Enabling Supply Chain Coordination with Information Sharing

By

Akiva Holzer

B.S. 2001, Operations Research and Industrial Engineering, Cornell University

Submitted to the MIT Sloan School of Management and the Engineering Systems Division
in Partial Fulfillment of the Requirements for the Degrees of

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and
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Signature of Author ______________________________
September 14, 2009
MIT Sloan School of Management, Engineering Systems Division

Certified by ______________________________
Jonathan Byrnes, Thesis Supervisor - Management
Senior Lecturer, Engineering Systems Division

Certified by ______________________________
David Simchi-Levi, Thesis Supervisor - Engineering
Professor of Engineering Systems and Civil & Environmental Engineering

Certified by ______________________________
Donald Rosenfield, Reader - Management
Senior Lecturer, MIT Sloan School of Management
Director, Leaders for Global Operations Program

Accepted by ______________________________
Dr. Nancy Leveson
Professor of Engineering Systems and Aeronautics & Astronautics
Chair, Engineering Systems Division Education Committee

Accepted by ______________________________
Debbie Berechman
Executive Director of MBA Program, MIT Sloan School of Management

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ABSTRACT

Virtual Business System (VBS) is a system with software and hardware components designed by Raytheon employees to improve operational performance by facilitating and reinforcing lean behavior. It has helped contribute to four years in a row of twenty-percent yearly reductions in costs by providing near real-time metrics information, visibility into the details underlying those metrics, and publishing results to provide accountability for continuous improvement efforts. Originally designed for use in a manufacturing cell, its use has since expanded to include project management, engineering, quality, and other functions. This thesis examines how VBS has contributed to internal alignment at Raytheon and explores whether it can fulfill Raytheon's external supply chain coordination needs as well. VBS was successfully upgraded to allow supplier access over Citrix; the next step is to conduct a pilot implementation to test the system in practice. As a "homegrown" system, VBS can be made to do nearly anything, and in time could fulfill Raytheon's supply chain integration needs. In the near term, additional work is likely to be necessary in the areas of data access control, user interface, and extension from stand-alone system to a peer-to-peer information sharing network. The VBS team will also need to continue gathering executive sponsorship and support in order to motivate the necessary change in business processes. A number of lessons applicable to supply chain integration systems in general can be learned from the success of VBS. These include: the importance of ensuring client control and security of the data; the potential gains made possible by sharing functionality in addition to data; the need to include information about improvement processes when sharing information; and the critical need that the application remain flexible and responsive to change in user needs.

Management Supervisor: Jonathan Byrnes
Senior Lecturer, Engineering Systems Division

Management Reader: Donald Rosenfield
Senior Lecturer, MIT Sloan School of Management
Director, Leaders for Global Operations Program

Engineering Supervisor: David Simchi-Levi
Professor of Engineering Systems
and Civil & Environmental Engineering

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TABLE OF CONTENTS

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1 Introduction

1.1 Problem Background

American manufacturers have, over the last century, been faced with increasing competitive pressure from low cost labor markets overseas. Combined with competitive pressure to reduce costs that has been enabled by implementation of six sigma, lean, and just in time methods, manufacturers are placed in a difficult position: the lower inventories and capacities involved with lean and just-in-time make them more vulnerable to upstream supply disruptions at the same time as the number of different firms in the chain has expanded, making supplier and risk management harder and more expensive. Government contractors have additional challenges, as they are required to place a certain value of work with small and disadvantaged businesses that may not have the knowledge, capital, or manpower to invest in process improvement.

These challenges are among the motivations for a recent focus on making supply chains work better – variously called Supply Chain Coordination, Supply Chain Integration, and Supply Chain optimization, among other names.

It has been suggested that the reliance on supply chains is such that competition is no longer merely between specific companies or Original Equipment Manufacturers, but between supply chains. For a supply chain to compete effectively as a unit, the partner companies involved need to share information and coordinate their activities. This becomes more complex as the number of partners increase; like national borders, corporate boundaries naturally restrict the flow of information, especially the tacit or latent information flow that generally arises out of frequent, unstructured, and unrestricted communication.

Following this 'border' analogy, today's supply chains composed of many specialized companies are like Europe, while a vertically integrated supply chain is like the United States. In Europe, the distinct currencies, languages, and trade regulations made commerce more difficult than it is within the larger geographical area of the United States. The creation of the European Union and the introduction of the Euro common currency eased restrictions on trade and made Europe more competitive with the US and the rest of the world. In the same way, lowering restrictions on communication and trade between supply chain partners makes the entire supply chain more competitive.

Perhaps ironically, lowering these communication barriers can be difficult in the U.S., where corporate relationships tend to be arms-length and competitive rather than cooperative. In the past, large firms have typically awarded contracts by competitive bidding and have often switched suppliers whenever a lower bidder appeared. To compete in this environment, suppliers would sometimes underbid to get business and then try to raise the overall price in other, less straight-forward ways. These dynamics tend to reduce trust and are barriers to information sharing.

There are many US companies that have decided it is in their interest to help their suppliers improve. Many suppliers are small businesses which do not have the resources or knowledge to implement continuous improvement. Companies such as Toyota, GM, and Raytheon all provide some resources to coach and teach suppliers to improve their processes, making the entire supply chain more efficient. This type of cooperation takes some time to provide a return, but leads to increased trust and can start a virtuous reinforcing cycle of cooperation for the benefit of all partners.

On the other hand, the limited communication regarding issues and important business information that characterizes many supply relationships has many consequences, including:

- Not seeing end-customer demand leads to poor forecasts and high variation in observed upstream demand (known as "the bullwhip effect").
- Observed variation in upstream demand leads to feast-or-famine situations rather than having just enough of all that is needed.
- Simultaneous excess inventory costs and production delay cost as customers attempt to compensate for supplier stock-outs.

Material quality issues and design changes are among information not shared as readily with suppliers. This can lead to wasted effort and cost from not dealing with issues in a timely fashion, and expediting cost of dealing with resulting situations and crises.

Even when information is shared, the way it is done is often not ideal. Even in relatively close supply relationships, information is routinely passed by ad- hoc phone calls, emailed attachments and FTP (File transfer protocol). While effective, these methods are difficult to document well, often require manual effort or intervention, and may occur only periodically resulting in data that is obsolete much of the time. Furthermore, communication that requires human intervention can add days of lag time versus automatic or real-time retrieval.

Automatic information sharing has typically been accomplished through Electronic Data Interchange (EDI). This has met the need, but has several disadvantages:

- EDI uses very strictly defined formats, which need to be negotiated in advance. Creating a new transaction format can be a significant undertaking, which makes EDI less flexible in practice than it is in theory.
- EDI takes large amounts of time, and money to implement. Custom programming is needed to extract data from local software, translate it into EDI format, and then translate and insert the transaction into other company's local software. This programming is rarely reusable, with the result that each transaction needs to be implemented separately.

While the cost of any single communication delay may seem small, the overall value lost is significant. Poor coordination generally leads to a mismatch in supply and demand. This in turn leads to increase in rises in the costs of stock out, transshipment, and expediting (due to insufficient inventory), as well as markdown, advertising and sale preparation, obsolescence, and disposal (Horvath, 2001, Fisher et al 1994). Low capacity utilization, long customer lead times, and poor order fulfillment rates are other costs of a lack of good coordination. Poor integration can result in the above and also lead to long times-to-market and lead times, poor quality, poor customer service (Ramdas and Spekman, 2000).

White et al. (2004), in their report to the National Institute of Standards and Technology, calculate the economic value of inadequate integration in the U.S. to be more than $5 billion per year for the automotive industry and almost $3.9 billion per year for the electronics industry; these amount to approximately 1.2% of revenues in each industry.

1.2 Problem Definition

In light of this lost value, there is a need for an information sharing solution that can enable good supply chain integration. Such a solution would:

- Be holistic, integrating metrics information from all corporate data sources, analyzing it together, and present a complete and coherent picture.
- Carry not just transaction information, but also analysis functionality
- Support Lean or other performance improvement education and behavior reinforcement
- Reduce the need for human intervention in data transfer
- Enhance knowledge management, building corporate knowledge in addition to individual.
- Be flexible and easily adapted to changing needs
- Enable fast, low cost development, resulting in good return on investment

Raytheon IDS has a system for internal information sharing that meets these criteria called the "Virtual Business System" (VBS). However, it does not have a system that meets all these criteria to facilitate coordination with its suppliers.

1.3 Research Question

VBS has assisted in aligning the company to meet its goals internally. Is it possible to meet Raytheon's supply chain integration needs by extending use of the system to Raytheon's suppliers and / or customers? If not, to what role(s) is it best suited and what lessons can be learned that would lead to a better method of enabling comprehensive, holistic information sharing (vs. function specific systems)?

1.4 Thesis Overview

This paper will first explore how VBS has helped Raytheon to date by discussing the needs for internal supply chain alignment and identifying gaps that VBS has filled. Raytheon's external supply chain needs will then be explored, and it will be shown that VBS is a reasonable candidate to fill the gaps that exist.

The research question is investigated by modifying VBS software or VBS-like systems to make them supplier accessible. The result of the investigation work is a working prototype that will be described. A next step (not reached yet) would be to test the prototype and draw conclusions about how well it works.

The method of modifying the VBS software will be reviewed, and the significant issues that needed to be dealt with explained.

The development process and prototype will be discussed to identify how well the prototype meets the needs previously identified, and how it compares to alternative solutions.

Conclusions will then be drawn about the answer to the primary research question, and how widely applicable the lessons learned here are to other situations and companies. Further areas for research will also be described.

