linking the data to the propositions
5. criteria for interpreting the findings

The study questions are outlined in Chapter 1. The research rationale is based upon supply chain management issue and concepts discussed in the literature review. While industry and academia have trudged through various supply chain growing pains over the last 30-40 years and learned of the importance of information-sharing and collaboration, DoD and Air Force progress in improving supply chain management has been slow, nearly non-existent. The unit of analysis to determine what information-sharing and collaboration exist within the Air Force supply chain is the aircraft part. The logic linking the data to the propositions, in other words the data analysis, will be based on identification of themes, commonalities and differences in the data. Finally, since there are only two cases used in the research interpretation of the findings will be based upon the consistencies and differences in information-sharing and collaboration across both cases and their impacts on operational effectiveness.

IV. Data Analysis and Results

Introduction

This chapter presents the information gathered during the data collection phase of this research in narrative form followed by individual case analyses and a cross-case comparison in preparation for answering the research questions. The research questions identified in Chapter 1 will provide the structure for the analysis:

1. *What are the key elements of an Air Force supply chain?*
2. *How is information shared across the Air Force supply chain?*
3. *How is collaboration used to make supply chain decisions?*
4. *What key supply chain metrics are used by the Air Force to evaluate the effectiveness of the supply chain and its impacts on operational readiness?*

Each case analysis contains the following: a detailed description of the case and its supply chain, identification of information-sharing and collaboration are discussed within each case, and a brief discussion of applicable metrics. The first section of each case description will identify the characteristics of the item and its supply chain and present an example of supply chain management, specifically for a situation that presents a supply chain challenge. The second section within each case will provide an analysis of information-sharing and collaboration, identifying how and with whom, information is shared and how decisions are collaborated when addressing this exception and what metrics are considered. Finally, a cross-case comparative analysis will be presented to identify similarities and differences between the two cases with regard to supply chain characteristics, methods of information-sharing and collaboration. It is important to note that this is not intended to be a complete and exhaustive presentation of all facets of Air Force Supply chain management nor all the efforts involved in each of the individual cases, since it would be difficult for all these details to be captured adequately in one thesis effort. Rather this chapter's primary objective is to provide the details necessary to answer the research questions. Finally, although all facts discussed in the cases have been compiled based on the methods previously discussed, the confidentiality of the subjects has been protected, and sources are not cited.

Case # 1: T-38 PTO Shaft

In order to keep up with its demanding mission and the dispersal of troops around the globe, the Air Force trains 1,100 pilots each year (Hebert, 2003). Part of that training requirement must be met in the seat of a T-38 Talon. The Air Force has been trying to overcome pilot shortages since 1997; however, these shortages have more directly impacted operational positions since 9/11 and are expected to result in shortages of over 1,000 pilots by 2008-2009 (Hebert, 2003). The combat pilot training capacity is nearly at its maximum with each bomber/fighter pilot in training required to complete 117.8 hours in the cockpit (Herbert, 2003; "T-38 Talon..," 2006). With such a demanding training mission, this aircraft cannot afford to sit on the ramp because of a lack of parts (whether they are consumables or reparables) often due to miscommunications along the supply chain.

In order to understand the supply chain challenges associated with the management of these parts, the context in which this supply chain operates must be discussed. Aircraft background, general supply chain characteristics (including key players and processes) and specific characteristics and supply chain actions of a single part, the Power Take Off (PTO) shaft, all provide insight into the Air Force supply chain.

T-38 Aircraft Background

The mission of this small jet varies, depending on where it is positioned, but its primary use is in undergraduate pilot training, so Air Education and Training Command (AETC) is considered the lead command for the jet and its components. The lead command has the primary responsibility for sustainment and modernization of the system (Headquarters, Air Education and Training Command, 2002). This jet was inducted into the Air Force inventory between 1961 and 1972, undergoing several modifications to the airframe, engine, and system components over the years to extend its life (Department of the Air Force, 2005e). Several integrated modification programs (Pacer Classic, Avionics Upgrade Program, Propulsion Modification Program) expect to extend the life of the T-38 to the year 2020, reducing maintenance time and improving reliability and performance through structural and component re-engineering ("T-38 Talon," 2006; Headquarters, Air Education and Training, 2002). T-38 supply chain customers include Air Force, Navy and NASA and are located at the following bases: Randolph, Sheppard, Vance, Moody, Laughlin, Edwards, Columbus, Eglin, Whiteman, Holloman, Beale, Paxtuent River (Navy) and Houston (NASA). Foreign Military Sales (FMS) customers also exist around the world including Turkey and Saudi Arabia who require some but not full-time supply support.

T-38 General Supply Chain Characteristics

To support the global customers of this jet, the supply chain must be responsive and flexible. Understanding this supply chain requires knowledge of each link and its role in supply chain management. Key supply chain partners include: the flightline maintenance function (orders needed parts), flightline supply (manages parts at the retail level), the Weapon System Supply Chain Manager (WS SCM; manages supply actions from a fleet-wide perspective), the Item Manager (manages parts at the wholesale level), the System Program Office (SPO) engineers and sustainment managers (responsible for fleet-wide engineering and long-term sustainment of the weapon system), and the manufacturer (produces parts). Figure 4-1 below provides a graphical representation of the interactions between these players, with more detailed descriptions to follow. The figure illustrates a continuous flow of information and materiel characteristic of the supply chain with no discrete beginning or end. Parts may enter and exit at any point throughout, based on a holistic “cradle to grave” philosophy of the entire weapon system lifecycle; meaning it begins with development of the aircraft and ends with its retirement. As this item is considered expendable, the parts flow only from the supplier to the customer, while supply and demand information flows both upstream and downstream.

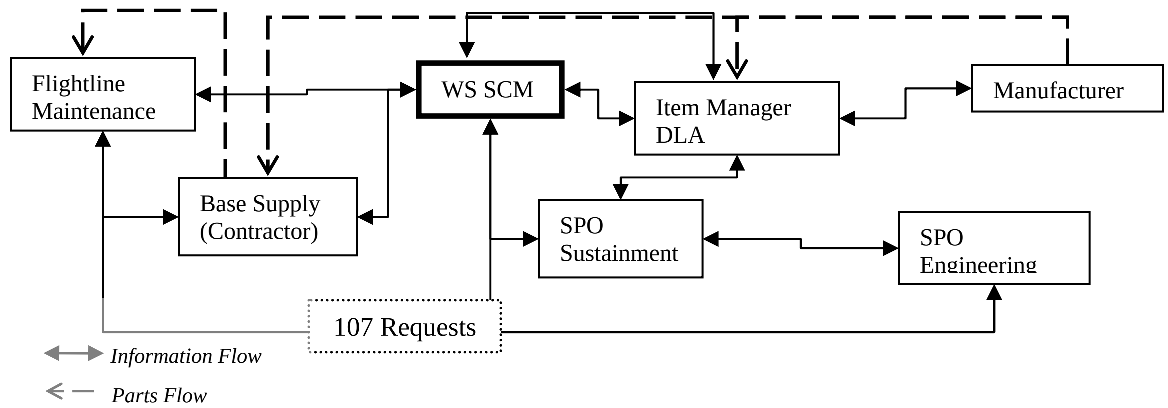


Figure 4-1: T-38 Consumable Supply Chain

The supply chain begins with the customer in flightline maintenance. Flightline maintenance can include: daily "as required" maintenance, "phase" inspections and preventative maintenance (similar to 30,000 mile check-ups on your car) as well as more involved aircraft modifications and updates The T-38 aircraft does not undergo a "depot" or overhaul maintenance operation but the majority of major system modifications and upgrades are performed at Randolph AFB, TX, while all routine and phase maintenance operations are performed based on Technical Order (T.O.) and work card specifications at the using locations. For expendable "throw away" items (not repaired at any level) other maintenance actions and inspections on the aircraft identify a need for a replacement. Flightline maintenance at AETC bases is performed by a mix of Civil Service and Contractor operations as summarized in Table 4-1. While the rest of the supply chain maintenance customers are civil service.

Table 4-1: AETC Base Level Maintenance

Base	Provided by
Columbus	Contractor
Laughlin	Civil Service
Moody	Contractor
Randolph	Civil Service
Sheppard	Contractor
Vance	Contractor

Adapted from: T-38 Roadmap, 2002.

Base level maintenance inputs demands for parts into the Air Force maintenance database (CAMS) which interfaces with the Air Force Standard Base Supply System (SBSS). This request is directly supported by the next link in the supply chain, the base supply function, for any parts requirements. The AETC base supply function is also a mixed operation, depending on the location as identified in Table 4-2.

Table 4-1: AETC Base Level Supply

Base	Provided by
Columbus	Civil Service
Laughlin	Contractor
Moody	Contractor
Randolph	12th Supply Squadron
Sheppard	Contractor
Vance	Contractor

Adapted from: T-38 Roadmap, 2002.

The contractor supply support is referred to as Contractor Operated and Managed Base Supply (COMBS) (Department of the Air Force, 2005f). It is responsible for base-level management of consumable and reparable supply parts in support of T-38 AETC bases according to contractual agreement. The contractor's supply database (if applicable) has visibility into SBSS. SBSS parts requests are monitored by base supply personnel and when demands cannot be supported by base supply, maintenance management and a supply liaison engage to facilitate support. They work through the Lead Command Weapon System Supply Chain Manager (WS SCM) who has daily oversight for parts throughout the command and can facilitate support through lateral-shipment, contact with the Sustainment System Program Office (SPO) and Defense Logistics Agency (DLA) Item Managers.

The T-38 WS SCM provides fleet-wide supply oversight and serves as a "trouble-shooter" to address supply issues before they have negative operational impacts such as a MIssion CAPable (MICAP). A MICAP exists when an aircraft is not available to fly the mission (either partially or fully) because of unavailability of one or more parts. This office uses several information systems to track and research supply chain problems including (but not limited to): several DLA systems, WinMASS for MICAP Parts, AMARC (Aircraft Maintenance and Restoration Center) website, SMART, D035A, D043, Supply Discover, and Asset Visibility System. Of the various systems/tools used by the WS SCM, the most useful and robust is the Supply Discover System which provides internal Air Force-wide visibility of parts posture and allows ad hoc queries. In addition to the automated tools, this office has established lines of communications with item managers, base-level customers and in some cases, suppliers. Demand, maintenance and supply information such as stock levels, forecasted shortages, changes in demand is shared in all internal directions, guided by the WS SCM office.

The SPO is responsible for working long-term aircraft sustainment issues, often involving engineering re-design of parts to extend or improve its life cycle. The SPO includes engineers (mechanical, electrical, systems, etc.), program managers (many of whom have item management background) and acquisition professionals to work these issues. Areas of responsibility include: engineering authority for Air Force managed items, systems engineering responsibility, modifications and upgrades to the aircraft and aircraft systems, management of technical orders, and as-required weapon system parts support for problem items. The SPO works with contracting, procurement, DLA, Item Managers, Equipment Specialists, AETC and field users to resolve supply issues. The SPO may work with DLA to coordinate a Special Program Request (SPR; one that is above and beyond normal programmed requirements) for an additional contract with the manufacturer. Occasionally, the SPO may coordinate support from an additional source of supply such as a local (organic) manufacture or an emergency contract with an approved source if DLA cannot deliver within the required time frame. However, this is an uncommon practice which requires extensive justification by the SPO and operational customers.

Another notable element of the supply chain is the link between the customers and the engineers through the 107 Request for Technical Assistance. The "107 Request" as it is commonly referred to, stems from a maintenance assistance request procedure in accordance with T.O. 00-25-107 whereby un-programmed maintenance, that cannot be accomplished by the unit, is supported by AFMC, usually from the SPO or a field team (Department of the Air Force, 1999). In the context of the T-38, a 107 Request is submitted by the customer, validated by command maintenance supervision and forwarded to the SPO Engineering department for resolution. These requests can be used to resolve immediate supply problems through an engineering or maintenance solution if approved by an engineer.

DLA represents the source of supply within the Air Force Supply Chain and has authority to contract for replacements with its commercial suppliers. DLA manages nearly all consumable items across all weapon systems DoD-wide and has a large supplier base to work with. DLA customer service is essentially organized into two interfaces: the customer relationship management side—as the Weapon System Support Manager who is responsible for support DLA parts provided to the overall weapon system and the supplier relationship management side, with teams organized by supplier (Goodrich, in this case) that manage all the demands placed on the supplier by all weapons systems.

Characteristics of the T-38 PTO Shaft

Considering the general characteristics of the T-38 and its supply chain as described above, deeper insight into the information-sharing and collaboration within the supply chain can be gained from a detailed look at supply chain management of a single part, the PTO shaft. The PTO shaft exemplifies one of those consumable parts which should be managed so as to avoid shortages that negatively impact critical pilot training hours.

The PTO shaft takes power from the engine (spinning at about 7800 RPMs) and uses it to power the gear box which in turn provides power to a generator and a hydraulic system. The PTO shaft, itself is made up of two halves, connected by splines. There are couplings on either end of the PTO shaft (which function similarly to the u-joints on a car) which connect it to the engine or gearbox. This connection is also made by splines, but the connecting joint is designed to "shear" if there is any type of mechanical (motion) failure at either end of the PTO shaft, engine-end or gearbox, generator, hydraulic pump/system, or any other component receiving power from the gearbox. If a failure occurs the quill shaft, which connects to the gearbox, breaks allowing the PTO shaft to continue to spin freely in the gearbox, without providing power to the components until the engine is shut down. The shearing of this connecting shaft prevents the gearbox failure from loading (putting too much torque on) the PTO shaft itself, causing it to break because it isn't designed to handle that much load. If this were to happen, the broken PTO shaft (still connected to the running engine) would be flailing around at 7800 RPMs, potentially causing serious damage to the engine and other components, including hydraulic lines.