1.5 Scope / Analysis limits

The analysis in this paper is based on the author's experiences and conversations during and after his six-month internship at Raytheon, not on multiple trials of controlled experiments at different companies. The investigation was substantive but not exhaustive; it is possible that the conclusions would need to be adjusted if key facts were present that the author did not uncover. Because the study was specific to Raytheon, the conclusions may not apply directly to other firms or different industries. The broad principles should remain the same regardless, although implementation details would need to be modified. Most importantly, while lessons learned have been drawn from the author's experience, the pilot implementation is a critical to a robust answer of the research question.

2 Background on Supply Chains and Supply Chain Management

The literature regarding supply chain, supply chain management, and supply chain integration is extensive. In this section, we will provide a brief description of the fields, eventually focusing in on recent papers which discuss information sharing and supply chains.

One clear theme that emerges from the Supply Chain literature is that the there is very little agreement regarding basic definitions (Chen and Paulraj, 2003). In addition to discussing the different points of view, we will endeavor to clarify the way terms will be used in this paper.

2.1 History of Supply Chains and Supply Chain Management

While de facto supply chains have existed since the beginning of commerce, the academic study of how to efficiently deliver product to consumers is estimated to have begun around the turn of the 20th Century with the study of agricultural economics, how to transport products from the farm to the point of sale. (Kent et al. 1997)

The optimization of production in the US made significant strides in the early 20th Century. The most notable was the development by Ford Motor Company of the moving assembly line between 1908 and 1915. Henry Ford also was among the first to describe supply chain management ideas in his 1923 autobiography *My Life and Work*, in which he outlines ideas that will later be called "Just-in-Time" (JIT). During and after World War II, the need to efficiently supply troops given limited resources led to intensive research and practical efforts on how to optimize functions such as warehousing, wholesaling, inventory control, inbound, and outbound transportation. Despite the fact that all of these items fell into category of "distribution," these efforts generally focused on each as a separate functional unit, to be executed by different parts of the organization. (Kent et al. 1997)

The "Integrated Function Era", starting in the late 1950's, was driven by a systems approach and a shift by the logistics community from narrow focus on specific distribution functions to how the various activities worked with and relied on each other (ibid).

In 1956 Lewis, Culiton and Steele introduced the concept of total cost analysis in their book *The Role of Air Freight in Physical Distribution*. This was followed by the publication in 1961 by Smykay, Bowersox, and Mossman of *Physical Distribution Management*, which discussed the system approach and total cost concepts in detail. These and other ideas were collectively described as *Integrated Logistics*.

In 1961, Forester's *Industrial Dynamics* introduced the concept of the "Bullwhip Effect," a common supply chain phenomenon so named because a graph of the magnified and oscillating demand upstream of even a relatively stable retail demand pattern is reminiscent of a cracking whip. As awareness of the concept spread (assisted by development at MIT of "The Beer Distribution Game" in the early 1960's), so did the understanding of the costs of operating in functional silos and the potential gains from supply chain integration. In particular, one major cause of the bullwhip effect is commonly believed to be that upstream supply chain partners do not have access to end customer demand and downstream decisions but see only the orders from their immediate customer. It has been shown that prompt sharing of end user point-of-sale demand information to all levels of the supply chain can reduce (but not eliminate) the bullwhip effect and its costs. This seems to be the most commonly cited application of information sharing and the beginning of focus on information sharing as an important supply chain function.

In the 1970's, the financial impact of holding inventory on the firm was quantified by Lambert in *The Development of an Inventory Costing Methodology: A Study of Costs Associated with Holding Inventory* (1976). This development allowed valuation of inventory throughout the firm from procurement through production to customer delivery, eventually a key enabler to recognizing local optimization that did not optimize globally. In that same year, Londe and Zinszer released *Customer Service: Meaning and Measurement*, reflecting the "Customer Focus" that was a primary contemporary concern. People began to think that logistics could be more than a cost center but have a role in increasing profits by satisfying the customer (Kent et al. 1997).

2.2 Definitions of "Supply Chain" and "Supply Chain Management"

The term "Supply Chain" is believed to have been coined by consultants in the early 1980's (Oliver and Webber, 1982) and reflected an increased focus on connecting the activities required to provide customer service in spite of intervening functional or organizational boundaries. As the field developed, its scope expanded and through the 1980's and 1990's the term was used interchangeably with logistics management, network sourcing, supplier-base reduction, and inter-organizational integration (Rogers and Leuschner, 2004) There still remains a great deal of disagreement about the scope of the "supply chain." While in many companies the function "supply chain" still refers merely to purchasing, in general the "supply chain" includes much more.

Cox et al. (1995) provide an expansive definition of supply chain that emphasizes its company-spanning nature:

1. The processes from the initial raw materials to the ultimate consumption of the finished product linking across supplier-user companies; and
2. The functions within and outside a company that enable the value chain to make products and provide services to the customer (Cox et al., 1995).

As people became more aware of the opportunities made available by looking at the supply chain as a system, a body of knowledge developed about how to optimize this system generally referred to as "supply chain management (SCM)." Although there are various perspectives on the precise definition, Simchi-Levi et al. (2008) defines supply chain management as "a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, and stores, so that merchandise is produced and distributed at the right quantities, to the right locations, and at the right time, in order to minimize system-wide costs while satisfying service level requirements."

Notably, these definitions make clear that the term "Supply Chain" should no longer be used as a synonym for logistics. While there remains significant disagreement both in theory and in practice, Cooper, Lambert and Pagh (1997) argue that there is a need for integration of the supply chain that definitely is beyond the scope of logistics. They cite new product development as an example of a function that is clearly not within the scope of logistics, but that must be within the scope of SCM in order to achieve its goals.

When the scope of "supply chain" is fully expanded to include supplier and customers, additional complexities are added: individual firms are working based on a local perspective with opportunistic behavior, and thus seem to have different interests. Such behavior leads to a mismatch of supply and demand and inefficiency for the supply chain as a whole. (Fisher et al. 1994)

3 Background on Supply Chain Coordination and Integration

3.1 Definitions of Supply Chain Coordination and Integration

The challenge of trying to optimize globally while dealing with conflicting objectives between parties led people studying supply chain management in the 1990's to focus on ways to "coordinate" or "integrate" the growing number of functions and relationships included in the scope.

The terms "supply chain coordination (SCC)" and "supply chain integration (SCI)" are widely used in an apparently interchangeable way, but are rarely well defined and the good definitions that exist often conflict with each other. (Arshinder et al. 2008, van der Vaart and van Donk 2007) Depending on the author, coordination can include integration and vice versa.

The Merriam-Webster Online Dictionary (2009) defines "coordinate" as "to bring into a common action, movement, and condition; to harmonize." It defines "integrate" as "to form, coordinate, or blend into a functioning or unified whole; to unite." Likewise, in the literature the term "supply chain integration" often implies a focus on joint business processes that allow a supply chain to be managed as a single entity. In business usage, the term tends to become even more concrete, referring to specific practices such as Vendor Managed Inventory (VMI) and information systems used to automate or ensure efficient operation of business processes across multiple functions, departments, or organizations (Vickery et al. 2003).

Combining concepts from various sources, we propose the following definitions:

- Supply Chain *Coordination* includes those actions, patterns, and attitudes (van der Vaart and van Donk 2007) meant to ensure that the optimal actions of each agent will align with the supply chain system's objective. (Line et al. 2008)
- Supply Chain *Integration* includes those business processes, technologies, and systems that enable seamless transfer of material, money, resources and information (Naylor et al. 1999) between supply chain partners (both internal and external to a firm) as easily as if they were members of the same organization.

The suggestion is that *coordination* should describe the subset of Supply Chain Management concerned with *identifying* the optimal actions for each member of the supply chain, while *integration* should describe the subset concerned with *executing* these actions efficiently. In practice, the two will almost always be observed together as they are ineffective on their own.

3.2 Implementing Supply Chain Coordination

So what is required for firms to successfully take advantage of the promise of supply chain management? Simchi-Levi et al. (2008, pg 16) list three critical abilities:

- The ability to match supply chain strategies with product characteristics.
- The ability to effectively manage uncertainty and risk.
- The ability to replace traditional supply chain strategies, in which each party in the chain makes decisions with little regard to their impact on other supply chain partners, with those that yield a *globally optimized* supply chain.

The first and second abilities are analytical, and involve identifying the optimal solution for a given situation. The third ability, on the other hand, is an organizational ability and requires obtaining the cooperation of the various parties involved.

Ballou, Gilbert, and Mukherjee (2000), in laying out a conceptual framework for SCM, identified it as being composed of three different types of coordination: intra-functional (e.g. within the planning or purchasing function of a firm), inter-functional (e.g. between logistics, production, finance, and marketing), and inter-organizational (between legally separate firms, such as buyers and suppliers).

Simchi-Levi et al. (2008, pg 165) provide two basic questions that need to be addressed by coordination schemes. First, who will determine the globally optimal course of action for the group? Second, how will the benefits obtained be distributed? Simatupang et al. (2004) propose that a primary objective of supply chain coordination is to resolve inter-functional conflict, suggesting a third question: how will conflicts and disagreements between parties be resolved?

In the case of intra-functional coordination, the answer is usually straightforward; whether the corporate structure is primarily functionally oriented, market oriented, or matrixed, most firms designate individuals to specific planning and coordination roles and identify the decision-making process for the group (which could be hierarchical, team-based, etc.).

Inter-functional coordination is more complex because different functions may have performance objectives that are not independent and require trade-offs. Ballou et al. (2000) list three items critical to maintaining relationships between different groups: *metrics* that enable benefit identification and analysis, information sharing mechanisms for transferring the metrics and other information, and an allocation method for distributing the benefits fairly.

The same three items apply to a greater extent in inter-organizational relationships between firms, where unlike functions of a single company 'esprit de corps' and inherent interest in the fortunes of the company is not naturally present. This greatly magnifies the importance of being able to effectively identify performance and benefits with metrics and to distribute benefits fairly between firms.

Byrnes and Shapiro (1991) emphasize that effectively implementing metrics and allocation methods to incentivize coordination requires making fundamental changes to the way a company does business. In particular, the way organizations and the people inside them are evaluated and compensated need to be re-aligned with the new metrics or people's behavior is unlikely to change.

Byrnes and Shapiro give one example of a case where a problem remained hidden because it involved the relationship of the companies, rather than within either one individually. They assert that one major reason for the delay in recognizing the problem was that the company's extensive computing system did not provide the data needed to understand the costs of intercompany product flows. They explain the failure of a competitor's attempt to implement a similar solution as the result of three flaws: 1) the effort was too unfocused and not tailored to the customers and products for which it was the best solution; 2) communication was not improved with the customers, so the company was unable to compensate for changes in demand or customer concerns; and 3) no reconfiguration of the actual product distribution process was made, and so cost efficiencies were not captured.

Byrnes and Shapiro warn that two problems may result from spending insufficient time in "awareness" and "orientation" stages of developing inter-company ties and proceeding immediately into "implementation": 1) a company may develop momentum in a low-payoff area and neglect more fruitful opportunities, and 2) moving directly into implementation may not allow sufficient time and focus to be spent on making organizational and management changes to align group and individual incentives with the new initiative.

There has been a great deal of research into the specifics of how supply chain coordination and integration can be implemented. Arshinder et al. (2008) categorized the research into five groups:

1. Role of coordination in supply chain models
2. Coordination across functions (e.g. Logistics, Inventory, Forecasting, and Product Design)
3. Specifics of coordination and integration at material interfaces (e.g. Procurement-production, production-inventory, production-distribution, and distribution-inventory)
4. Coordination Mechanisms (Supply Contracts, Information technology, Information sharing, Joint decision making)
5. Empirical Case Studies

Opportunities for integration generally exist where inter-organizational dependencies appear between functions. Appropriate modes of integration depend on the specifics of the interface and the functions involved.

Simchi-Levi et al., Simatupang et al., and Ballou et al. provide a series of questions that must be answered to maintain effective coordinating relationships. Combining them, we have:

1. Who will determine the globally optimal course of action?
2. What metrics will be used to enable benefit identification?
3. How will these metrics and other information be transferred?
4. How will benefits be distributed?
5. How will conflicts and disagreements be resolved?

3.3 Coordination Mechanisms

As noted above, Arshinder et al. listed the four areas most commonly applied as Coordination Mechanisms: Supply Contracts, Information technology, Information Sharing, and

Joint Decision Making. Byrnes and Shapiro emphasize information sharing, and add an additional mechanism: an agreement that one channel member takes operational and financial responsibility for key portions of another channel member's operations. (Byrnes and Shapiro)

3.3.1 Contracts and Incentives

The main drawback of global optimization by a single party is that an optimization will usually give uneven advantage to certain members of the supply chain and may actually reduce profitability for other members. Since presumably the disadvantaged members would decline to participate, sharing of benefits is a critical enabler of coordination. Supply contracts are the most common method for allocating benefits, and are generally designed to maximize each supply chain partner's profitability when they comply with the globally optimal strategy. (Simchi Levi et al 2008 pg 129, Li et al 1996, Moses and Seshadri 2000, Chen and Chen 2005, Tsay 1999)

In fact, supply contracts can also address the question of who determines the globally optimal course of action. Supply contracts can achieve global optimization without the need for an unbiased decision maker, and when carefully designed can achieve the same results as global optimization by allowing buyers and suppliers to share the risk and the potential benefit. Typical contracts used in this way for make-to-order supply chains usually shift risk from the customer to the supplier and include buy-back and quantity-flexibility contracts, which allow some degree of refund for unsold goods and allow the supplier to share risk with the customer. Revenue sharing and sales rebate contracts, in conjunction with pricing, alter the risk and incentives leading parties to make optimal decisions. Contracts used with make-to-stock supply chains include take-or-pay (also known as pay-back) and cost-sharing contracts, which shift risk from the supplier to the customer. Contract manufacturers and suppliers that need to expand capacity to provide a product may use capacity reservation and advance purchase contracts to increase the chances of getting credible forecasts from the customer (Simchi-Levi et al. 2008).

Each contract type has drawbacks and limitations. Buy-back contracts can incent customers to steer demand to items from other suppliers that have no buy-back policy. Cost and revenue sharing contracts typically require a high degree of trust and information technology infrastructure that enables both parties visibility to otherwise private internal information. (Simchi-Levi et al. 2008) In many cases, the objective of global optimization is met by carefully calculating the contract terms based on a variety of demand and cost factors. If any of these factors change and the contract does not have flexibility built-in then the contract will no longer ensure optimal results.

Both Simchi-Levi and Byrnes et al point out that especially when contracts are involved, effective measurement of performance relative to performance goals and making financial benefits for both partners explicit are essential for gaining and maintaining support for the project.

3.3.2 Information Sharing

Simchi-Levi et al (2008) argues that abundant information has a host of benefits which relate to reducing variability in the supply chain. Abundant information helps suppliers make better forecasts, and enables retailers to react and adapt to supply problems more rapidly. It enables coordination of manufacturing and distribution systems and strategies, leading to reduced lead-times. It also enables retailers to better serve their customers by offering tools for locating and special-ordering desired items.

Among the more dramatic benefits of information sharing is the reduction of the "bullwhip effect," an increase in variability as we travel up the supply chain (Simchi-Levi et al 2008 pg 154). Described by Forester as a system dynamics example, this phenomenon was named by Lee et al (1996, 1997) and has since been the subject of significant research, including by Chen, Drezner, et al (2000) and Chen et al (2000).

Graves (1999) makes an apparently contradictory finding, demonstrating that for nonstationary integrated moving average (IMA) models "there is no value from letting the upstream stages see the exogenous demand." This finding, however, assumes that the upstream stage already knows the demand distribution and its parameters. Graves notes that if the upstream stage does not know the specific customer demand process then having access to the actual demand data could help characterize it.

Information sharing will be discussed further below.

3.3.3 Information Technology

Supply Chain Information Technology (IT) has four primary goals: 1) Collect information on each product from production to delivery or purchase point, and provide complete visibility for all parties involved; 2) Allow access of any data in the system from a single point of contact; 3) Partially or fully automate the process of analyzing, planning activities, and making trade-offs based on information from the entire supply chain; 4) Facilitate collaboration with supply chain partners (Simchi-Levi et al 2008 pg 414).

IT is especially useful when used to improve inter-organizational coordination, where time, distance and lack of social networks can make more informal communication methods less effective. (McAfee 2002, Sanders, 2008) The internet and world-wide-web, due to wide availability, can be particularly useful in enhancing effective coordination of operations. Examples of applications include enabling review of current SC performance metrics, as well as a history of past performance. Visibility into partner inventory can also enable decisions about when and how much of certain products need to be produced and to manage workflow systems (Liu et al 2005)

One important issue to consider when developing IT is the need for broad applicability andcode reusability in order to gain economies of scale and provide a satisfactory return on investment. Hsu, et al (2007) in examining the "on-demand information exchange problem," identify several problems with state of the art IT integration projects such as CFAR by Wal-mart and Warner-Lambert. First, the mechanism is not readily expansible to include other supply chain participants. Second, the mechanism hard coded the information to be transferred rather than providing it on demand. They add that while global database queries would resolve these issues, companies (or even departments within companies) are generally reluctant to surrender much control of their databases. One result is IT projects are as much political challenges as they are technical.

Another key issue in supply chain IT is that company's computer systems are generally not directly compatible and may not be well equipped for electronic integration. White et al (2004) noted that repeated manual entry of data is a common symptom of poor integration. Finding ways to establish connectivity, security, and compatibility between systems is the key to integrating IT systems to enable supply chain coordination.

One recent trend in dealing with this issue is the "third party intermediary" e-marketplace (Nucciarelli et al 2008), an independent- or consortium- owned website that serves as a central hub for information, usually within a specific industry. By storing the information in one accessible location in a standard format, some economies of scale can be achieved and all tiers of the supply chain can use the same system. (Hewitt 2001, as cited by Beckman and Rosenfield 2008). One example of a consortium-based e-platform is Exostar, which serves the defense and aerospace industry and of which Raytheon is a member.

3.3.4 Joint Decision Making

Joint decision making can come in many forms, but involves making decisions cooperatively to reach a global optimum that could not be reached if they were made separately. In this way, the question of "who optimizes" is answered by "both parties, together." Arshinder et al (2008), in creating their Supply Chain Coordination Index, specifically included joint consideration of costs, replenishment, forecasting, and ordering.