Because of its robust design and built-in failure point of the connecting joint, the PTO shaft itself has not been expected to have a high failure rate. As such, each unit is not individually tracked within the supply chain, it has no inspection criteria, and no constantly flowing supply pipeline exists for it. The sporadic flow of the supply pipeline for the T-38 is demonstrated by its procurement history summarized in Figure 4-2. Several small purchases of the PTO shaft were made during the 1970s and 1980s, with two large purchases of 226 and 177. The last purchase was made in 1998 for 8 shafts.

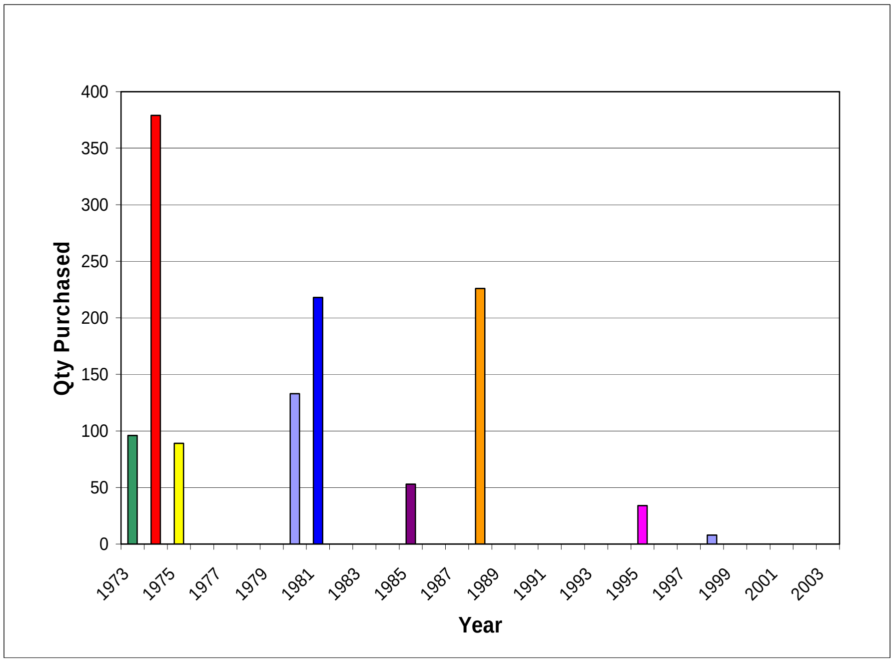


Figure 4-2: T-38 PTO Shaft Procurement History

In addition to the sporadic purchasing characteristics described above, the low failure rate of this item continues to drive low demands. The PTO shaft's recent demand history of only 9 orders for a total quantity ordered of 13 over the last 8 quarters is illustrated by Figure 4-3.

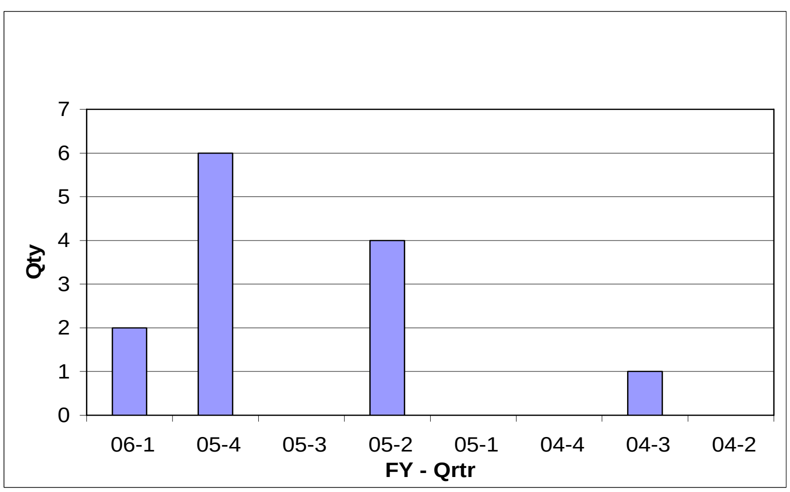


Figure 4-3: T-38 PTO Shaft Quarterly Demand

Sporadic demands and lack of a permanent supply pipeline present tough challenges for management of the PTO shaft. Recently, there has also been increasing wear on these parts due to uneven loading caused by vibrations, possibly attributed to maintenance not strictly adhering to the alignment requirements during installation. This wear is beyond acceptable standards determined by SPO engineering. In summary, this part presents two supply chain circumstances for consideration. First, historically low demands have resulted in the lack of an established supply pipeline, a characteristic common to Air Force parts engineered for reliability. Second, after years of reliable performance, increased wear on the PTO shaft may lead to higher demands, placing stress on an already weak supply chain.

T-38 PTO Shaft Supply Chain Actions

An Integrated Product Team (IPT) was formed at the SPO to address customer and engineering concerns over the unusual wear conditions of the PTO shaft and to formulate a supply strategy to address the situation. Members of the IPT included a program manager, an engineer, a DLA liaison and AETC WS SCM, representing the customer. AETC provided oversight of the IPT and was the ultimate decision-making body for the ensuing operational decisions. All members of the team agreed that the worn PTO shafts would require replacement and that the supply chain wasn't prepared, at the time to handle the demands of a fleet-wide replacement. The IPT collaborated on two decisions. First, they decided which type of replacement of the shaft would be implemented: either a one-time Time Compliance Technical Order (TCTO) change or a recurring inspection process that would become a permanent, periodic maintenance procedure. Secondly, the team worked through the best way to prepare the supply chain for this replacement.

Initial engineering analysis resulted in a recommended “change out” of all PTO shafts on the AETC fleet over a period of approximately 3 years to address the extensive wear on these parts. In addition, engineering recommended a regular inspection of the PTO shaft with detailed measurement criteria be added to the maintenance T.O.s to avoid this wear in the future. The customer wanted to minimize the amount of maintenance hours and supply backorders that would potentially result from this change out. A TCTO would meet engineering’s recommendation with a complete one-time fleet-wide replacement of the PTO shaft, to be completed within a specified time-frame, usually 6-12 months. Adding inspection of the PTO shaft to the 400-hour phase inspection work card (published maintenance and inspection criteria) would require maintenance to inspect the shaft during every 450-hour phase inspection and replace it if its outside the tolerances set by engineering. The TCTO would put an immediate stress on the supply chain but would not establish long-term requirements for a more robust pipeline. Inclusion on the work card would provide the opportunity to inspect the entire fleet over a longer period of time (20 months versus 6-12 months) thus putting a less immediate strain on the supply pipeline. Additionally, the inspection requirement would most likely result in more consistent future demands and better address engineering’s concerns that improper installation was a problem. Ultimately, the decision to implement the work card approach was agreed upon by the customer, engineer, program manager and DLA.

Additional PTO shaft supply chain collaboration by the IPT occurred in determining the supply chain strategy for the replacement shafts. The source of concern was timing the release of the inspection requirements to the field in consideration of the shaft's 254-day cycle time from item request to receipt. There was some risk to delaying the inspection, as a PTO shaft failure during flight would result in loss of power to the auxiliary systems and create an In Flight Emergency (IFE) and mission abort. Given these considerations, the decision was made to delay the inspection requirement for the field until the partial delivery of a new contract of PTO shafts was received. The Program Manager worked with DLA to coordinate a "jump start" of the supply pipeline with a SPR for 582 new PTO shafts to avoid extensive backorders due to the inspections resulting in increased demands as was expected. DLA secured a manufacturing source and awarded a contract to procure PTO shafts for all inventory aircraft, delivering 30 per month to DLA stock. Currently, AETC is delaying final approval and implementation of the inspection, pending first contract delivery from the manufacturer.

T-38 Supply Chain Information-Sharing

As data for this case was collected, several examples of information-sharing within and across the supply chain surfaced. These examples were facilitated by information systems in some instances (but not in all) and ultimately resulted in better informed members of the supply chain working together. However, several supply chain links were not included in some of the information-sharing or information was not shared in both directions.

The many automated information systems used across the supply chain provide tools for sharing supply and demand information. Information on item stock levels, backorders, changes in demand, changes in repair and MICAPs are a few examples of some of the information shared across these systems that aid in supply chain decisions, mainly at the customer level. The CAMS and SBSS systems allow communication of customer demand information to other automated warehousing systems the retail and wholesale item management system (D035) and SMART that can be accessed by other internal (government) members of the supply chain. Information from these systems is also used by other systems (*i.e.* procurement, engineering, etc.) to create new information on item characteristics such as quarterly demand rates, Mean-Time Between Failures (total number of operating hours divided by the total number of failures) and condemnation percentages (how often the item is inspected and deemed unserviceable based on T.O. guidelines.) This information drives item management decisions such as how many items to buy, how often, and when.

These information systems also facilitate asset visibility. For example, the Supply Discover system is automatically fed by SBSS data from all base-level customers and provides the viewer with asset posture by stock number and location. Visibility of demand information is provided to the relevant players in the supply chain by different systems, depending on where the item is managed (at DLA or an Air Force Depot). As for the T-38 PTO shaft, any member of the supply chain with an access account can log on to the DLA WebCATS website (in the process of migrating to the DoD EMALL system) to view current backorders and expected shipments of an item by National Stock Number (NSN). There is also a field for the Item Manager to include updates on the status of the item such as a contract delay or acceleration. As discussed in Chapter 2, many logistics information systems provide asset data and visibility and based on this case many of them are, infact, being used as tools for information-sharing.

In addition to information-sharing through automated information systems, this case illustrates several elements of information-sharing through methods involving human intervention. The connection between automated information systems and human intervention is illustrated by item details annotated by the item manager in DLA's WebCATS. The item manager makes notations in the "comments" section of WebCATS regarding more detailed information such as issues being worked through by the contractor, engineering, or other unique details which may be impact other supply chain decisions. Unfortunately, due to the high volume of items each Item Manager is responsible for, these notes are not always as current as they could be. Often email and phone conversations augment this information-sharing across the supply chain between most members.

The "107 Request" system illustrates an effective use of information-sharing via email within this supply chain. When a part fails beyond the tolerances with in the T.O. flightline maintenance may send an email request to the Command, requesting engineering assistance from the SPO. All supporting documentation is attached, including pictures, T.O. references and supply status of a replacement. The command will approve or disapprove the request from maintenance based on the information provided, and if approved, forward it on to the SPO engineer for final determination. The SPO responds with either an approved unique engineering solution for that particular instance or a disapproval, usually in less than four days. These requests are monitored by engineering and may result in a permanent change in procedures if a consistent problem surfaces. In addition to an occasional supply chain workaround, this system provides another way of sharing information between the customers and other functions within the supply chain.

Information-sharing which led to the PTO shaft problem's initial identification occurred prior to formation of the formal IPT. Members of the supply chain (field users, command WS SCM, SPO) shared objective information such as part failure rates and customer demand increases. They also shared more subjective information such as observations made by maintenance on the condition of the PTO shafts and the theories of the engineers that incorrect installation of the shafts may be causing some of the failures. This became an iterative trouble-shooting exercise accomplished through constant sharing of information and resulted in the creation of the IPT.

The IPT meetings themselves provided a forum for centralizing information across the supply chain so that all participants were provided the same information for decision-making. DLA played an integral role in sharing the most current information regarding contract status and lead time with the rest of the supply chain which was critical to the decision of when to implement the new inspection criteria. In fact, recent information that the contractor has requested a time extension and delivery will be delayed has been shared, and the IPT agreed to delay implementation of the inspection to allow the supply chain more time to improve its posture for the PTO shaft replacements.

This case also presented some weaknesses in information-sharing. While government members of the supply chain had reasonably easy access to customer demand information and topics discussed by the IPT, the actual supplier was left out of the information loop. The supplier is not privy to customer demand information and must rely on communications through DLA (as a second- or third- intermediary). Additionally, the contractor provides a delivery schedule as part of its contract, but this may or may not match its actual production schedule. There is no automated visibility of assets beyond DLA’s database which indicates expected deliveries and backorders based on an individual unit's order. On the customer end of the supply chain there is also some weaknesses when dealing with the COMBS operation. Research revealed that visibility of the COMBS inventory is not available to the rest of the supply chain, although COMBS has visibility into Air Force systems. COMBS backorders and shortages are dealt with from a much more "hands off" approach, with the belief that if they can't support a supply request, they lose money, so it shouldn't happen often (or they'll go out of business).

T-38 Supply Chain Collaboration

The sharing of information across the supply chain helps ensure members of the supply chain have accurate information with which to make decisions. Ideally, collaboration involves everyone sharing in the decision-making process. Collaboration as described by Anthony (2000) involves "share[ing] the responsibility of exchanging common planning, management, execution, and performance measurement information." This case illustrates the use of collaboration to make supply chain decisions about the T-38 PTO shaft that would ultimately impact the overall supply chain as well as the operational effectiveness of the T-38 fleet. The formation of an IPT is becoming a common tool for addressing Air Force parts problems whether the problem is caused by operations, engineering, supply, and/or maintenance issues. Without an effective problem-solving and collaborative approach by this cross-functional team, the engineering decision to implement tighter inspection criteria for the PTO shaft may have placed a huge strain on the its supply chain, ultimately impacting the T-38's training mission. The participation of decision-makers from major internal links in the supply chain (engineering, DLA, program management, AETC), allows for a free-flowing information exchange and ultimate collaborative decision-making. This extends to the far ends of the supply chain (field users and DLA's supplier) so they may also make better-informed decisions. In an interview, a DLA liaison actually described the relationship fostered by this IPT as "a definite partnership" one that involved a constant sharing of information and coordination of supply chain decisions.