Collaborative Planning, Forecasting, and Replenishment (CPFR) is both a web-based standard and a business process designed to facilitate such cooperative decision making. The standard allows partners to exchange comments with supporting data to allow the partners to resolve differences in forecasts or production plans. The CPFR Roadmap (CPFR, 1999, cited by Simchi-Levi et all 2008) has the supply chain partners agree on:

1. Guidelines for the relationship
2. Joint Business Plan
3. Sales Forecast, and how to deal with exceptions
4. Order Forecast, and how to deal with exceptions
5. Actual Orders

3.3.5 Delegation of Responsibility

In some relationships, integration is achieved by one party delegating operational responsibility for a part of the operations to a supply chain partner. The classic example is Vendor Managed Inventory (VMI), in which the customer delegates the responsibility of keeping themselves stocked to the supplier, and provides the supplier with demand and inventory information with which to do so. These relationships differ from other outsourcing in the degree of integration; in many cases, some supplier personnel work at the customer's site to ensure quality service, and it may not be clear to an observer or visitor that there are two companies involved at all. (Byrnes and Shapiro 2001)

4 Discussion of Information Sharing

4.1 Types of information

While in the literature to date "information sharing" tends to be used to refer specifically to sharing of inventory and demand data, effectively integrating a supply chain requires much more. In order to make sense of the possibilities, the author proposes the following framework for types of information that can be shared, based on how the information is used:

1. *Business Process* Information includes the entire value stream of the product, and describes both the physical transformation and movement of the product from raw materials to finished goods at the customer and the related information flows that trigger or facilitate these movements, such as purchase orders, invoices, or advance shipping notices (ASN). It is useful to break down such a large category further:

    a. *Basic Commerce* information includes the bare minimum information that must be exchanged for arms-length transactions to occur: Product catalog, purchase order, shipment information, and invoices.

    b. *Exceptions and Issue Resolution* information describes any situations that do not fit into the normal business process, such as an unexpected stockout or transportation delay. It also includes information about the plan of action for resolving the issues.

    c. *Product Detail* includes any other relevant information about the product, including engineering drawings, quality test results, batch traceability, and metal content for compliance with European REACH regulations.

    d. *Operations* information includes data used tactically to keep the supply chain running smoothly, such as: inventories, production and procurement plans, and forecasts.

    e. *Extended Supply Chain* information regards all supply chain partners who have agreed to work together. Information may include the identity of the other customers and suppliers in the chain, end-user demand, and original raw material costs. It may also include parameters needed to find globally optimal policies, such as production and inventory capacities, process throughputs, and transportation times.

f. *Internal Operations* information is other operations information such as line efficiencies, rework rates, and internal costs that don't need to be exchanged for supply chain activity (in fact, most companies prefer to keep this private) but may be shared in certain situations, such as in cost-plus contracts and when the customer is assisting the supplier in improving its processes.

2. *Supply Chain Integration Process* information describes how the supply chain partners work together. It includes the contract and benefit sharing agreements (if relevant), points of contact, and metrics that indicate supply chain partners' performance and how the supply chain as a whole is performing. It also includes decision rules that dictate how exceptional situations are to be dealt with, and a dispute resolution process for dealing with any controversy. Finally, it includes documentation of the supply chain continuous improvement plan (if one exists), along with the issues currently outstanding, their costs, and action plans to resolve them.

3. *Continuous Improvement Meta-Process* information shows if the supply chain integration and continuous improvement processes are effective. It includes metrics on the rate of improvement, as well as employee participation and compliance with the continuous improvement process, and documentation. This information is used to improve the supply chain's ability to improve as unit.

4.2 Ways to share information – systems and processes

There are too many different possible communication methods to list. However, they can be grouped by characteristics that affect their utility for supply chain coordination.

- Manual or Automatic – Does the communication require human intervention? While exceptions will inevitably occur requiring intervention, manual methods should be minimized for routine communications, reducing clerical work and freeing people to do other tasks. Kauremaa et al (2009) categorize inter-organizational information systems as human-to-system (involving human intervention, e.g. a web portal), or system-to-system. They find that while human-to-system integration is better than none, system-to-system IT integration provides significantly more operational benefits, reducing manual work by 90% compared to the human-to-system process.

- Documented – Does the communication leave a record of its contents that can be referred to later? How hard or easy is it to search for specific content? Can conversations be threaded (grouped together) for easy discussion, and linked to other relevant files? Phone calls, while very convenient, leave no record and therefore do not contribute to institutional knowledge. Documentation must be done manually by the participants, which is unreliable. However, new automatic transcription services are becoming available that may change this.
- Push or Pull - Is information pushed by the provider (like EDI and Email) or pulled (available on-demand, like a web page or SQL database) by the consumer? Information push works well for routine communications, but consumer needs change, they must convince the provider to push different information, which can take time and is therefore less responsive. Having updated information that can be pulled by the user (or the user's system) when they need it provides more timely information and allows the user to take what they need, and change their own pull as necessary.

4.3 Impact of Information Sharing Platform Architecture

Information Sharing "e-platforms" can be private (owned and operated by a particular member of the supply chain), peer-to-peer (each member has a server, which communicates with the others), or a third-party hub (operated independently). Third-party e-platforms can be owned by a consortium of industry members (such as Exostar) or be an independent business.

According to Grieger (2003), cooperative supply chains aim to reduce the number of suppliers and create long-term relationships in order to gain a strategic advantage. Private e-platforms, since they are tailored to the needs of the specific context, generally provide superior collaborative capabilities to the supply chain, and therefore a better opportunity for competitive advantage. (Nucciarelli and Gastaldi 2008) However, when one supply chain partner runs the platform they have access to all data stored there; this is only satisfactory when the host company is dominant in the supply chain and would have access to this data anyway. Even so, partner companies are often concerned about putting private data on a server they do not control, and may be reluctant to participate. They would certainly be reluctant to allow another firm direct access to their information systems, and so if they lack an external "gateway" database they will most likely be disinclined to participate. Furthermore, while immediate partners may be comfortable participating on a private platform, supply chain partners two or more tiers away who have no direct relationship with the host firm may be reluctant to trust the host or invest in the system.

Third-party hubs have the same access problems, but as independent brokers have fewer trust issues. They also have the advantage of economies of scale – a third party hub can provide services to competing supply chains, as does Exostar. More participating firms lowers the cost for each participant. Third party hubs also have the advantage of not requiring installation or maintenance expertise from the participants, who need to learn only how to use the system.

4.4 Difficulties, costs, and limited returns

The presence of a strategic willingness to put more investment into portal management and the availability of personnel skilled in working with legacy systems are some of the most relevant factors for the success or failure of B2B e-marketplaces (Buhalis 2004; Kirby 2003; Duke-Woolley 2001). For supply-chain platforms, collaboration requires the development of shared information technology structures. This strategic intention must extend to the restructuring of partners' value chains for information sharing to be effective. (Nucciarelli and Gastaldi 2008)

Hsu, et al (2007) in examining the "on-demand information exchange problem," identify several problems with state of the art integration projects such as CFAR by Wal-mart and Warner-Lambert. First, the mechanism is not readily expansible to include other supply chain participants. Second, the mechanism hard coded the information to be transferred rather than providing it on demand. They add that while global database queries would resolve these issues, companies (or even departments within companies) are generally reluctant to surrender much control of their databases.

Integration agreements meant to obtain the highest level of synergies include sharing of critical assets, and require the development of centralized systems that allow economies of integration, scale, and learning. From Nucciarelli and Gastaldi (2008)

4.5 Confidentiality

Li and Zhang (2008), examining the situation of one manufacturer providing material to two or more retailers competing on price, conclude that if the manufacturer discloses one retailer's information to the others that the retailers will be hurt and will not cooperate further. On the other hand, if the manufacturer provides confidentiality to the retailers that the highest supply chain profit is achieved and also that each party's incentive to participate fully and truthfully is maximized. This occurs because the wholesale price charged by the manufacturer becomes a signal for the state of the market as a whole. They caution that if the retailers compete on quantity, confidentiality increases the wholesale price and reduces the supply chain efficiency.

5 Project Context and Background

5.1 Raytheon Background

Raytheon Company describes itself as "A technology and innovation leader specializing in defense, homeland security and other government markets throughout the world" (Raytheon Corporate Overview)

Founded as the "American Appliance Company" in Cambridge, MA in 1922, Raytheon has a long history of technological innovation, especially in radar, microwave, and other electronics technologies.

Headquartered in Waltham, Massachusetts, Raytheon is one of the top ten prime defense contractors in the US (Dorsch 2009). In 2008, it had sales of $23.2 Billion, of which 79% were to the US government. International sales, including sales to foreign militaries through the US government, represented 20% of total sales and include customers in 80 different countries. The remaining amounts included sales to state and local law enforcement agencies (2008 Annual Report).

The international side of the business is growing, and in 2008 international business accounted for 28% of total bookings (firm orders and contracts for future work). In particular, in 2008 Raytheon was awarded a $3.3 Billion contract to provide the UAE with an updated version of the Patriot missile.

Raytheon operates as six largely independent divisions: Integrated Defense Systems, Intelligence and Information Systems, Missile Systems, Network Centric Systems, Space and Airborne Systems, and Technical Services. The research for this thesis was conducted during the author's internship with Integrated Defense Systems.

In the past primarily a high technology electronic component firm, Raytheon has increasingly tried to position itself as a prime contractor for major defense projects. In 2006 Raytheon beat aerospace giant Lockheed Martin to become one of two finalists for Prime Contractor of the Joint Cargo Airplane, despite no longer being an aircraft manufacturer. While it did not win the contract, becoming a finalist showed that Raytheon could credibly compete with

Boeing and Lockheed Martin for lucrative prime contractor / system integrator roles. (Global Security.org)

Raytheon's Integrated Defense Systems (IDS) division is the prime contractor for the Patriot Missile system, and is also the Mission System Integrator for Zumwalt-class destroyer (DDG-1000) program, Raytheon Company's single largest contract in 2008.

Integrated Defense Systems in based in Tewksbury, MA. The primary manufacturing site is the "Integrated Air Defense Center" in nearby Andover, Massachusetts, where the author was based during his internship. Originally constructed to build Patriot Missiles, the facility is again preparing to build Patriot Missiles for the UAE contract. It also is the primary manufacturing site for many other programs including land and sea-based radars used for missile defense.

5.2 VBS Background

Virtual Business Systems (VBS) is a system with software and hardware components designed by Raytheon employees to improve operational performance by facilitating and reinforcing lean behavior.