Collaboration efforts are also evident in the various periodic review meetings. At the base and command level, maintenance and supply representatives conduct weekly meetings to address daily challenges, sometimes involving engineering and item management if the problem is viewed as more than a unique occurrence. The WS SCM collects information from the operational units regarding issues of concern (parts shortages, unexpected increases in parts failures, excessive backorders, etc.) to ensure the best representation of the facts is considered when a decision by maintenance is made (as they have the ultimate responsibility for making a change to maintenance and operational schedules). Additionally, bi-annual reviews are conducted by the SPO to provide updates on current supply and engineering initiatives to all interested T-38 customers including NASA, Navy and FMS representatives. Overall health of the fleet is addressed with agreed-upon metrics including MICAP rates and top drivers impacting those rates in a general forum. Smaller, "break out" sessions are also held to discuss details of specific items/topics of concern, as in the case of the PTO shaft. Often suppliers are also invited for the informative portion of the meetings.

However, the "break out sessions" where decision-making often happens for future sustainment efforts (such as an engine modification, upgrade to the ejection seat, or brake replacement) does not include supplier or contractor involvement. This is most likely due to the sensitivity of the information that may be shared, and the risk of violating Federal Acquisition Regulations by providing an unfair advantage to a visiting supplier on a future acquisition. Again, the supplier is eliminated from the management of the supply chain in this way, thus limiting the extent to which collaboration happens outside the internal supply chain. Additionally, the involvement of the flightline maintenance customer is non-existent in these meetings. The customer is essentially represented by Command-Level maintenance supervision who makes decisions “in the best interest” of the overall fleet. Actions that result from these meetings filter down to the customer level on a “need to know” basis, but they have little direct involvement in collaboration efforts.

T-38 Metrics

The monitoring of metrics for this weapon system occurs at each point in the supply chain. Because of the permanent “training” mission of the T-38, it is not authorized to classify parts shortages as high priority MICAPs (albeit a lower priority, a MICAP situation may still exist). When in a shortage situation over a part used on another weapon system, most often, the other weapon system will have a higher priority, and the T-38 usually “loses.” To avoid the situation, the field’s management goal is to minimize the backorders and MICAPs as much as possible through supply chain and maintenance actions and monitoring. Other metrics such as backorders, Mean Time Between parts Failures (MTBF) and Awaiting Parts (AWP) (usually status for intermediate “backshop” maintenance of components that are being repaired for stock) are closely tracked to help forecast supply chain problems. The same metrics are followed by the SPO and when the field catches an anomaly, it wastes little time in seeking an explanation or resolution to the problem. For example, parts physically related to the PTO shaft (connected to, driven by, etc.) were experiencing higher-than-normal backorders and failures which contributed to determination of a problem with the PTO shaft and consideration for replacement.

MICAP metrics are followed closely, when they occur, by all members of the supply chain, from the flightline to DLA. However, in the case of the PTO shaft, there were no instances of MICAPs for this part, either before or after the decision to include it in the work card inspections.

Case # 2: F-15 PTO Shaft

Annually, approximately 1100 Air Force officers are inducted into the “rated” status of pilot, commanding either fighter/bomber aircraft or cargo/air refueling “heavies.” Only one-third of these pilots earn the opportunity to fly fighter jets, engaging in “attack” missions such as air-to-air, air-to-ground and close-air support. Once fully trained in the T-38 Talon in both Undergraduate Pilot Training and Introduction to Fighter Fundamentals, approximately 330 pilots each year enter the operational Air Force to fly fighter jets such as the F-15, F-16, F-117 and F/A-22 (Hebert, 2003; Headquarters, Air Education and Training Command, 2002). Global events, Air Force downsizing, and roles and responsibilities of the U.S. as a democratic superpower has spread our forces as well as our equipment thinner than ever before. This increases demands and stresses the capabilities of our supply chains. Efficient and effective supply chains to support the dynamic missions of fighter jets like the F-15 are critical to mission success and national security. Unavailability of parts due to ineffective supply chain management translates into diminished operational effectiveness and in a hostile environment, may turn these F-15s into “sitting ducks” for enemy attack. The PTO shaft for the F-15 is a mission critical part whose unavailability of a replacement may ground the aircraft and impact the aircraft’s ability to complete the mission.

F-15 Aircraft Background

The first F-15 entered operational service in 1976 as an air-to-air fighter jet at Langley AFB, VA, and has transitioned through several functional model changes since then from the original A and B models to the improved single-seat C and two-seat D models by 1979 (Department of the Air Force, 2005c; “F-15 Eagle Design,” 2005). The dual-role (air-to-air and air-to-ground) F-15E model entered the Air Force inventory in 1988. The F-15 is noted for its high engine thrust-to-weight ratio and low-wing loading (ratio of aircraft weight to its wing area), allowing superior acceleration and maneuverability (Department of the Air Force, 2005c; 2005d). All models use two Pratt & Whitney F100-PW-100, 220 or 229 turbofan engines with afterburners (Department of the Air Force, 2005c; 2005d; “F-15 Eagle Specification,” 2005). Varied design characteristics allow the jet to perform either air-to-air missions as the A/B and C/D models or air-to-ground missions as the E models (“F-15 Eagle Specifications,” 2005). Although the F-15E is still in production, several upgrades and modifications have been made to the existing fleet to extend its life and improve capabilities, the most recent being a radar upgrade program in 2000 (Ciborski, 2002). The F-15 A/B models are expected to fly to 2009, the C/D models to 2025 and the E models to 2035 and beyond.

The mission of the F-15 Eagle (A/B/C/D) is that of air superiority: “to clear the skies of enemy aircraft whenever needed” while that of the F-15E Strike Eagle is “to put bombs on target" (Warner Robins Air Logisitcs Center, 2005b). Currently, the F-15 models flown by both Active Air Force and Air National Guard units including A, B, C, D and E, are permanently stationed at twenty locations around the world in addition to the many deployed locations (Warner Robins Air Logistics Center, 2005a). The total managed inventory currently includes 226 F-15E, 275 F-15 A/B and 410 F-15C/D model aircraft ("F-15 Eagle Specifications," 2005). International F-15 customers include Israel and Saudi Arabia through the Foreign Military Sales program, Japan with its own production contract, and the Republic of Korea is currently contracting with Boeing for a "K" version of the jet ("F-15 Eagle Foreign Military Sales," 2005).

F-15 General Supply Chain Characteristics

The F-15 supply chain stretches around the globe, with the "ultimate" maintenance customer operating at CONtinental United States (CONUS) and Outside CONtinental United States (OCONUS) bases, deployed locations and the depot maintenance facility at Warner-Robins Air Logistic Center. The global characteristic of F-15 customers and the multiple aircraft models introduces a high level of complexity into the supply chain and requires it to be robust and flexible to ensure effective support. Although a complete discussion of all supply chain players and impacts is beyond the scope of this research effort (for detailed descriptions see Lee, 2004) key supply chain partners and processes will be identified. For the purpose of this case study, key supply chain partners include: flightline and depot maintenance (order required parts), flightline supply (retail management), Maintenance Supply Liaison (MSL; functions as an information "belly button" at the base level), Air Combat Command Regional Supply Squadron (ACCRSS; monitors command-wide supply issues), Eagle Control (responsible for fleet-wide support), Sources of Repair (include organic/depot and contractor), depot F-15 Programmed Depot Maintenance (PDM), Item Management, Secondary Power Systems (management [engineering, program management, equipment specialist] of all power systems components), Lead Command Weapon System Manager (WSM) and DLA. Figure 4-4 illustrates the complex nature of the supply chain players through its representation of supply chain parts and information exchanges, with more detailed discussion to follow. This figure captures the supply chain of a reparable part, so both information and parts flow multi-directional.

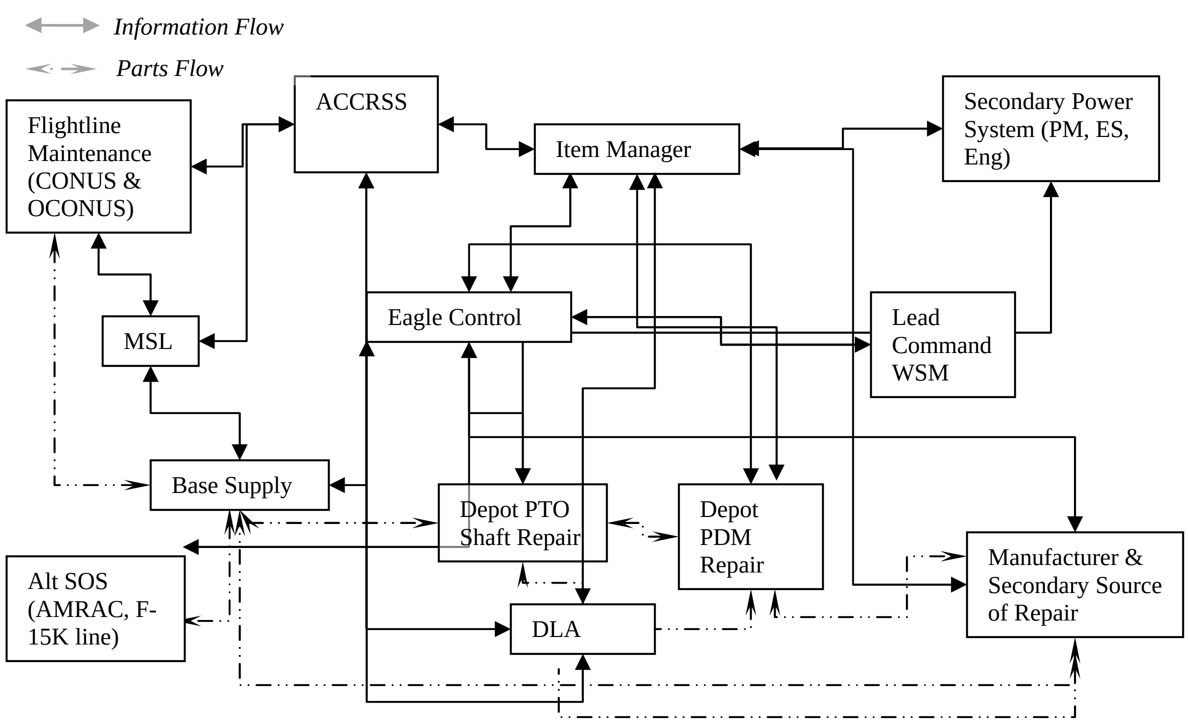


Figure 4-4: F-15 Reparable Supply Chain

The supply chain begins with the customer in flightline maintenance units who perform all daily “as required” maintenance actions including phase inspections (every 200 hours) based on the T.O. Major preventative and overhaul maintenance is done by depot maintenance, another supply chain customer. Additionally, major modifications are performed at both the Depot and a contractor's facility. The deployment operations of the jet also put an additional requirement on the supply chain, introducing added transportation requirements and often reduced visibility and communication. The supply chain must support these various customers: field maintenance at 20+ permanent locations, depot maintenance at the component and aircraft levels, and maintenance at any number of transitory deployed locations as well as the possibility of surge requirements in support of additional war efforts.

Operational F-15 maintenance enters supply requests into the CAMS system, which communicates that request to the SBSS system. In normal operations, the part can be pulled from the shelf; if not available, a backorder for the part is established and other supply chain activities become more involved. If the mission status of the aircraft is affected by the part *i.e.:* NMCS (Not Mission Capable Supply), NMCB (Not Mission Capable Both [supply and maintenance]), the backorder for that part may be upgraded to MICAP (mission capable) status. MICAPs are also coded with additional priorities, depending on other factors such as the unit's mission, type of aircraft, deployment status, etc. MICAPs usually receive "special" attention of members throughout the supply chain, especially when an aircraft begins to accumulate MICAP hours (hours when it is out of service due to that part). In addition to the standard supply and maintenance information systems used for standard ordering and backorders (SBSS, CAMS, D035, etc.), the WinMASS system is solely devoted to identifying and tracking MICAP parts.

The Maintenance Supply Liaison (MSL) coordinates support issues between maintenance and supply at the base, the Regional Supply Squadron (RSS), and sometimes (unofficially) through item managers. Air Force regulation establishes the

RSS as command focal point for supply and transportation. For analysis of the effectiveness of this organization see Hardrath, 2005. The RSS, responsibilities identified by Air Force regulations are as follows:

> 1.5.2.1. General supply responsibilities include: MICAP management; stock control; stock fund management; information systems management, to include records maintenance; equipment management; *operational* assessment and analysis; reachback support procedures; and, in AMC, forward Supply System management.
>
> 1.5.2.2. General transportation responsibilities include: shipment tracing & tracking; transportation source selection; traffic management research; movement arrangements; shipment expediting; customs pre-clearance, clearance, and release; channel requirements/assessment analysis; and interface with the Air Clearance Authority and AMC aerial ports. The RSS also provides special handling guidance for hazardous, sensitive, or classified shipments, and shipping guidance for destinations within their assigned area of responsibility (Department of the Air Force, 2006).

When the RSS and its co-located DLA representative have exhausted all efforts to satisfy and manage MICAP requests through lateral support from other F-15 bases, the SPO and engineers or item managers, they contact the Eagle Control Office. This office is designated to work priority concerns and MICAPs through the manufacturer and/or additional supply channels that are not visible to the RSS and item managers such as the Aircraft Maintenance and Reutilization Center website (AMARC, or more commonly known as “The Bone Yard”), the Boeing Production line for Korea’s F-15K, parts owned by Depot Maintenance (where Depot maintenance is considered the end-user, and the parts are already “purchased”) and bench stock storage.   If Eagle Control has exhausted its resources and multiple customer MICAPs are competing for limited parts (with no good solution available) it provides all applicable data to the Lead Command Weapon System Supply Chain Manager, the WS SCM (in this case Air Combat Command [ACC] at Langley) for resolution, identifying the item as a Fleet Distributed Item (FDI). The lead WS SCM, makes a determination on the priority of MICAPs to be filled that is in the best interest of the overall fleet and mission based a multitude of information, including (but not limited to): supply chain inputs provided by Eagle Control and RSS, impacts of the MICAPs on the affected units' missions, fleet health and availability and other sensitive operational or mission data.

The SPO is responsible for overall management of the weapon system. In 1991, when Air Force Systems Command combined with Air Force Logistics Command to form the current Air Force Materiel Command, the F-15 provided the test bed for the Integrated Weapon System Management (IWSM) ("F-15 Eagle Management," 2005) Although SPO "North" at Wright-Patterson retains overall responsibility for new capability acquisitions and SPO "South" at Warner-Robins manages sustainment support and modifications, the two have joined forces with decision-making tools that include functional involvement from both locations through Integrated Product Teams (IPTs) and Process Management Teams (PMTs) ("F-15 Eagle Management," 2005). These teams include representatives from engineering, program management, Lead Command (in this case ACC), procurement, and DLA/Air Force Item Managers.

For F-15 reparable items, the source of supply may be the depot repair facility, a contractor repair facility, DLA or a commercial supplier providing new parts. Most reparable items, however, are managed by Air Force Item Managers rather than DLA.

Characteristics of the F-15 PTO Shaft

The F-15 PTO shaft serves the same function as the T-38 PTO shaft, providing power to secondary aircraft systems. In the case of the more complex F-15, the PTO shaft transfers power from the engine to the Airframe Mounted Accessory Drive (AMAD), which in turn powers other aircraft systems. The F-15 PTO shaft is considered a reparable part, with its primary source of repair at Ogden Air Logistics Center (ALC.) As a sub-component of the secondary power systems, management of this item draws the attention of engineers, program managers, production managers, item managers and equipment specialists from several areas including secondary power systems, flight systems and engines. This research will focus only on the PTO shaft supply chain as previously summarized by Figure 4-4.

Information and parts each flow both upstream and downstream along the supply chain, while information also flows across to other supply chains such as those for bits and piece parts used at depot repair and the secondary power system. The flow of parts is relatively simple compared to that of information. It must be noted that this depiction does not include the possibility of cannibalization of the part, meaning removing a broken PTO shaft from one jet and replacing it with a functioning shaft from another jet. Maintenance supervision has made decisions to cannibalize PTO shafts from aircraft down for other parts/maintenance in order to keep operational aircraft available, however, based on low cannibalization rate targets and man-hours involved in taking out the engines of both aircraft, removing this part from one aircraft, reinstalling it on another and pre-flight inspections, this decision is not made lightly, or often.

The supply pipeline of the PTO shaft has been well-established due to relatively constant demands. Until the last few years, customer demands have remained steady at approximately 30 per month. Because this is a relatively high-usage item, MICAPs are not unusual and are tracked within various information systems by most members of the supply chain. The PTO shaft gains management attention when the number of hours a plane is grounded due to MICAP parts changes significantly as illustrated in Figure 4-5 in Oct 2004. Another indication of a supply chain problem is that of a smaller number of incidents resulting in a high number of hours, as illustrated during the Dec 04 through Jun 05 time frame. This indicates a longer cycle time.

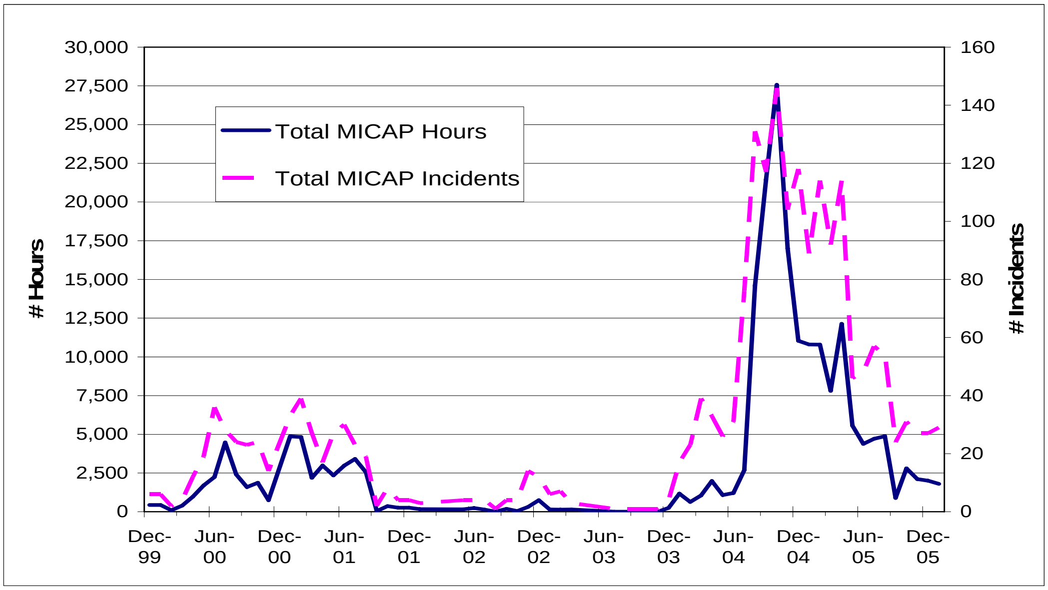


Figure 4-5: F-15 PTO Shaft MICAP Summary

F-15 PTO Shaft Supply Chain Actions

Spikes in demand and increased MICAPs within the last few years have been caused by reliability issues related to unusual wearing of PTO shaft splines. Air Force and Pratt and Whitney engineers analyzed engine vibrations and gearbox failures which began in the late 1990s, and determined the PTO shaft to be a major contributor to the problem. Inspection of a sample of the shafts revealed extensive wearing of the spines. A team of engineers from the SPO, the Engine repair shop, Boeing, Pratt & Whitney and Ogden, program managers and command representatives (Eagle Control) established an

IPT to address the PTO deficiencies and vibration concerns. It appeared that the focus and membership of this team may have shifted throughout the process. Initial engineering focus guided the IPT toward high regard for the technical analysis coupled with the high cost to repair the engines damaged by this problem ($800K) and may have resulted in the decision to implement a 200-hr phase inspection of the PTO shaft in October 2003, as a first step to mitigating the problem. Other IPT members were aware of the decision, and were aware of the likelihood of increased demands of the shafts due to inspection failure. However, because of the perceived risk to the aircraft and engine, the supply chain was not allowed time to prepare and plan for the impending shortages. However it was a concern of all players involved. Depot maintenance for the PTO shaft indicated that the increased demands would be supportable with an increase in production and added support contracts.

Although an increase in demands was expected, the monthly demand rate (MDR) nearly doubled, increasing from 38 to 64 and the depot was unable to keep up with demands. Result: the PTO shaft became a top MICAP driver within six months. The stresses on the supply chain created by this new inspection is expressed by the significant increase in the ratio of unserviceable to serviceable assets as illustrated by Figure 4-6.

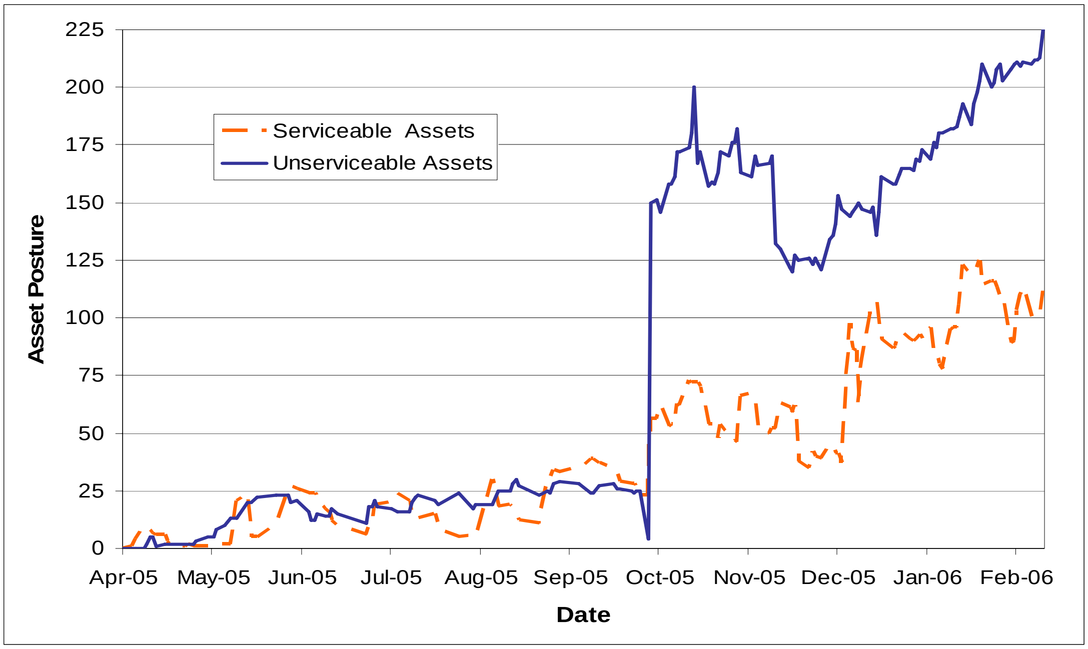


Figure 4-6: F-15 PTO Shaft Serviceable vs Unserviceable Parts

The inability of the supply chain to meet the increased demands was caused by several factors. First, the depot maintenance initial repair capacity for the PTO shaft was stressed. Although the depot was informed of the anticipated increase in demands and had additional contracts in place to deliver within a year to augment their own repair capability, the above graph indicates that this was simply not enough. Second, the capacity constraint was complicated by a shortage of a "bits and piece" part from DLA needed to repair the shaft—an already "troublesome" coupling. This shortage imposed additional constraints on the depot to complete repairs. Finally, the unusual wear problems identified initially by the flightline also impacted the depot repair line. Rather than repairing some of the parts being shipped in from operational bases, an increasing number of parts were damaged beyond acceptable engineering limits and had to be condemned (disposed of). This action removed assets from the supply pipeline, putting an even greater strain on the overall supply chain.

To counter the increasing MICAP hours and decreasing pipeline assets the IPT developed several solutions. First, a supplemental repair contract was established with Goodrich to reduce backorders, but DLA was having trouble keeping up with support of the constraining coupling. However, by spring of 2005, DLA was providing 30 couplings per month to the organic repair shop at Ogden, as a result of accelerating the contract and Ogden was producing 45 low-speed shafts per month. Second, a "revised" high-speed balanced shaft, expected to reduce some risk to the engine was procured through the original manufacturer (again Goodrich) as a modification to a current contract. The high-speed balanced shafts would be re-coded as consumable items with a new stock number and the long-term plan was to acquire the test equipment to high-speed balance the shafts at the Depot (which is still currently unfunded). This was an interim "fix" to address both the supply chain shortages and reduce the some of the excess vibrations of the "low speed" balanced shaft. Goodrich ordered the long-lead time materials prior to official contract award to reduce some of the delay and minimize interruptions in support. Additionally, to ensure all possible pipeline assets were retained, units were instructed not to condemn any at the base level, but to send all shafts which did not pass inspection directly to depot repair for disposition and/or repair.

The coding of the new (high-speed balanced) shaft, National Stock Number (NSN) identification assignment and linking the two in the supply information systems also created problems for the supply chain. A change in the ERRC (Expendability, Recoverability, Reparability, Category) code from reparable to consumable and two unique NSNs caused supply chain visibility problems and unit funding issues. Without a way to link the two stock numbers in the system, the item manager could not maintain direct oversight of both. From the field user's perspective, they were losing money since a reparable normally has a monetary "turn-in" value that gives the customer credit towards the repaired asset but there is no credit for turning in consumable items.

Finally, a long-term solution to mitigate the original problem of excessive vibration and possible damage to the engine was determined. The IPT decided to seek a contract for complete re-design of the PTO shaft. A solicitation for this re-design went out in Jan 2005, a contract was awarded in April 2005 (again to Goodrich) and delivery is expected 2008.

Interestingly, users at the field level were under the impression that the large increase in MICAPs was due to delayed batch shipments of the PTO shafts (perhaps misunderstood for the couplings) from the contractor to DLA. Base-level maintenance and supply indicated that the breakdown in communication stemmed from the contractor continuing to batch ship the replacement shafts, despite its creation of multiple aircraft in MICAP status. This idea, however, was not identified as a problem by other links in the supply chain.

F-15 Supply Chain Information-Sharing

As data for this case was collected and explored, instances of consistent information-sharing within and across the supply chain were revealed. Although the sharing of information occurred in both automated and non-automated forms, in this case, information-sharing not directly facilitated by automated information systems appeared to be the preferred approach.