5.2.1 VBS Components

VBS consists of a client software application called the "launch pad", from which are run a variety of function-specific "dashboard" applications; a database called the "VBS Data Factory," and "SMART" (Self Monitoring Adaptive Real Time) display monitors positioned throughout the IADC. VBS is set up on a client-server model, in which the server responds to data requests while the program logic, analysis, and formatting is performed on the user's computer.

The "front end" (user interface) applications are written using the National Instruments Labview platform, a graphical programming language most often used for controlling and analyzing data from computerized testing setups. The primary application is a "launch pad," which enables the user to browse through, search for, and launch function-specific "dashboard" applications which they have access to. The launch pad downloads any dashboard that the user doesn't have installed, and ensures that the user always has the most current version of each dashboard. The launch pad also runs a small program in the background that enables the "express messaging" pop-up communication.

The "back end" is a Microsoft SQL server database which stores a near real-time digest of data harvested from a wide variety of company systems. The data harvesting and administrative functions are mainly performed by a collection of specialized dashboards programmed in the same way as the client applications and run on a dedicated server.

SMART monitors consist of small "appliance" computers and flat screen monitors positioned throughout the workplace. These monitors can be used to display any of the VBS client screens, including metrics charts, performance graphs, etc. They can be set to rotate through the desired screens, and can also display pictures or "bulletin board" announcements. The SMART monitors need only be connected to power and network; when they are turned on, they autonomously connect to the VBS server, downloading their assigned display programs and beginning the screen rotation.

Monitors are placed in groups near facility entrances, to display announcements and metrics of facility-wide interest. They are also located in the work centers, where they generally display information relevant to that department. Monitors are used to inform managers and passers-by of the recent performance, and have more recently also been used by team leaders as information sources and references for team meetings.

5.2.2 Most Common Applications of VBS

Since its inception, dozens of 'dashboard' applications have been developed for VBS. Its flexibility has enabled it to be used for functions as varied as calculating small and disadvantaged business (SDB) spending and automatically allocating overtime hours, but its primary purpose has been to bias people in favor of efficient and lean behavior. The common categories of VBS applications are:

1. *Visual Metrics,* used to generate awareness, reinforcement, and accountability for desirable behaviors within the company.
2. *Real-time data* for decision making, harvested from a large number of corporate systems and brought together in one place for analysis and display. Many metrics "drill down" to the supporting data, allowing immediate analysis of anomalous numbers. Reports are customized to meet the users' needs and reduce wasted time for data collection and review.

3. *Communication and collaboration tools,* including "express messages", announcements, problem solving database, issue escalation, and employee-contributed "raise your hand" issues.
4. *Lean and Raytheon Six Sigma practice tools* for problem solving, standard work, cause and effect diagramming, 6S audits, and more.
5. *Improving the Improvement Process* by tracking Total Employee Engagement (TEE), usage of each dashboard, audit compliance, etc.

5.2.3 Short History of VBS and its organization

VBS was created in 2003 by John Day, a Raytheon electrical engineer and Raytheon Six Sigma Black Belt who was looking for a way to reinforce lean behavior and improve performance by displaying metrics and simplifying data retrieval. Several years later, Mike Kaczmarski joined him and introduced a highly reusable software architecture incorporating modularity and templates. The initial applications were developed to display metrics in one manufacturing workcenter. Through grass roots and referral, it eventually spread throughout the IADC as additional functionality was added to in response to user demand. It is currently the primary tool used by IADC manufacturing to compute and display metrics, handle overtime bidding and assignments, and communicate electronically with the hourly workforce. IDS's Integrated Supply Chain and Quality (ISCQ) organization has been funding development of a "cost of quality" dashboard that combines metrics from the four life cycle phases of a product at Raytheon: engineering, manufacturing, supply chain, and whole life support. This dashboard will calculate a single overall measure of value-chain performance and allow drill-down to the supporting data. Additional Raytheon facilities in IDS and other divisions are looking at bringing VBS on-line in their areas as well.

The VBS team is an unusual organization. Technically, it does not exist: It does not appear on organization charts, have a budget in the accounting software, or have any employees assigned to it. In fact, during the author's internship it had two rooms dedicated to it, four full-time personnel (including the author), three half-time personnel, and at least four others who were doing some development work each week. Each of these people is unofficially attached to

VBS but is officially assigned to a different organization. John Day, the team lead, is an electrical engineer. Other common assignments include test and quality engineering.

Likewise, the VBS team has no official budget but relies on using charge numbers provided by client organizations. Each new client organization gets the benefit of VBS software developed to date, and helps support development of functionality that will benefit not only themselves but the rest of the VBS community. Client organizations typically also are asked to assign one or more people to the VBS team to help with development on a part time basis. This has several benefits: 1) the client organization is consistently well represented when decisions are made, increasing the chance of meeting the client's needs; 2) the pool of people qualified to develop VBS grows, and the client organization has at least one of their own who can make changes or upgrades with support from the core VBS team; 3) it leverages the expertise of the core team, who can spend time coaching or resolving difficult problems and not be completely absorbed in the minutia of each project.

The VBS team receives network and hardware support from the IT division but operates completely independently from the applications and enterprise reporting IT groups. As a result, there is sometimes tension between the VBS team and IT, many of whom consider VBS to be a "shadow" IT group. However, the VBS team is so productive and responsive to its clients that the VP of IT who recently visited was heard to comment "I expected to see a shadow, but this shadow is taller than the tree!"

In many ways the VBS group is an excellent case study of successful entrepreneurship in the midst of a bureaucratic corporation. It has survived, and even thrived, on the team's ability to produce a useful product that is a more attractive option than either packaged software or custom options available from IT. Its ongoing existence depends on the team's ability to continue selling product growth and on the continued goodwill of the team members' respective management to permit deviation from normal departmental duties.

VBS has succeeded so well, in fact, that this year it finally attracted the attention of IT executives who decided that VBS would have to be reconciled with the official IT strategy "roadmap." To do so, they face a considerable challenge: to take a successful entrepreneurial group and re-integrate it while identifying and preserving the characteristics that made the group successful in the first place.

Since then, the VBS group and IT have tentatively begun to collaborate. As a result of a recent ERP implementation, IT has acknowledged that VBS fills some important gaps and has confirmed an important role for it in the transition plan. The VBS team is also collaborating with IT to improve the VBS database's performance, and to make it available as a data warehouse for other IT applications as well. (Day, 2009)

5.2.4 VBS Development Approach

One of the characteristics that Day credits for the success of VBS is the group's approach to development, which is "fundamentally evolutionary and adaptive." As opposed to delivering a finished application from a specification, VBS developers first aim to quickly—often within days—develop a "60% there" prototype, which is then put into use by the client. Frequent feedback meetings with users provide the priorities for the next iteration of development. Usually within a few cycles the application will be "95% there," at which point the process pauses until changes are needed. By repeating the process in quick cycles and maintaining regular contact with users even when no active development is taking place, coordination with the client is maximized and VBS can be quickly adapted to the users' processes and needs.

5.3 LFM with VBS

McCraghren (2005), the first LFM to work with the VBS System, "explored the idea that [manufacturing] decision making can be improved through the automated transformation of data into information for real-time display on the factory floor." While his research was focused largely around the use of metrics to motivate improvement, he discussed several important characteristics of information that made it useful for decision making: it must be understandable, timely, of reliable quality, and available widely throughout the organization to provide the greatest benefit.

Wolbert (2007) applied dashboards in the inspection area to enable an area "to understand how it is performing and initiate continuous improvement projects to improve performance." He concluded that "Raytheon must continue to examine both its internal and external supply chains to make them more lean," an effort which is advanced by the project which led to this paper.

Antoniou (2008), in studying the use of visual analytics to change behavior in the program management function, concluded that one major benefit of the system he implemented is that it freed the stakeholders from data gathering and information reporting. These tasks had previously taken up ten percent of the total work hours for the stakeholder group. This type of benefit is likely to apply for other functions using such a system.

Ho (2008) gave an example of how in engineering "existing metric presentation introduced lots of non-value added work… the metrics had to be collected from different databases, which increased lead time." This provides additional evidence for the wide applicability of Antoniou's finding.

6 How has VBS assisted in aligning efforts inside the company?

6.1 Needs

In order to operate effectively, companies need certain characteristics. They need metrics, effective communication, information access, process improvement methods and tools, employee engagement, knowledge management and sharing.

6.2 Existing Systems

Raytheon, like many companies, has a plethora of computer systems, which promote communication, assist with data gathering and analysis, promote communication, or automate tasks. The following list specifically excludes VBS, which will be discussed in more detail below.

6.2.1 Business Process Information

Communication and collaboration tools include tools that facilitate rich or robust communication in addition to merely allowing messages to flow. Communication tools in use at Raytheon include phones and voice mail, lotus notes email, online calendar and meeting scheduling, Sametime Instant Messaging, teleconference services, and Sametime Webconferencing. 'E-rooms', secure locations for file sharing and collaboration, enhance teams ability to collaborate while giving local administrators strong control over access.

Data gathering, analysis, and process optimization tools help manage the enormous amount of data generated by the company's activities and help support good business decisions. At Raytheon, these include SAP, Raytheon's Enterprise Resource Management software, which is used to manage accounting and financial data and Wavetrack, IDS's Warehouse Management System (WMS) which tracks inventory in stock, as well as providing workflow support for warehouse tasks such as cycle counts, "picks" and "put-aways." It also provides support for prioritization of those tasks.

Other data gathering systems also provide workflow support – making sure that material or documents go through the correct process. SFDM (Shop Floor Data Management) tracks material flow through manufacturing, capturing inputs of time and materials, while providing information to ensure that each work piece is undergoes the correct process steps. Other workflow systems are built into Lotus Notes (such as ACMS, the change management database) or accessed via 1RTN, the internal Raytheon website.