Automated information-sharing was accomplished through the collection of data within various centralized information systems. The SMART (System Management

Analysis Reporting Tool) system provided a snapshot and narrative description of the item's current supply information including: production rates, Mean Time Between Demands, sources of supply, sources of repair, backorders, MICAPs, assets in repair, and a narrative account of current progress by the item manager or program manager, when applicable. SMART is accessible by all government users with a username and password. DLA's systems (WebCATS and EMALL) provide visibility of the "bits and piece" parts and status of orders for DLA-managed parts, WinMASS for MICAPs, GTN for transportation, JTAV for asset visibility, and PC LINK (logistics information system) for analysis of DoD-wide assets. Consistent with all operational Air Force maintenance and supply procedures, CAMS and SBSS feed into these various systems to ensure near-real time data is available to members of the government supply chain. The base maintenance data system (CAMS) served as the tool for communicating the initial problems with engine vibrations as seen at the field level to the engineering and program management community.

This information shared through automated information systems was augmented by human intervention between field maintenance, Command-level maintenance management, program management and engineering over the vibration problems. This sharing of information across disciplines (maintenance, engineering, etc.) through CAMS inputs and maintenance assessment of the problem facilitated identification of the PTO shaft as the cause before major damage to the engines occurred. Information provided by the field was important when determining the best approach to evaluating the extent of the damaged shafts.

Information-sharing through human intervention was also critical to managing the shortages created by the new inspection criteria. Regular meetings, email, phone conversations and information systems were used extensively (almost on a daily basis, if needed) to help facilitate communication across the various key players and ensure the availability of accurate information for decision-making. At the depot maintenance level, the quarterly requirements review discussed the future status of the repair line, highlighting any shortcomings or changes to the expected repair schedule. Eagle Control, depot production and item managers, engineers and customers attended this meeting. At the field and program level, daily attention was given to monitoring metrics and discussing supply and maintenance actions that may require intervention from other levels of the supply chain such as SPO engineering or item management.

Both engineering and the Command agreed that the risks of engine damage were too high to delay implementation of the inspection. Once the decision to include the PTO shaft in the 200-hr phase inspections was made, information-sharing became a constant process across the supply chain from customer to supplier to minimize the impacts of this decision on the supply chain. Increases in demands caused by inspection failures were communicated upstream to item and program management to gauge necessary support increases and provide justification for additional contracts. The item manager provided updates in the SMART system, indicating status of the contract deliveries and changes in lead time of the parts and status of backorders. Information on demand increases and part failures was shared with both the organic source of repair and the contractor source of repair. The contractor also shared information regarding production and materiel delays downstream.

F-15 Supply Chain Collaboration

This case presents reactionary supply chain management approach in which collaboration and information-sharing may have been key to reducing negative impacts when planning ahead was not considered a viable option. Collaboration in this case started with the identification of the engine vibrations. Engineering representation from the Boeing, Pratt and Whitney, and the SPO as well as maintenance and program management facilitated the sharing of resources and expertise to fully troubleshoot the problem and identify possible causes from multiple viewpoints, from the manufacturer to the customer. This allowed for thorough evaluation of the problem and more informed decision-makers who partnered together to make the decisions. However, this appeared to be a primarily engineering-based decision.

The discovery of the PTO shaft as a maintenance concern and ultimately labeling it as a substandard flight safety critical item, caused a definite ripple effect throughout the supply chain which was minimized by collaboration through IPT meetings. The meetings facilitated a corporate knowledge environment that allowed risks and rewards of options to surface and a unified decision to be made that resulted in development of a "joint business plan" to combat the parts shortages. A more thorough analysis of the supply chain options due to contributions from multiple functional areas (maintenance, depot repair, engineering, etc.) again, allowed for more informed decision-making. When considering the inspection method, the customer identified possible impacts to operations including increased man-hours, lost aircraft flying hours and procedural concerns. Depot contributions included impacts to the production schedule, other production lines that could have been impacted and new requirements such as the new test equipment. Engineering representation allowed other members of the supply chain understand the technical concerns and implications of the options of replacement versus repair. The supplier participation from Goodrich (although somewhat limited and not directly involved in actual decision-making) brought additional insight into options for increasing pipeline assets.

This collaboration was facilitated by the information-sharing strategies identified above, often in an IPT setting. As changes in the status of the information (parts shortages, increased depot condemnations, etc.) occurred, the team worked to address those changes. Figure 4-7 illustrates some the dynamic attributes the team had to take into consideration and work through when attempting to minimize the impacts of the inspection on the supply chain.

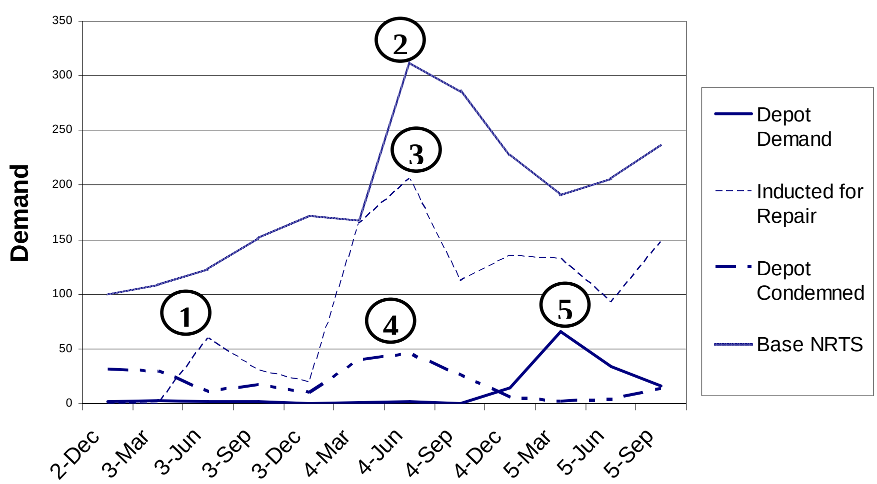


Figure 4-7: Dynamic Changes in F-15 Shaft Supply/Demand

The slight peak at (1) represents the depot's initial attempt to "ramp up" for the anticipated demand increase created by the inspection. The sharp increase in Base NRTS at (2) indicates the impacts of the new inspection criteria on the base-level customer. The corresponding increase in parts inducted for repair (3) at the depot happened slightly earlier. This coincides with the team's decision to increase repair capability at the approximately the same time that the inspections were introduced, as an attempt to alleviate some supply shortages. Had the team not collaborated on these decisions, the Bullwhip effect would be indicated by a lag in the depot repair and the field users would have been waiting for assets for a longer period of time, while MICAP hours continued to build. The small spike at (4) reflects the increased condemnations at the depot repair line. Finally, the peak at (5) represents the impacts of the condemned parts on the depot PDM line.

The IPT continually shared information and collaborated on decisions as new information become available. In fact, collaboration with the supplier for1500 newly designed PTO shafts to be delivered in 2008 resulted in Goodrich pre-ordering long-lead time materials for the new shafts prior to actual contract award. This reduced some of the lead time to minimize interruptions in support. The information-sharing and collaborative efforts of this supply chain resulted in a nearly complete recovery from the increasing MICAPs as illustrated in the previous MICAP summary in Figure 4-5, and aircraft are no longer grounded because of the PTO shaft. The supply chain is still working to reduce priority and routine backorders to fill some empty shelves with an expected "get well" date of July 2007.

F-15 Metrics

The metrics evaluated for the F-15 differ depending on the perspective (link in the supply chain.) On the user end of the supply chain, base maintenance and supply monitor the number of MICAPS, aircraft that are down for maintenance actions and those that are

Awaiting Parts (AWP) without a “MICAP” code associated with them (usually means there is something other than that part driving its mission status such as a maintenance action). At the base level, the most scrutinized metrics appear to be: the number of MICAPs, the amount of time (hours) the MICAP is active, and any patterns in the specific parts that are MICAP (called drivers). At the RSS and Eagle Control level, MICAPS and backorder status (amount, number of days and drivers) are followed and monitored for trends across the command. The SPO tends to look at Mean Time Between Demands and Failures, maintenance cause codes (reasons why maintenance had to repair the part) and other data that may indicate a chronic part or systemic problem. The WS SCM focuses on overall Aircraft Availability across the fleet and high MICAP drivers that could impact the F-15 mission.

On the item management side of the supply chain, the item manager is also following MICAPs, as well as demand patterns to forecast future buys. The depot source of repair looks at internal metrics such as production lead time and customer wait time, as well as the increasing or decreasing number of field MICAPs, in order to determine the depot impact on the supply chain. Overall, the number of MICAPs/MICAP hours and the top drivers appear to be the most common metric tracked throughout the supply chain. In the case of the PTO shaft, MICAPs were affected by the decision to implement the inspection without first robusting the supply chain (see Figure 4-5.)

Cross-Case Analysis

Analysis of the data is guided by the research questions and the matrix in Appendix 5. By identifying the similarities and differences across both cases, some conclusions can be drawn to address the investigative questions and the initial research question. The cases will be compared based on the following areas as they may impact overall supply chain management: general characteristics of the aircraft and part, characteristics of the units of measurement (for this research, the supply chain of the PTO shaft), elements of information-sharing, and elements of collaboration.

General Characteristics of the Aircraft & Part

In analyzing the degrees of information-sharing and collaboration in the two cases presented here, it is important to identify the similarities and differences in the supply chain environment. The characteristics of the aircraft, the aircraft part and its supply chain each impact the supply chain management for the part and ultimately the elements of information-sharing and collaboration. There are several similarities in this area between the two cases, which may allow for some generalizability of the results. However, there are also some notable differences which may impact the conclusions.

Similarities exist in the aircraft as well as in the aircraft parts of interest. First, both aircraft are small, maneuverable jets with two engines designed to pull high-g maneuvers. Both parts have multiple users, including FMS customers. The part of interest in the case study is functionally the same, a PTO shaft (although not identical) both manufactured by Goodrich. The PTO shaft in both cases is part of the mechanical and propulsion systems of the aircraft. Both aircraft are maintained at base-level and have base-level supply support available. Finally, the PTO shaft is an item of concern for both supply chains, suffering from excessive wear, causing vibration problems for both airframes.

These two aircraft do have some significant differences in design and mission.

The T-38 was initially designed and built nearly 50 years ago. Although it has undergone several modernization efforts to provide a realistic training environment for pilots, the technology of the F-15 is far superior with its state-of-the art technology and continuous upgrades. As such, the F-15 is also a much more complex system with its dual-role capabilities designed for high maneuverability. The T-38 was designed by Northrop Grumman Corp. while the Original Equipment Manufacturer (OEM) for the F-15 is McDonnell-Douglas (Department of the Air Force; 2005c; 2005d; 2005e). The engine OEM for the T-38 is General Electric, while Pratt & Whitney produces the F-15 engine. Finally, the unit cost for the F-15 is nearly ten times that of the T-38; while the F-15 was built with air superiority in mind, the T-38 promised to be a sound trainer that was relatively inexpensive and easy to maintain. As such, many of the “throw away” components of the T-38 are designed to be cheaper to replace than maintain but the same parts may be more robust and considered reparables on other weapon systems.

While all T-38 customers are CONUS (excluding FMS), the F-15 is stationed across the globe in both deployed and non-deployed units. The deployment element of the F-15 mission imposes unpredictable wear on its components caused by harsh environmental conditions and increased usage, while the training mission of the T-38 imposes consistent wear on the aircraft and components. Reliability concerns due to the environment may be less of an issue for the T-38 than the F-15 which operates in a variable environment that can have unpredictable impacts on its system components. However, the impacts of age on the aircraft may be a tougher challenge for T-38 system management. Finally, because the F-15 is still in production, the concern for diminishing sources for replacement parts is not as pressing as for the aging T-38.

A final area of notable difference in the two aircraft is the supply and maintenance environments of each. The COMBS base supply operation at several T-38 locations introduces a lack of visibility into its supply chain, an element not present in the F-15 whose supply support is predominantly run by military "green suiters." Also, the maintenance for the two jets differs in that the F-15 undergoes Programmed Depot Maintenance (PDM) at Warner-Robins ALC, while all T-38 maintenance operations are performed locally (or at Randolph for one-time major upgrades.) PDM is a scheduled maintenance overhaul that all F-15s go through throughout their life cycles. The PDM line introduces customer that is not present in the T-38 supply chain.

Although the item used for each case is the same, some of its characteristics differ. The most notable difference is that the T-38 PTO shaft is considered a consumable (throw away) item, while the F-15 PTO shaft is a reparable. This difference introduces several differences in the parts flow and the members of the respective supply chains. While the T-38 shaft is managed by DLA, and procurements are based almost exclusively on demands, the F-15 shaft is managed by item management at Ogden ALC and other factors impact buying decisions such as (but certainly not limited to) NRTS percentage, depot condemnation percentage, and Readiness Spares Package (RSP) inventory levels (additional inventory reserved for deployment support). Finally, the parts also differ in demand patterns. The T-38 PTO shaft has very low demands, thus the supply pipeline has been relatively dormant until recently. The more predictable demand characteristic of the F-15 shaft allows for an active pipeline; one that has an established source of supply and repair and contractual procurement vehicles in place. This may allow for more supply chain flexibility and responsiveness for the F-15.

Supply Chain Characteristics

Similarities in the Supply Chains of these two parts are primarily due to the regulations and information systems which guide supply chain actions. As all government procurement actions are regulated by the Federal Acquisition Regulation (FAR), both supply chains must play by the same procurement rules whether contracting for parts or repair support. Both supply chains will be limited in the amount of supplier involvement in supply chain decisions due to the FAR's intent to maintain fair and open competition. Because Air Force Materiel Command maintains oversight for all inventory policies and supply functions such as ordering, stocking, etc., this provides another source of consistency across both cases—they are both held to the same stockage policy requirements at the field level.