Optimization systems process data to both automate and optimize decision making processes; examples include Raytheon's MRP (Material Requirements Planning) systems, AIMS and WINS. MRP coordinates the flow of material to ensure that it will be available when needed. MRP is used to coordinate purchases, material releases, and shipments to ensure that Raytheon can meet its contractual deadlines.

A new Enterprise Resource Planning (ERP) system called "PRISM" is scheduled to take place after the author's internship. PRISM includes implementation of SAP's core ERP solution, which will replace Raytheon's legacy MRP systems; VM, a shop-floor management tool which will replace SFDM; and PDM (Product Data Management), which will take the replace current Engineering Document Control systems including ACMS. When complete, this implementation will significantly reduce the number of legacy systems in use, simplifying the process of gaining access to and translating data sources for VBS use.

6.2.2 Integration Process Information

Many of the same systems are used for internal integration information. The 1RTN internal website has information about corporate policies and tools, and is one of the more important internal integration systems. Others include the accounting system, which provides financial metrics, and the generic communication systems such as email that are used to communicate about both integration process and business processes.

6.3 Gaps

How can the gaps between Raytheon's needs and the available systems be identified? If a definitive catalog of systems could be developed identifying which needs each system met and how well it met them, the gaps could be seen in what needs are not covered. However, there are so many different systems at Raytheon, many of which the author may not be aware of, that this is impractical.

Alternatively, if we make the assumption that people intuitively will seek to fill unmet needs using the available tools, we can identify some of the unmet needs by observing the functions that VBS has been used for and working backwards to identify which needs it fulfills.

6.4 What Gaps VBS has filled

This section will discuss how VBS fits into the information sharing framework discussed in chapter four. As a general rule, VBS tools are as automatic as possible, well documented, and set up for pull retrieval so that users can get near real-time data when they need it.

6.4.1 Business Process Information

6.4.1.1 Integrating data from many systems for analysis and presentation

Raytheon does have "data warehouses" that, like VBS, harvest data from a variety of legacy systems, and in fact VBS gathers much of its data from these warehouses. However, Raytheon does not have another front end that is as responsive to user needs, allowing development of customized reporting and analysis in a short time period (a few days to few weeks). In many cases, legacy systems do not provide for customized presentation of data, requiring many steps to gather daily data. Most other custom reporting at Raytheon is done on the web; while web technologies provide a great deal of flexibility, requests for such reporting must be made to the Information Technologies group, which typically takes much longer, costs more, and often results in product less ideal to the customer. This is partly a result of the reusable code architecture that is the basis of VBS programming.

6.4.1.2 Automation of regular tasks

VBS is regularly used to automate repetitive time-consuming data analysis or processing tasks, freeing the individuals responsible to spend more time on value-adding activities. No other software in place can provide this ability. These function-specific dashboards cause processes to become inherently leaner, requiring less human intervention to provide the same value, thereby creating a permanent performance boost.

6.4.2 Integration Information

6.4.2.1 Promoting lean behavior

The biggest gap filled by VBS is that it is the only computer system currently in use in IDS designed to reinforce and motivate lean behavior. According to John Day, the core value of VBS is to "bias people toward continuously improving lean behavior and practices" (Day, 2008).

It does this because it forms several important parts of reinforcing feedback loops promoting lean behavior and efficient business practice, described below:

The "inner loop", focused on measuring and promoting lean behavior using metrics to ensure people follow established processes:

1. Gather data from whatever systems necessary to create a set of metrics that is comprehensive for a person or group's responsibilities.
2. Publish these metrics to the individuals measured, their supervisors, and peers to encourage accountability and harness social pressure to encourage desired behavior.
3. Provide real-time information to help individuals know their priorities for work and for improvement.
4. Provide visibility into details to help individuals successfully improve their processes and performance.
5. Gather data that documents efforts toward continuous improvement (a leading indicator), as well as actual performance improvement (a lagging indicator).
6. Repeat.

The "outer loop", focused on continuously improving the processes themselves to be inherently more lean:

1. Identify where widespread gaps exist in implementing and sustaining lean behavior
2. Respond by working with users to create lean tools to make it easier for users to do the right thing. These tools might include adding accountability (with new data capture and metrics), automating data analysis allowing the user to spend more time on value-adding activities, or assisting with use of lean tools (such as cause and effect diagramming tool for problem solving, or project book to organize problem solving efforts)
3. Gather data that documents the use of these tools (leading indicator), as well as actual performance improvement (lagging indicator).
4. Repeat.

6.4.2.2 Comprehensive data and metrics

While many systems in use provide data and metrics relevant to the subject covered by each system, there is no other system in place at Raytheon that can provide comprehensive and customized "balanced scorecard" type metrics that use data from different systems, including offering manual entry options for categories of data not otherwise captured. Furthermore, there are not at present any systems that can report on the lean metrics such as Total Employee Engagement (TEE) and 6S implementation.

6.4.2.3 Electronic communication with hourly employees

Raytheon IDS has a policy that hourly employees do not have company email or instant message accounts. This makes it more difficult for shop floor employees to contact their managers to alert them about problems that develop on the line, and much more difficult to collaborate as members of problem solving teams. VBS includes bulletin board announcement capability allowing managers to publish information to their teams. It also includes "express message," a rudimentary instant message-type communication tool that causes a pop-up with a desired message to appear on the recipients' screen. This is generally used for brief two-way communication with managers or with problem solving team members. It also includes an electronic suggestion box allowing hourly employees to "raise your hand" and report any production or safety related issues for their manager to look into.

6.4.2.4 Tracking of problem solving efforts

While issue-tracking databases are certainly available, none had been implemented widely at Raytheon to track continuous improvement projects. The "project book" application in VBS has the advantage of including a list of all team members on each project. This is one of the major sources of data for the TEE metric, which otherwise would be very difficult to calculate.

6.4.2.5 Lean support tools

The VBS team regularly creates software tools to help users implement strategies from the Raytheon Six Sigma (R6S) and lean toolboxes. Examples include tools for creating cause and effect diagrams and for identifying and tracking standard work.

6.4.3 Continuous Improvement Meta-Process Information

6.4.3.1 VBS self-monitoring metrics

VBS monitors itself. It continuously tracks usage of each dashboard to check for compliance, as well as query response times to ensure that the system is running smoothly and at high performance. The VBS team uses these metrics to improve VBS, for example by investigating why a certain dashboard is not used or whether long response times signal a need for database maintenance.

6.4.3.2 Public monitor viewing and rotation

VBS includes software for managing what material (metrics, trends, announcements, audit results, etc.) will be displayed on publicly visible SMART monitors, a key part of the behavior reinforcing feedback loop. Duplicating this capability with alternate solutions, including those utilizing the existing closed-circuit television system, would be far more expensive and difficult to implement.

6.4.3.3 Integrated, easily administered presentation

VBS does all this in a single self-updating application that is easily accessed, managed and upgraded with new functionality.

6.5 Weaknesses of VBS vis-à-vis internal alignment

Not all data systems are included – One of the most difficult tasks for the VBS team is gaining permission to access data from systems that are not already included by VBS. Database and application administrators often have the ability to decide whether or not to grant access to VBS, decisions that leave the team with little recourse. One common complaint from VBS team members was that data administrators "talk about letting us access '*their* data.' It's not theirs, its Raytheon's data!" Many important systems are not directly available to the VBS development team, including SAP and several Product Data Management (PDM) systems. In many cases, only data already exported to the data warehouse for other purposes can be used; in others, as with SAP, special data exports must be set up for each new data point requested.

Some tools not effectively implemented – In particular, the "Escalation" tools have not been set up for use by any departments. One possible explanation is that while people want to be informed if their subordinates don't handle issues, they may be reluctant to have their own managers automatically informed if they don't handle issues quickly enough.

Knowledge Management – The Project Book helps to organize and coordinate problem solving efforts. While it includes a log that allows people to make notes about the problem and how it was solved, it isn't really used as a knowledge management tool. To be useful as such, it would at least need better categorization of problems and the ability to do keyword searches of the project title and the log text, both of which would make finding relevant issues easier. It would also require more comprehensive logging of problem descriptions and solutions by users to make the entries helpful for users with similar problems.

Integration – because functionality has been added by different people and at various times, in some cases new functions have been built as new dashboards rather than integrated onto other dashboards in the most sensible place. One example is the Escalations function, which uses completely different dashboards than the other communication tools and is not integrated with Project Book as "Raise Your Hand" issues are. Poor integration reduces usage, which weakens VBS's ability to assist with internal alignment.

7 What unfilled Supply Chain Integration needs exist?

To determine if VBS can meet Raytheon's supply chain integration needs, we need to determine what those needs are. We will first discuss the needs in general, and then establish what gaps remain to be filled.

7.1 How much coordination and integration is desirable in a supply relationship?

Supply Chain coordination and integration have two main benefits:

1. Lower costs by reducing waste
2. Reduced risk from additional information and communication

How much coordination and integration is desirable is not an all or nothing answer; like all business decisions, it depends on the costs and benefits. The expected costs of any proposed coordination or implementation effort need to be weighed against the expected reduction in cost and production delay risk. Because there is generally a large fixed component to the expected costs (i.e. a certain cost per partner regardless of size or trade volume), economies of scale matter and different types of relationships need different levels of coordination and integration.

7.2 Which relationships need coordination and/or integration?

Raytheon works with dozens of customers and thousands of suppliers. There is no need to assume that they should all be treated the same; on the contrary, Raytheon will need to judge what levels of coordination and integration to pursue with each supplier. However, because of the sheer number of partners involved, it would make sense to categorize the partners into groups and determine a policy for each group. It is important to note that these groups may or may not be similar to existing supplier and customer categorizations.

There are four dimensions of categorization of partners, including suppliers and customers:

1. Importance of the partner to Raytheon relative to total sales (or spend, as appropriate) and volume. Clearly, the larger amounts of money and material involved the more potential gain there is from coordination and integration.

2. Importance of Raytheon to the partner as a proportion of sales/spend and volume. Even if a supplier is relatively minor for Raytheon, if Raytheon represents a large proportion of their business some level of coordination is beneficial to both parties.
3. Criticality of the parts supplied at this time. The more critical a part is, the more beneficial the risk reduction to be achieved through coordination.
4. Willingness and ability of the partner to coordinate / integrate. Different policies will be needed when dealing with partners who are unwilling or unable to coordinate to the level that would otherwise be desired.

For example if each parter was rated high or low in each category, there would be 16 potential categories and as many as 16 policies to take the individual needs of the partners into account. One such category might be: partner important to Raytheon, Raytheon not important to partner, parts not critical, willing and able to partner. In this case, Raytheon would want to pursue a coordination strategy that would require relatively little cost and effort from the partner and involve a moderate level of coordination.

In this context, we are using part criticality to mean how sensitive production is to disruptions in supply. Relevant factors include:

1. Is the product a commodity or a specialized good?
2. Are there many potential sources for the product or is the supplier the only source?
3. How much inventory (in days of production) is held by the customer?
4. How severe are the consequences of a stockout?

A final consideration regarding how much coordination to pursue is whether Raytheon expects the partner company to move from one category to another in the future. Effective supply chain coordination and especially integration require substantial investment in change effort and money. The Net Present Value of that investment depends on the expected return each year over the life of the relationship, so the longer the expected relationship the better the return. For short term relationships, find ways to coordinate but avoid investment in integration. For long term relationships, both coordinate and integrate to make the most of the relationship.

Sometimes, integration may be worthwhile in the context of a full supply chain even if it may seem not to justify itself directly. This would be true if the effort made to integrate a small partner could be leveraged and applied to make integration easier for many other partners, thus providing economy of scale.

Similarly, in international trade policy countries may make bilateral pacts with a variety of partners, or they may join a larger treaty. Treaties may offer the advantage of less overall negotiation, and more overall benefit, while bilateral trade pacts offer the ability to favor or disfavor a given relationship. Likewise, looking at the benefit to the supply chain has opportunity to provide indirect benefits that would not seem worthwhile when only considering a dyad.

7.3 What are Raytheon's supply chain integration needs?

As discussed above, the key aspects of supply chain coordination are metrics, communication, benefit sharing, and dispute resolution. Two other items seem to deserve specific mention discussing supply chain integration in particular: data access, which might be seen as a subset of communication; and decision rules, which would hopefully help avoid the need for dispute resolution.

7.3.1 Metrics

The classic supply chain metrics have to do with Quality, Delivery, and Cost; examples of metrics might be conformance to spec, percent of deliveries within delivery window (neither too early or too late), and cost based on a price schedule, with either per order, per item, or both taken into account. Raytheon measures these metrics for its suppliers on its Supplier Rating System (SRS). However, it also needs to know the performance of its supplier's suppliers, etc. in order to understand what affects the supplier scores. These metrics fit into the information framework as supply chain integration information, because they measure the partner performance, not a specific process.

Additional metrics that might be considered would involve implementation of lean or other process improvement systems; quality of information sharing and other collaboration efforts; these metrics would be considered continuous improvement meta-process information, because they measure effectiveness of the continuous improvement and integration processes.

If variance from optimal levels of inventory, production lot sizes, etc. can be obtained, they could be helpful as well. These metrics would be considered operations information, because they directly affect the operation of the supply chain.

7.3.2 Information Sharing - Communication

The key to cooperation in any setting is good communication. Ideally, partners in a supply chain would communicate so well that the supply chain would act as if all the principals worked next to each other in the same room. Supply chain partners are at a disadvantage, since they work for different firms and often in different locations; there is less opportunity for informal communication and the transfer of 'tacit knowledge.'

Raytheon has a need for information sharing with its supply chain partners that is rich, robust, and timely. 'Rich' information sharing implies more than just sharing of transactional data, although customer demand data is certainly included. It implies sharing all the different types of information described in chapter four – not just local business process information, but extended supply chain information, supply chain integration process information, and continuous improvement meta-process information. It implies sharing not just data, but the functionality that turns that data into useful information. It also implies opportunities for transfer of tacit knowledge that cannot be easily packaged in an EDI transaction or a powerpoint, which usually means some face-to-face time at each partner's facility. Finally, it includes knowledge management – building a common store of institutional knowledge about how the supply chain works and how to deal with issues.

Robust information sharing implies reliability. It involves easily identifying the right person to speak with for a given situation and the ability to contact them with minimal delay. It also includes having a plan to ensure that someone with subject knowledge and decision authority is immediately available to deal with urgent situations.

Typically, the earlier information is available the better because it allows more time to act on that information. Timely information sharing includes near real-time data, being able to pull information when it's needed without delay, and knowing about possible changes in plans in advance of actual decisions so contingency plans can be developed.

7.3.3 Information Sharing – Data Access

Ideally, everyone in the supply chain should have access to the information necessary to optimize the flow of the material. On the other hand, confidentiality of information is also important and members should not have access to information from direct competitors or from branches of the tree other than their own. One rule that might satisfy these conditions would be to grant access to information about demand, material movement and manufacturing plans for sections of the chain above and below, but not in parallel branches (presumably occupied by competitors, if present).

The classic example of information sharing is of inventory and end-user demand data that can be used to reduce the bullwhip effect. However, rich and robust information sharing would include on-demand access to all information needed to optimize the supply chain. This would include design drawings and bills-of-material; contractual delivery dates; forecasts, planned production, and planned orders; and potentially batch traceability information and quality data.

7.3.4 Information Sharing - Security

There are two different types of security issues to deal with:

1. Access control. Does the system effectively differentiate between who should and who should not have access to a particular type of data? Does the system accurately identify what rules should apply to a given datum?
2. Network and information security. Does the system effectively prevent unauthorized persons from gaining access to the information?

Both of these issues must be dealt with. In the case of supply chain coordination, overly strict access control can render the effort moot, while lax security can cause loss of business or worse.

7.3.5 Supply Chain Process Integration Information

This and the following sections describe supply chain *integration* needs that do not fall into the category of information sharing. However, they are discussed here because the operating guidelines, decision rules, dispute resolution process, and benefit sharing arrangements are all part of the supply chain integration process information, and the documentation of these guidelines, rules, and processes need to be shared and easily available to all employees involved in the relationship. A web site would be a suitable method for sharing this information, provided that it was kept up to date.

7.3.5.1 Operating Guidelines

Every group needs rules and norms that lay out expectations and procedures, and a supply chain is no different. Supply chains need metrics that will be used to evaluate performance, along with expected values for each metric. They also need rules about how decisions will be made, and methods to deal with disputes or disagreements.

7.3.5.2 Decision Rules

Key questions that need to be answered:

1. What are the appropriate actions to be taken with shared information?
2. When does the plan change, and who can change what aspects of the plan?
3. What forecast should the supply chain as a whole use?
4. What should lot sizes, delivery frequency, ordering policies, and stock levels be? How are these to be agreed on?
5. Will decisions be made manually or will optimization be performed by software?
6. Who is responsible for dealing with urgent situations? Should advance plans be developed for possible scenarios or decisions made on the spot?

7.3.5.3 Dispute Resolution

This is closely tied to decision rules and metrics, and deals with how to resolve situations of disagreement over decisions, or when one party is not meeting expectations regarding performance vs. metrics or following decision rules. If handled carefully, dispute resolution can strengthen a relationship; otherwise disputes may weaken it.

7.3.5.4 Benefit Sharing

Benefit sharing is necessary both to ensure that neither partner is worse off under better coordination and to incentivize partners for whom coordination is not as big a priority. Benefit sharing can take the form of:

- Assistance with process improvement
- Profit sharing via side payment
- Additional services / payment in kind

It is worth noting that good benefit sharing schemes requires the parties to identify and measure the benefits obtained through the collaboration! While this is often difficult, the effort is worthwhile because having the benefits quantified is critical for building support for similar initiatives.

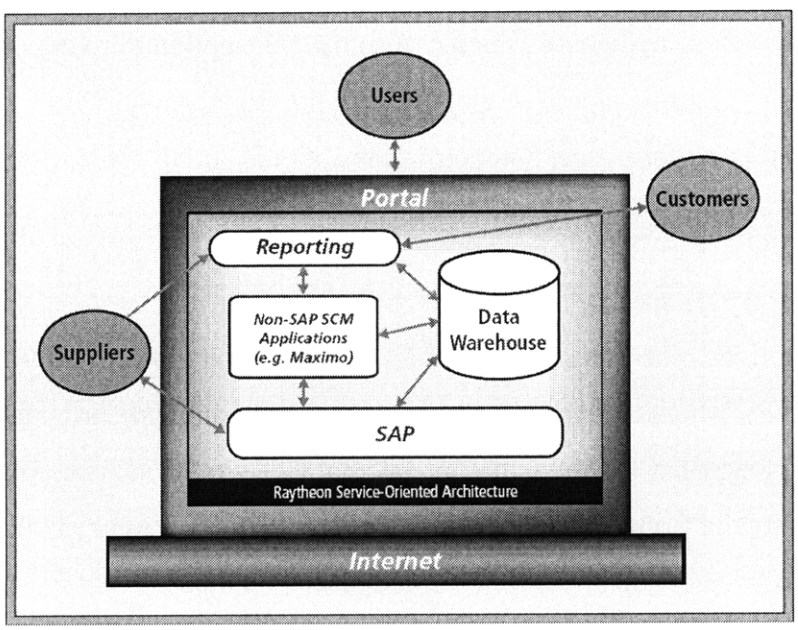
7.4 What existing systems are being used to address these needs?