The information systems used by the supply chain for each of these parts also provides some cross-case consistency. Again, DoD regulations mandate this consistency, but research indicated that both supply chains actively use primarily the same systems to manage these parts. CAMS and SBSS are both used at the base level for supply and maintenance data. Overall, both supply chains are supported by Legacy-based systems which essential maintain information in functional stovepipes. Members of both supply chains indicated preference for systems that attempt to bridge these legacy stovepipes and encourage cross-functional information-sharing such as WebCATS, SMART, JTAV, WinMASS, especially when researching and collecting supply chain information. Even those with web interfaces are still supported by Legacy logic with the exception of DLA's BSM which is not fully operational yet.

The primary difference in the Supply chain management of these two parts lies in the ultimate item management and engineering responsibility, driven by the reparable/consumable characteristic of the part. Since DLA is responsible for management of most DoD consumables, including the T-38 PTO shaft, visibility and supply chain decisions are limited for the rest of this part's supply chain. Although a good working supply chain relationship has been established with DLA for the management of this part, research indicated that is not always the case. The management of the F-15 PTO shaft resides with Ogden ALC as does its source of repair. The co-location of these two functions may provide improved supply chain coordination. Additionally, the existence of a current production line for the F-15K provides an additional source for supply emergencies not afforded to the T-38.

Similarities and differences also exist in the key players within each supply chain. In both cases, two System Program Offices (SPOs) exist: one for sustainment and one for new system acquisitions. In the case of the F-15, the acquisition SPO (SPO North) resides at Wright-Patterson AFB, while the sustainment SPO (SPO South) is located at Warner-Robins ALC. In the T-38 case, the acquisition SPO (SPO East) is also at Wright-Patt, while the sustainment SPO (SPO West) is stationed at Ogden ALC. The separation of SPO offices produces different levels of involvement in supply chain management in each case. The F-15 IPT included members from both SPO north and SPO south and both were included in supply chain communications for this part. However, the acquisition SPO played no role in any of the T-38 IPT meetings and they participated very little overall, even at periodic system reviews and meetings. Responsibility for the overall weapon system resides with the Lead Command of each aircraft, and in both cases the Lead Command appears to take an active supply chain management role. However, AETC's involvement is much more direct. As previously mentioned, the

AETC WS SCM appears to be the focal point in the supply for this part, while ACC plays a more ancillary role, getting directly involved when all other resources are exhausted. This may be due to two additional differences in the supply chain management of these to parts: the existence of the ACCRSS and Eagle Control for the F-15. The ACCRSS plays an active role in sourcing and prioritizing parts across the regional (CONUS) F-15 customers. Support is augmented by the Eagle Control office which plays a similar role, primarily for MICAP support and from a fleet-wide perspective. The T-38 has neither of these supply chain links and the Command WS SCM appears to perform both roles.

A few minor differences exist in information systems used in the supply chain management of the parts (again, primarily due to the reparable nature of the F-15 PTO shaft). The depot item manager relies more on the D035 and D043 systems and the production manager uses EXPRESS for production line oversight, while DLA item information is facilitated by WebCATS and DoD EMALL.

Elements of Information-Sharing

The information-sharing across the supply chain for each case illustrated several similarities and a few differences in the types of information shared and the methods/systems of doing so. These similarities highlight significant areas for improving this element of supply chain management which may be applicable to overall Air Force supply chain management.

Both cases appeared to share demand information such as increases in demands customer anticipated demands. Supply information such as contract delivery dates, lead time and additional sourcing options was also shared. However, the T-38 appeared to share more information with the item management function (DLA) than was the case for the F-15. The DLA item manager was included on nearly all communications and in turn, provided regular updates to the rest of the IPT on contract status and changes. Repair data did not appear to be freely given by the F-15 PTO shaft source of repair and the customers were not always informed of changes to expected contract deliveries. In both cases, the flightline customers did not appear to have real-time information on status of supply and repair actions, but also did not appear to need that level of detail in most instances.

The cases present similar methods of information-sharing across the supply chain, most of which were facilitated by human intervention. The use of an IPT for supply-chain problem solving was a common element in supply chain decision-making for both cases. Although the participants on each IPT varied slightly, key functions represented include: systems engineering, mechanical engineering, program management, WS SCM, item management (either AF or DLA, as appropriate), and Production Management (for reparable F-15 shaft.) Both teams met on a weekly basis at the height of the decision-making, and both continue to meet as needed to monitor the PTO shaft supply chain health. As a minimum, email traffic continues to be the vehicle of choice for sharing information within the team as well as with other members of the supply chain. Communications within the IPTs were accomplished via teleconference, phone and email when face-to-face meeting was not possible.

Information-sharing is also accomplished by both supply chains through periodic reviews. Both supply chains use daily reviews at the field level to address parts support issues such as MICAPs and backorders. Information is shared between maintenance and supply regarding resolution of these issues, often as provided by the item manager or

RSS, to ensure informed decisions are made. Both supply chains also used monthly program reviews at each level within the supply chain and the information is then shared across the supply chain via email and PowerPoint presentations. Information-sharing was also accomplished in both cases through careful monitoring of metrics. Tracking MICAP hours and incidents as well as backorders was common to both cases.

Another common element in the information-sharing within both cases is the lack of customer and supplier involvement. Although the supply focal point (the WS SCM for the T-38 and the Eagle Control office for the F-15) claimed to represent the customer in the decision-making process, in both cases it appeared that the flightline maintainer was often uninformed of the problem and/or progress made. The lack of complete information at the flightline customer level was especially common in the inspection procedures for both shafts. Eventually the engineering community ensured the correct information reached all users of the supply chain. From the supplier viewpoint, FAR regulations limit the amount of information that can be provided to suppliers and the classification of data such as flying hour schedules prohibit release outside the government. In both cases, the supplier was not an active member in the IPT and appeared to be provided information on an “as needed” basis.

Differences in information-sharing did exist between the cases. Most differences appear minor, but may provide an opportunity for improvement. F-15 information-sharing included development of documentation in support of decision-making. Talking papers and executive summaries were used to share information up the chain of command. T-38 information was primarily shared throughout the supply chain through emails and monthly slides. The F-15 did not appear to use the 107 Request as an opportunity to share information and achieve supply workarounds as the T-38 customers did.

Elements of Collaboration

Collaboration on supply chain management decisions was similar between the cases, but was used at different points in time and more extensively in the case of the T-38 supply chain. The F-15 as well as the T-38 case each illustrated that supply chain decisions would benefit from a collaborative decision approach, rather than simply letting the supply chain "catch up" to the decision. Both cases illustrated collaboration with key members of the supply chain to resolve the PTO shaft issues. Both cases involved some degree of collaborating with the customers as well as suppliers.

The differences in both the timing and extent of collaboration in each of the two cases are important. In the case of the F-15 shaft, collaboration initially happened among the various engineering communities including that of the OEMs as well as field users to help accurately identify the problem. Some collaboration continued within the IPT as the PTO inspection procedures and criteria were identified. However, this IPT appeared to be primarily composed of various engineering members, and focused almost solely on the risks associated with possible part failures. The decision reach by this group did not allow time for collaborating on a supply chain strategy to avoid the sharp increase in MICAPs seen by this part. There was no attempt made to coordinate pipeline robusting with the implementation date of the inspections in order to alleviate the impacts of the inspection on the supply chain and ultimately operational readiness. In the case of the F-15 PTO shaft it appeared that the operational risks were used as a justification to avoid collaborative planning on the item, although there was no indication a risk analysis was performed to compare the “perceived” risks of more closely coordinating the inspection with supply chain actions with the chosen path. Following the IPT decision to implement the inspection collaborative efforts between nearly all members of the supply chain in reaction to the increase in demands helped improve the ability of the supply chain to respond to the increase. The collaborative efforts helped identify alternate solutions, such as the high-speed balance shaft and the complete re-design. Nevertheless, the F-15 collaboration was reactive in nature, calling to question the amount of input all members of the supply chain really had in the decision-making process early on.

In comparison, the T-38 collaboration did not involve supplier or OEM engineers at the onset to help identify the problems associated with the PTO shaft and engine vibrations. However once the problem was identified, the IPT involved all members (DLA, field users, engineers, program managers, and WS SCM) to collaborate on the supply chain strategy with the focus to address the shaft problem and minimize the operational impacts. The T-38 team took a proactive approach to alleviating stresses on the supply chain, even to the degree of continuing delay of the inspection until replacement PTO shafts were on the shelf. The benefit of this approach is best illustrated by the absence of MICAPs for this part. Collaboration between the field users and engineers helped identify the requirement for inspection as well as inspection criteria and its urgency. Additional collaboration with DLA allowed for coordination of the inspection implementation with DLA deliveries of the item.

Metrics Comparison

A comparison of the role of metrics between the two cases is limited due to the scope of the research. However, there are a few similarities and differences that may impact the interpretation of identifying the impacts of the supply chain on operational readiness. Both T-38 and F-15 pay close attention to the number of MICAPs and the length of time in MICAP status. However, the F-15 overall experiences thousands of MICAPs each month and sets a threshold for concern as indicated by the "top 100 MICAP Buster List." The T-38 case appeared to scrutinize MICAPs closer at the filed level and actually attempted to avoid most MICAPs by also monitoring backorders and maintaining constant communications with field users. Overall, the MICAP metric appears to be the best measure of supply chain effectiveness in both cases, whether trying to minimize or eliminate them.

Summary

The case study data presented here identifies information-sharing and collaboration elements in two different Air Force supply chains. Similarities and differences have been identified between the cases in accordance with the research questions, in several areas: characteristics of the aircraft and supply chain, elements of information-sharing, elements of collaboration and supply chain metrics. This analysis provides the basis for answering the research questions and drawing final conclusions about the overall information-sharing and collaboration with in the Air Force supply chain in Chapter 5.

Chapter V. Conclusions and Recommendations

This chapter will address the objectives of the research, discuss unique limitations of the study, identify areas for future research and summarize the overall research effort. The investigative questions will each be answered based on the evidence presented and the research question will be thoroughly discussed based on the analysis of the previous chapter. A final recommendation for future Air Force supply chain management will be provided as a result of the overall research effort.

Addressing the Research Questions

Investigative Question #1:

What are the key elements of the supply chain for an Air Force aircraft part?

The key physical elements of the Air Force supply chain are identified by the simplified supply chain diagram in Figure 5-1. The lines connecting each of the supply chain links represent flow of both information and parts.

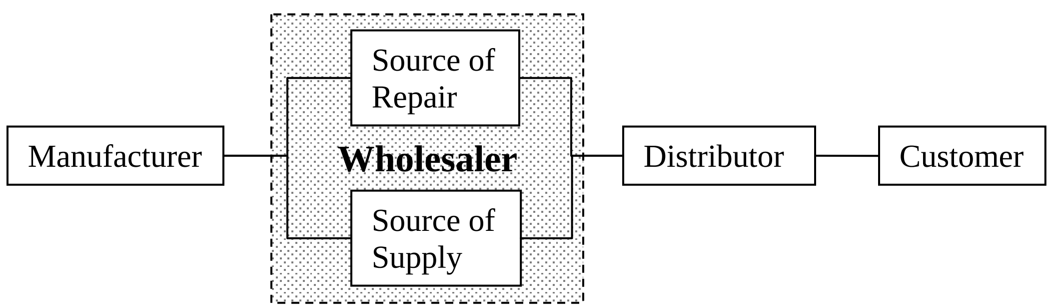


Figure 5-1: General Supply Chain Description

The “manufacturer” provides the parts and is usually a contractor. Physical production of the part in some cases may be sub-contracted but this does not play a direct role in the supply chains evaluated and so was not considered. Other management influences such as engineering for sustainment (redesign and upgrade efforts) at both the item- and system-level and Weapon System Managers are important to the overall health of the fleet. Finally, the parts themselves (not identified in the diagram) are key elements of the supply chain, whether the part is a reparable or a consumable, impacting the flow of parts and/or information and decisions that are made.

The “wholesaler” is responsible for providing serviceable parts for the supply chain, through repair, new procurement, or both. In the case of (most) consumable items (those which are replaced only through new procurement), DLA is responsible for this element and has divided responsibilities between a Weapon System Support Manager and a Supplier Support Team. These elements respectively either work to manage all the demands of a specific weapon system or to manage all the demands placed on a given supplier from all weapon systems. In the case of reparable items, replacements are provided by a source of repair and/or a source of supply where the source of repair may be organic (within the Air Force) or contracted (often with the source of supply if repair capability exists). The item manager is responsible for interfacing with the customer and the engineering community, while a contracting officer works with the source of supply or repair.

The “customer” is ultimately identified as the maintenance unit; either at the base level using parts to fix jets on a routine basis, or at the depot where jets are overhauled and parts are replaced as directed by inspection/overhaul procedures. Although part of the wholesale link, the source of repair for a reparable part is also considered a customer, where a broken part must be "inducted" for repair. The base supply function may also be considered customer when parts are authorized for storage at the base level and a stock level represents a demand must be satisfied.

The "distributor" represents any element that can make decisions as to whom will receive parts. This may be the RSS, the WS SCM, the item manager or any member of the supply chain who can source parts from another member of the supply chain.

Information flow represents a non-physical but critical element of the Air Force supply chain, represented by the connecting lines in Figure 5-1. Customer demands and the nature of those demands must be understood: Are they causing grounded aircraft? Were they the result of unexpected failures? Were they caused by controllable factors such as an inspection or TCTO? Supply information such as stock levels, available pipeline (sources of supply, repair), and lead time impact supply chain decisions. Changes in supply and demand information is necessary for effective management of the supply chain for these parts.

Investigative Question #2

How is information shared across the Air Force supply chain?

Types of shared supply chain information that were considered for this research effort were based on those previously identified by Lee and Whang (2001):

1. Inventory level (most common)
2. Sales data
3. Order status for tracking/tracing
4. Sales forecast
5. Production/delivery schedule
6. Other (*i.e.* performance metrics, and capacity)

Because the research focused on evaluating the management of a supply chain "exception," that is, a circumstance outside of normal supply and demand, "sales data" and "sales forecast" information were not considered. The other four elements of information were considered in the discussion of information-sharing.

The results of this study indicate that information is shared via automated systems as well as through human intervention. The Air Force has a multitude of logistics information systems to facilitate automated information-sharing throughout the supply chain. Perhaps too many, according to GAO reports (US General Accounting Office, 2004; 1996a; 1996b; US Government Accountability Office, 2005; 2004) . Quantitative, objective data such as orders, backorders, item records, inventory levels, and transportation information may be accessed by most members of the supply chain with the appropriate database/access and authorization, with the exception of the ends of the supply chain: the customers and the suppliers. Customers do not have visibility into inventory levels across the supply chain or the status of orders, contracts, or production levels. Field-level customers have access to *expected* supply dates but in many cases this information is outdated or incomplete. They may request status on MICAPs and backorders up the supply chain via the MSL and the RSS or WS SCM. Suppliers do not have direct visibility of customer demands and must rely on their interface (supplier team or contracting officer) for most of this information because of government concerns with making this data public.

Information-sharing is also facilitated through more human methods such as phone calls, emails and conference calls. This seems to apply to the more "subjective" information such as problems with parts or suppliers (unexpected changes in supply and demand), quality issues, maintenance or reliability concerns and, of course, complaints and justifications. It is difficult to generalize the practice and depth of information-sharing across the Air Force supply chain because the two cases evaluated exhibited different levels of this types of non-automated information-sharing. In the case of the T-38, phone conversations and emails occurred on almost a daily basis regarding the status and decisions surrounding the PTO shaft. The F-15 supply chain appeared much more "hands off" with email exchanges months apart, despite increasing MICAPs for the PTO shaft. Additionally, the F-15 community was more apt to spread the "formal" word through executive summaries and talking papers that were filtered up the supply chain, but apparently not down to the field-level. This difference in information-sharing may be attributed to the complexity of the supply chain. The F-15 touches more customers in very different areas of the world than the T-38 and the types of information shared may be much more variable. Most of the T-38 fleet is located within a close proximity of its supply chain focal point, the WS SCM. It is reasonable to conclude that larger, more complex supply chains share information less efficiently than smaller more cohesive supply chains.

It appears that automated systems make detailed item information such as inventory levels and delivery tracking, available across much of the supply chain, but not all members are accessing them. The Supply Discoverer system and the AFKS (among others) appear to have centralized supply information, but are quite often unobtainable because of access barriers. For instance, through the course of this research, the researcher attempted to gain access to some of the systems mentioned herein, and in most cases was unsuccessful. It was discovered that the Air Force Knowledge Now (AFKN) website (accessible through the Air Force Portal) provides access to general information, including supply chain topics as applicable to various weapon systems, commands, even bases and units. AFKN also facilitates the use of "Communities of Practice" in which a user can create an information-sharing forum about any topic for others to access (it may be open to any AFKN users, or accessible by "membership" only). Interestingly, there was little helpful information on either the F-15 or T-38 supply chains or parts problems found within AFKN. Other automated information-sharing "tools" such as the Supply Discoverer are available, but it appears they are under-utilized.

Investigative Question #3

<u>*How is collaboration used to make supply chain decisions?*</u>

Based on the collaboration illustrated in the two cases, collaboration is used on a limited basis to make supply chain decisions. The F-15 case appeared to use some degree of *coordination* between field users, engineers, and the program office during the initial identification of the PTO shaft as a problem item. However, true collaboration did not occur in this case, based on the definition of collaboration developed in this research:

> Two or more units <u>continuously</u> working together to <u>share information</u> and knowledge and <u>make decisions</u> in an effort to <u>improve</u> overall supply chain processes.

The interactions that occurred did not appear to be of a continuous nature. It seemed that some IPT members played a more active role as it was deemed necessary. Engineers played a heavy role up front while considering the design issues. Depot production and Item management chimed in as the PTO shaft climbed to the #2 MICAP driver for 2005. The RSS played no role (didn't even know of the new inspection criteria), but was left to put out the MICAP fires when they flared. Thus, collaboration facilitated by this environment and available information was not used as extensively as possible.

Although the members of the F-15v supply chain share knowledge and information in the IPT setting, there did not appear to be any collaborative decision-making. This was evidenced by the depot source of repair being consulted *after* the decision to implement the inspection was made, rather than being involved in it. Additionally, no data was found that indicated an analysis of the risks associated with the wearing of the PTO shaft (and possible engine damage) while waiting for the supply chain to "prepare" for fleet-wide replacement was actually compared (numerically) to the risks associated with the excessive MICAPs, increased cannibalizations, contract acceleration costs, and loss of aircraft availability, of the decision made.

Finally, the F-15 IPT did not improve the supply chain *process* in this case, but only improved the reactivity to the problems it created. This is the final criteria of collaboration as specified in the definition, indicating further, a lack of collaboration. Had the decision to implement the inspection been made in a way that would actually improve the supply chain response to the failing parts collaboration would have been successfully applied.

The T-38 case, however, did illustrate a good use of collaboration to make supply chain decisions. Nearly all members of the supply chain worked together to identify the problems with the PTO shaft as well as possible solutions. Information and knowledge was shared from customer to supplier to determine possible courses of action and ultimately agree on the best decision for the T-38 fleet with the least negative impacts on all affected. The decision avoided the traditional impacts of increased parts shortages and reactive supply chain "fixes." Again, to determine how collaboration *is* used in an Air Force supply chain depends on the situation, but this research revealed examples of how it *isn't used* and how it *can be used*.

Investigative Question #4

What key supply chain metrics are used by the Air Force to evaluate the effectiveness of the supply chain and its impact on operational readiness?

The possibility of a MICAP (a mission capable part) impacting the operational availability of an aircraft is a daily threat in the Air Force. Stated simply, a MICAP means there's an otherwise perfectly good airplane sitting on the ground, waiting for the replacement of a broken part. In other words, the aircraft's operational readiness is being impacted by the unavailability of a spare part.

As such, the measures of the quantity and duration of MICAPs are tracked throughout the Air Force by each weapon system, to evaluate supply chain effectiveness. Specifically, the "MICAP Buster List"—a list of the top 100 aircraft items that have generated the most MICAP hours for the aircraft fleet—is monitored at the field, SPO, WS SCM and RSS level. Because of the large amount of MICAPs the F-15 fleet deals with, supply chain-wide attention is usually only given to those items that have open MICAPs and either have moved up the list 30 or more steps or that have appeared as a driver for the first time in six months. Although T-38 MICAPs are not as abundant they are always a serious concern because of the threat of diminishing sources of supply (due to the age of the system) for the aircraft. Once a part shows up on the MICAP list, it may or may not have an available source for replacement.

The relationship between MICAPs and operational readiness is not a directly correlated or cause-effect one. However, they are both closely monitored, and it can be concluded that the presence of a MICAP translates to a missing part or "hole" in an aircraft, and that aircraft is "unavailable" to perform its mission. Although, there are other factors impacting the Aircraft Availability such as NMCM rates (Not Mission Capable Maintenance) and NMCB (Not Mission Capable Both supply and maintenance), HQ AFMC identifies Aircraft Availability as the best measure for operational readiness as previously discussed. Considering the "most relevant metrics" for each supply chain perspective as cited in Chapter 2 (p. 54) and the scrutiny given by the units to MICAPs and MICAP hours, it would appear the best measures of the effectiveness of the supply chain and its impact on operational readiness would be MICAP hours MICAP incidents. Aircraft Availability and Customer Wait Time (the average time between warfighter order and receipt) may also be considered but were not evaluated in the course of this research effort. These four metrics may function as an analytical tool box for evaluating supply chain initiatives (or lack thereof) and the impact on operational readiness.

Research Question

How can the application of information-sharing and collaboration to management of the Air Force supply chain improve operational readiness?

In answering the individual research questions this study has identified elements of information-sharing and collaboration within the Air Force supply chain. Specifically, the research identified one example of good information-sharing and collaboration and one example of incomplete information-sharing and collaboration. Through comparison of these two supply chain examples, it is apparent that using shared information and knowledge to collaborate on *preventative* supply chain decisions rather than *reactive* supply chain decisions can lead to better operational readiness as measured by aircraft availability. The supply chain operations in both examples dealt with managing an "exception" to standard supply chain procedures, but the approach to sharing information and collaborating on that exception in each case produced drastically different results. In one case the exception created MICAPs while in the other MICAPs were avoided.

Based on these findings, information-sharing and collaboration should be adopted in Air Force supply chain management to facilitate **proactive** supply chain decisions versus **reactive** supply chain efforts when dealing with supply chain exceptions, those situations that the supply chain is not designed to accommodate well.

Limitations of the Research

The scope of this research was to identify the application of information-sharing and collaboration techniques to improve supply chain management of Air Force parts exceptions. The research was limited by several elements: the type of parts used in the case study, the characteristics of the aircraft, nature of the missions that use those parts and the type of documentation available for the research.

Due to the complexity of the Air Force supply chain and time restrictions, the research was limited to evaluation of supply chains for two parts: the T-38 PTO shaft and the F-15 PTO shaft. At the onset of the research, these two parts expected to provide similar case platforms. Despite the fact that they are functionally the same part and exhibited similar design/failure problems, research revealed extensive differences in their supply chain characteristics and levels of information-sharing and collaboration within their respective supply chains. This makes the genaralizability of the results limited.

Additionally, although the original intent of the research was to establish literal replication logic through multiple cases, more differences in the two cases were discovered than was expected. Because of this lack of commonalities in the two parts, little time was available for in-depth exploration of the individual case studies. Most of the research time was spent touching the surface to identify as many similarities (and ultimately differences) between the cases and iteratively addressing the research questions.

While these two items represented supply chains from two unique aircraft, with unique missions, they do not capture all possible aircraft characteristics, some of which may create additional supply chain challenges. Engineering characteristics, item management authority, aircraft age and usage stressors are a few examples of elements of the aircraft which were not comprehensibly evaluated within the research.

In addition, the demands placed on the supply chain as a result of mission characteristics were not thoroughly captured. The aircraft chosen for this study represent two mission types: CONUS training and air superiority/long-range tactical fighting. However, the characteristics of other missions such as Air Mobility Command's transport missions, which make up a large portion of the Air Force supply chain and the very specialized supply chain demands of Special Operations Command, were not considered. Supply chain characteristics of these other commands will undoubtedly impose supply chain stressors that are beyond the scope of this research. Therefore, the genaralizability of this research is again limited.

Finally, the pursuit of an IRB exemption and the conditions under which that was granted posed a significant limitation on the research. The nature of the proposed interview questions was deemed sensitive enough that anonymity was required for exemption status. Interviews were not recorded, notes were not included and data retained from the study was so "sterilized" that the chain of evidence was not maintainable. Duplication of the research in its present form may be difficult to achieve and it is recommended to seek IRB approval, rather than exemption in the future.

Suggested Future Research

This research used a case study methodology to identify opportunities for supply chain information-sharing and collaboration in the Air Force supply chain environment. Due to the time-consuming and iterative nature of case study research, this effort has simply scratched the surface. There are several areas for further research that may augment these initial findings and identify additional benefits of information-sharing and collaboration within the Air Force supply chain.

One logical next step would be to perform an in-depth analysis of one of the weapon systems analyzed here, to determine if consistent patterns of information-sharing and collaboration exist. Evaluation of information-sharing and collaboration on other T-38 or F-15 parts would help to establish literal replication logic and establish more generalizable results. Future research could also investigate the areas for application of information-sharing and collaboration through a quantitative methodology such as a marginal analysis or simulation of the supply chains described here. Quantitative analysis of the ability of current metrics to capture the specific impacts of information-sharing and collaboration on aircraft availability, MICAP rates and other operational metrics may also augment the applicability of the research.

With all the “home grown” logistics transformation efforts and initiatives underway currently and in the recent past, it appears that agreement on the road ahead is lacking. In researching DoD supply chain philosophy and initiatives, a plethora of disjointed efforts were uncovered. There have been so many “improvement efforts” that identifying the most influential/accepted ones became ultimately a hunt for those with the deepest “roots” or the most visibility. Many supply chain initiatives surfaced, but often in a vacuum, independent of any identifiable unifying philosophy. A suggested area for future research is to identify and characterize all the logistics and supply chain initiatives in the DoD since the 2001 Quadrennial Defense Review (QDR). This analysis needs to address: the differences across the initiatives, characteristics common to both successful and not successful initiatives and ultimately identify the best current initiative to be considered as “the DoD enterprise logistics transformation.”

Another area for future research is to evaluate the success of the APS Pathfinder initiative in terms of its impact on information-sharing in the supply chain. While supporting contractors have provided after-action reports and the “successes” of this pilot program have been the touted, ultimately providing the justification to implementation Air Force-wide, a comparative analysis has not been done between APS forecasting techniques and the current D200A system. The APS system appears to match the philosophy and processes of CPFR, with its “exception-management” approach to forecasting and collaborative demand planning. A comparative case study of the APS model and the CPFR may identify areas of improvement or better application to the Air Force supply chain.

Finally, this research does not address the manufacturing or procurement elements of supply chain management in the DoD. The theories of collaboration and information-sharing as it applies to production planning and MRP II at Air Force Depots should be explored. The Air Force's initiatives to develop "Commodity Councils" to streamline procurement and encourage a more effective supply chain might provide another interesting context in which to evaluate information-sharing and collaboration.

Research Summary

This research used an exploratory case study analysis to determine how supply chain information-sharing and collaboration may increase the effectiveness of Air Force Supply chain management and improve operational readiness. The F-15 case did not involve everyone in the decisions and they ignored key logistics and supply chain considerations, resulting in the grounding of a significant number of aircraft. Based on a decision un-aided by the insight they could have received, they took a part that wasn't even in the top 100 MICAP items, and drove it to number 2. On the other hand, the T-38 folks involved all members through the process and adjusted their efforts to account for logistics and supply chain considerations--impact? NO MICAPS for PTO shafts. SIGNIFICANT finding from the research: a good example for how to implement collaboration that works!

Appendix 1. AFMC Metrics

Metric:	Description:	Type:
Aircraft Availability (AA)	Percentage of the time an aircraft is not unavailable due to supply - expressed as 1 minus the Total Non Mission Capable Supply (TNMCS) time	Performance
MICAP Hours	Measurement of the hours accrued in a given month for items affecting mission capability that are on backorder	Performance
Customer Wait Time (CWT)	A pipeline measurement of customer due-outs (not including stock replenishment and kit fills) expressed in days measuring the average time between issuance of a warfighter order and receipt	Performance
Net Operating Result (NOR)	Financial measurement showing the difference between revenue and expenses or a bottom line profit and loss indicator	Performance
Total Requirements Variance (TRV)	Evaluation of Expected Backorders (RBL forecasted customer due-outs) vs. actual due outs (with option to view masked due-outs caused by laterals and non-project coded kit issues)	Process
MICAP Incidents	Measurement of the number of incidents based on the number of MICAP requisitions accumulated	Process
Backorders (BO)	Measures the number of demands placed on the supply system that can not be immediately satisfied from existing inventory (including stock replenishment)	Process
Issue Effectiveness (IE)	Measure of supply accounts ability to satisfy any customer demand (issue item off-the-shelf vs. backordering item)	Process
Stockage Effectiveness (SE)	Measure of supply accounts ability to satisfy customer demand for authorized stockage items	Process
Logistics Response Time (LRT)	A pipeline measurement of warfighter and base/depot retail requisitions expressed in days measuring the average time between issuance of a warfighter/base/depot retail order and receipt at base/depot supply	Process

Appendix 2. Case Protocol

1) Pilot study/site surveys
   a) Visits to customers to determine potential cases
   b) Results:
2) Field notes
   a) Taken during pilot interviews
   b) Reviewed by advisor for completeness/validity
   c) Documented in case descriptions/Ch. 4
3) Telephone interviews
   a) Recorded
   b) Interview key players within each supply chain (customers (maint/supply), Weapon System supply chain manager, acquisitions program manager, RSS, Item manager, suppliers (if available)
   c) Used to clarify/robust case description
4) Follow-up correspondence
   a) Email "Supply Chain Questionnaire"
   b) Assure of confidentiality (per Human Subjects IRB waiver approval)
      i) Request non-identifying replies in word doc (no personal info)
      ii) Destroy "linking" emails
   c) Email additional factual questions for clarification
5) Coding
   a) Data that relates to each of three areas: SCM, Info-sharing, collaboration(Analysis Matrix)
   b) Relationship/impact on metrics
6) Display data
   a) Narrative format
   b) Included in Ch. 5
7) Conclusions
   a) Summarized in Ch. 5

Appendix 3. Case Outline

1) Set the stage

2) Background
    a) Mission description
    b) A/c description
        i) History
        ii) Specs
    c) Customers/locations

3) Supply chain summary
    a) Key players
    b) Flow of parts/information
    c) Supply/demand histories
    d) Metrics

4) Supply "problem"
    a) Part description
        i) Supply concerns
        ii) Unique design characteristics that may affect supply chain
    b) Problem
        i) Nature (high demands, Engineering Change, unexpected failure, supply shortage/shortfall, etc.)
        ii) Impact (who, how)
        iii) Flow of events
    c) Resolution
        i) Lessons learned
        ii) Treated as a "uniquity"

5) Wrap-up

Appendix 4. Supply Chain Questionnaire

Disclaimer: All responses are elicited on a voluntary basis. While responses will be incorporated into the written case study, any personal information will be kept confidential. These questions do not reflect, in any way, the official position of the US Air Force.

Please describe your role in the [part type] supply chain? Position Title?

What past experience is important to this position?

What decisions do you make which impact the effectiveness of the [part type] supply chain?

What information is important for you to make these decisions?

Who do you think are the key players in this supply chain?

Are each of these players heard equally? If not, who should be heard the most?

What sources (people, reports, information systems) do you rely on for this information, how do you acquire it?

What information systems do you use? (WebCATS, D035, EXPRESS, etc.)

How would you describe the health of the [part type] supply chain? Strengths? Weaknesses?

What information do you provide to others for decision-making?

Please explain your view of the flow of parts and information in the [part type] supply chain.

Where do you think “breakdowns” exist in this supply chain?

What do you see as the biggest challenges in ensuring part availability in support of the mission?

Who do you work with to resolve supply chain issues as they arise? Transportation? Contracting? Maintenance? Communication? Others?

What assumptions do you make when resolving supply chain discrepancies?

What metrics do you think best measure the health of the supply chain?

What improvements to the supply chain would you make?

What tools are available to you that improve your ability to gather and share information?

What relationships do you think need to exist in your supply chain to improve effectiveness?

Appendix 5. Comparative Data Analysis Matrix

Characteristics		T-38	F-15
Item	A/C part	+	+
	Name	PTO Shaft	PTO Shaft
	System	Mech/Prop	Mech/Prop
	Manufacturer	Goodrich	Goodrich
	lead time		
	Unit cost (current contract)		
	QPA	2	2
	constant demand	-	+
	reparable part	-	+
	consumable part	+	+
	Managed/SOS	DLA	OO-ALC
	qtrly demand rate	<1	68
	ERRC	XB3	XF2/XB3
	MTBD		
	SOR	n/s	OO-ALC
A/C	Type	Fighter/trainer	Multi-role Fighter
	Model	T-38	F-15
	Date Deployed	1961	1972/1988
	OEM	NGC	McDD
	# engines	2	2
	Engine Type	GE	P & W
	# of locs (permanent, not incl FMS)	13	21
	# in inventory (all models)	509	749
	Unit cost (adjusted, est. 2005$$)	$3.9M	$34.4M/$35.9M
	Still in production	-	+
	Deployed	-	+
	field maintenance personnel	mix	mil
	depot a/c maintenance	-	WR
	mods/upgrades	Randolph	WR/Contr
Retail Supply	Field supply personnel	contr	mil
	On-hand stock?	n	y
	MAJCOM WS SCM	AETC	ACC
	MSL?	-	mil
	MSL loc?		Maint SQ
	RSS	na/	Langley

Characteristics		T-38	F-15
Information Systems	WebCATS	+	+
	BSM	+	+
	SAMMS	+	+
	D043	+	-
	D035	+	+
	AFKS	+	-
	Supply Discovery	+	-
	SBSS	+	+
	CAMS	+	+
	D200	+	+
	SMART	+	+
	GTN	-	+
	JTAV	+	+
	WinMASS	+	+
Info-Sharing Exchanges	Base Supply - base maint	+	+
	Base maint – MSL	n/a	+
	WS SCM – base	+	-
	Engineer (item) - Engineer (SPO)	same	+
	Engineer (SPO) - Engineer (OEM/contr)	-	+
	Engineer (Sys) - Engineer (SPO)	same	+
	RSS - IPT	n/s	-
	Command WS SCM - IM	+	
	Manufacturer - IM	+	
	Engineer (SPO) - IM	+	
	IM - RSS	n/a	-
	IM - WS SCM	+	
	IM - SPO PM	+	
	Engineer (SPO) - SPO PM	+	
	Field - RSS	n/a	+
	Field - WS SCM	+	-
	107 requests	+	

Characteristics		**T-38**	**F-15**
Collaboration tools	(bi)Annual customer Review	+	+
	Lead by	SPO	RSS
	Monthly Program Review	+	+
	Lead by	SPO	
	weekly status updates?	-	+
	daily ops meeting (field)	+	+
	Item IPT	+	+
	loc	SPO	
	IPT lead	SPO PM	SPO Engineer
	Same players throughout	+	-
	IPT meetings	+	+
	Pre-decision	+	-
	At Decision point	+	+
	Post-decision	+	+
	email	+	+
	as needed	+	+
	regularly	+	-
	focal point (SC leader)	WS SCM	Eagle Control
	face to customer	WS SCM	ACC RSS
	face to supplier	DLA supplier Mgr	Contracting officer
Metrics	MICAPS pre-decision	0	
	MICAPs post-decision	0	
	Back orders pre-decision	0	
	Back orders post-decision	0	
	new contract	y	
	deliveries per month	30	60
	deliveries on-time?	-	+
	AA pre-decision point		
	AA post-decision point		
	current AA		

Appendix 6. Demand-Driven Supply Chain Actions

- Maintenance customer orders part from supply using CAMS (Computer Aircraft Maintenance System).
- Base supply fills the request with stock on-hand.
- If no stock available, a backorder is established in SBSS (Standard Base Supply System.)
- For bases with COMBS, the COMBS downloads order information into its own automated system.
- If an a/c is “down” (not flyable) this backorder is coded as a MICAP (high priority) and tracked as such.
- Different locations (CONUS, OCONUS), missions (training, Iraqi FREEDOM, Korea, humanitarian), and MAJCOMS (AETC, ACC, etc.) have different priorities for supply support both in filling requisitions and transportation requirements (when military Air Transport is used).
- Depending on who manages the part (AF or DLA) the respective Item Manager works to fill the backorder according to the requisition type (routine fill for shelf, routine backorder, MICAP) based on the priority code assigned.
- The lead Command has responsibility for using lateral shipments to fill MICAP requisitions when low supply chain priority (AETC usually carries a lower priority than ACC, due to the “training” nature of their mission) is delaying the fill.
- Laterals between commands are worked through the RSS or Command WS SCM.
- DLA uses several information systems to fill the requisition (contracting, shipping, supply, etc.) However, the recently implemented BSM consolidates that information from the DLA Legacy System, SAMMS and the interim WebCATS into a focal system, the EMALL. The EMALL system provides a “snapshot” of the status of the customer’s request, as updated by the item manager.
- The complexity of the Air Force Logistics Information System architecture is beyond the scope of this research, but systems will be identified, as necessary.
- “Routine” AF requisitions are worked by the Item Manager responsible for the NSN.
- The Sustainment SPO (SPO South) works unique supply chain issues such as the PTO shaft situation as directed by engineering and customer “problems” as they arise.
- In these unique circumstances, the SPO Program Manager works with a DLA Liaison for DLA-managed items; usually putting an SPR into the system (this also requires documentation to support this “above and beyond” supply request).
- For AF-managed items, the SPO works with the IM, who in turn often works with the contractor and AF contracting office directly to resolve support issues (contract “slippages”, quality issues, new requirements, etc.).
- Contractual status/information (including date contract awarded, contract line items, estimated/required delivery dates, etc.) is maintained in the BSM system, only accessible by special access.
- When the contract for the part/parts is awarded, delivery may be “for stock” or direct to the customer, depending on the urgency of the requisition.

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Vita

Captain Wendy S. Kierpiec graduated from Polaris School for Individual Education in Oak Lawn, Illinois. She entered undergraduate studies at Loyola University of Chicago where she graduated with a Bachelor of Science degree in Psychology in January 1996. She was commissioned through Officer Training School at Maxwell AFB, Alabama in August 1998.

Captain Kierpiec's first assignment was to the 366th Air Expeditionary Wing at Mountain Home AFB, Idaho as a squadron Supply Officer. In 1999, she completed the Supply Officer's course at Lackland AFB, Texas. While assigned to Mountain Home, she served as the Combat Operations Support Organization Flight Commander and the Logistics Group Executive Officer. In 2001, Captain Kierpiec was reassigned to Ogden Air Logistics Center, Hill AFB, UT. During her three year tour at Ogden ALC, she served in various acquisition and logistics positions including; Just-In-Time Bushing Program Manager for the Landing Gear Maintenance facility, Demand Planning Program Manager for the Commodities Division, and T-38 Sustainment Program Manager. In August 2004, she entered the Graduate School of Engineering and Management, Air Force Institute of Technology. Upon graduation, she will be assigned to HQ AFMC, Supply chain management division.

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14. ABSTRACT

This research sought to identify key elements of the Air Force supply chain as it relates to industry, determine how techniques of information-sharing and collaboration are used to make Air Force Supply Chain decisions and how the resulting impacts on operational readiness may be measured. A multiple case study research design was used to investigate the application of information-sharing and collaboration in two distinct Air Force supply chains. Cross-case comparative analysis of two unique supply chains evaluated each supply chain's characteristics and the levels of information-sharing and collaboration within each. The research highlighted one example of proactive sharing of information and collaborative decision-making to avoid supply chain inefficiencies and one example of using information-sharing to recover from a decision made without using a collaborative approach. The culmination of this effort provided insight into the interactions and complexities of the Air Force supply chain and highlighted a need for a more thorough evaluation of the impact of supply chain relationships, information-sharing and collaborative decision-making on operational readiness.

15. SUBJECT TERMS

Logistics Management, Spare parts, Commodities, Air Force procurement, collaborative technique,
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