Raytheon has a large number of systems that it uses to interact with suppliers and customers. Some are generic communication tools that are almost taken for granted like the postal service, overnight delivery services, telephone, fax, and email. (Raytheon uses Lotus Sametime internally, but does not have an instant message program authorized for external use.) Others, more purpose-specific for supply chain use, are part of what Raytheon calls its "Integrated Supply Chain Management" (ISCM) solution set. The ISCM solution set includes:

1. SAP Enterprise Resource Planning (ERP) system for accounting, procurement, quality, and production planning.
2. Maximo Enterprise for maintenance and operations management
3. Raytheon Spend Analysis and Supply Chain Business Warehouse for analysis of procurement activities
4. Supply Chain Data Warehouse with query and reporting tools to access data from the SAP system
5. Supplier Rating System (SRS) to evaluate supplier performance
6. Standard Reporting for customers
7. Enterprise Supplier Database provides central source of supplier data
8. Supplier Portal for suppliers working with Raytheon Technical Services Company

9. Connectivity to Exostar, a third-party supply chain integration service provider for the aerospace and defense industries.
10. Radio Frequency Identification (RFID) tags and readers for asset tracking
11. Raytheon Enterprise Material Sourcing (REMS), corporate-wide agreements which leverage Raytheon's spending power to negotiate lower prices.

The Enterprise Supplier Database, SRS, supplier portal, customer reporting, and REMS could be considered supply chain integration information. The other systems all carry business process information, mostly of the operations variety. As shown in the diagram below, SAP and Maximo interact mainly with the data warehouses to which outside users connect via a portal. In some cases of electronic transactions, some SAP modules may connect directly to the suppliers' systems. SAP is an important aspect of supply chain integration because in some cases SAP modules use the information acquired from partners to optimize further actions. Because the data warehouses are accessed via the portal and not directly, we will not discuss them in detail. However, it is useful to note that in many cases databases or data warehouses that hold only information to be shared externally are used as a buffer between portals and other firewall-spanning applications and essential business systems as a precaution.



(Raytheon Website)

We will now discuss the other systems, grouping them using the categories of information sharing needs described above: Metrics, Communication, and Data Access / Collaboration. In this chapter, we are distinguishing communication from data access in that communication systems allow users to send messages or data, whereas data access systems allow users to retrieve data on demand.

7.4.1 Metrics

The Supplier Rating System (SRS) is Raytheon's primary metric for evaluating suppliers, and is calculated monthly. Suppliers can connect securely to SRS via the web to receive a Supplier Performance Relationship Report listing their scores over the previous 12 month period. The SRS score is a weighted average of several measures of Quality and Delivery. Quality is given a weight of 60% and is calculated by combining scores of part failures in parts per million (PPM), the incoming Lot Acceptance Rate (LAR), and the number of punitive Supplier Corrective Action Requests (SCAR). Delivery is scored on the On Time Delivery (OTD), with "on-time" meaning delivery in a window from five days early to two days late. Deliveries received later than 2 days after the purchase order date receive no credit; early deliveries receive partial credit depending on how early they arrive, with no credit awarded for deliveries more than 25 days early. A handbook and a calculator spreadsheet are provided online to help suppliers understand the system. Raytheon Businesses also have the option of rating suppliers qualitatively on performance areas including responsiveness, management, technical, price/cost, schedule/delivery, and quality performance, but their use is optional and the scores are not factored into the quantitative rating.

7.4.2 Communication Systems

In addition to Email, the other internet standard communication protocol often used is File Transfer Protocol (FTP), which allows both access controlled or anonymous connection to a server to download and upload files. Raytheon has an external FTP site which is used as a drop for files being transferred to and from Raytheon. One example is that each week, a "flat" data file with MRP information is automatically generated and placed on the FTP site for Arrow to retrieve and use in stocking the Proximity warehouse. Although FTP is sometimes used as a data access tool by providing on-demand access to an archive of shared files, Raytheon seems to use it primarily as a mailbox for passing specific files and so we have included it with the communication tools.

Raytheon uses Electronic Data Interchange (EDI) to conduct electronic transactions with suppliers and customers. It has an electronic commerce operations center in Dallas, Texas, and routes EDI transactions from there via the Sterling Information Broker "Value Added Network (VAN)", the EDI equivalent of an internet service provider. EDI relies on using standard formats for transmission, with translation at each end. Raytheon uses the Aerospace Industry Association (AIA) implementation of the ANSI X12 standard version 4010. EDI works very much like email, with messages being sent via the sender's VAN and either delivered to the recipient's mailbox on that VAN or routed to the VAN where the recipient maintains a mailbox.

Raytheon conducts a variety of transactions via EDI, including invoice submission and payment, purchase order submission, and Advance Shipping Notices (ASN). ASNs, which include a manifest of the material in a given shipment, are received by ITAMS, Raytheon's receiving system. This example of integration allows Raytheon employees to receive material and induct it into inventory without having to manually enter the material information.

A central aspect of Raytheon's supply chain coordination and integration strategy is its external website, where "Supplier Connections" and "Customer Connections" pages provide relevant information along with links to several supplier- and customer– related systems. A communication-related link available from the Connections pages connects to Raytheon's external web-conferencing servers, which run Lotus Sametime. Teleconferencing is also used both together with and independently from web-conferencing.

7.4.3 Data Access and Collaboration Systems

One data access system accessible from the web page is the Quality Note database. Quality Notes are contractual requirements, usually specifying handling or processing conditions of the purchased parts, that are attached to purchase orders by adding a specific two-character code in the text field on the purchase order for such codes as opposed to printing the full text of the requirement each time. The supplier has the contractual responsibility to look up these Quality Notes in the database and comply with those requirements.

There are several collaborative tools that can be used with suppliers. These tools all provide both access control and network security, which are prerequisites for their use.

"Electronic Collaborative Environment iCenter (iCenter)," which is described as connecting "distributed teams to program related information and engineering resources through custom application portlets in a secure framework." (Raytheon website) Within IDS it is used to provide suppliers and customers with access to engineering drawings, a process that requires a Raytheon user authorized to release drawings to suppliers to manually transfer each drawing to iCenter.

Exostar, a website founded in 2000 by a consortium of aerospace and defense companies, acts as an independent third party "trusted workspace for secure information sharing, collaboration, and process integration across global supply networks (Exostar, 2009). Although Exostar includes a wide range of solutions, Raytheon uses primarily the identity management service for 'two factor' verification (utilizing a code generator key fob and PIN), and the Supply Chain Platform (SCP), which Raytheon calls "Collaborative MRP (cMRP)." Suppliers can access Exostar to see outstanding purchase orders from Raytheon and respond with promise dates, create Advance Shipping Notices (ASNs), and track shipment receipts.

Raytheon also has a special purpose-built portal called the "Weapon Information System and Data Management" (WISDM) for collaboration by Raytheon's Technical Services company with the customer for the Standard Missile, the U.S. Navy's Integrated Warfare Systems. The portal integrates with the Navy's systems, providing access to data needed for design, production, maintenance, and support of the Standard Missile. (Raytheon 2006)

Two other ways that Raytheon provides remote data access are by granting certain suppliers direct access to the Raytheon network using Virtual Private Network (VPN) and dedicated Raytheon remote Local Area Networks (LANs) at certain suppliers such as Banneker Industries. This network runs Wavetrack, Raytheon IDS's Warehouse Management System, and is used to keep inventory for the "Supplier Material Center" and "Proximity Warehouse" programs. For the Proximity Warehouse program, the inventory is tracked in Wavetrack despite being located at Banneker and on consignment from Arrow. Wavetrack has been upgraded to allow an inter-plant transfer request for that inventory to trigger purchase of that material.

Wavetrack is therefore also a supplier integration system, although that was not its original purpose.

One potential problem with these solutions is that many software solutions for internal use are not set up with access control. When VPN or remote LANs are used to give network access to suppliers, there is potential for those users to view data meant to remain within the company.

The final data access system Raytheon has in place is called "Citrix MetaFrame." The Citrix server is used to generate secure and highly configurable virtual computers that users can access using a web browser. Raytheon has both internal and external Citrix servers. The advantage of using Citrix vs. a VPN for data access is twofold:

1) when connected to the Raytheon network via VPN, all other network connections (like network printers and file servers) are unavailable, while Citrix does not interfere with those connections and even can be set up to access those resources.

2) When using Citrix, programs actually run on the Raytheon Citrix server, with the display routed to the user's browser. For data intensive operations, this vastly reduces the amount of data that needs to be sent over the internet. This also means that Raytheon has control over which programs the user runs to access the network, not necessarily the case with VPN.

7.4.4 Current VBS use for Supply Chain Coordination and Integration

During the author's internship at Raytheon IDS, two VBS applications were being developed that relate to supply chain coordination.

The first is an SRS analysis and reporting tool designed for use by the Raytheon staff responsible for operational liaison with suppliers (i.e. making sure the suppliers maintain high quality and delivery standards). The tool, which has been released and is in regular use, allows the liaisons to analyze the SRS data in different groups and over various time periods, and also allows their management to analyze the data grouped by liaison to look for trends that might suggest which supplier managers are particularly effective or underperforming. While not available to suppliers or customers, the tool has become very useful to the liaisons and plays a role in intra-functional supply chain coordination.

The second is a customer-communication application. The "customer" for most U.S. Government work is the Defense Contract Management Agency (DCMA). Because many government contracts are structured as "cost plus" (the contractor is reimbursed for all costs, with profit being accounted separately), DCMA must approve declaration of waste as part of the Failure Reporting Analysis and Corrective Action System (FRACAS) and give permission for material to be scrapped. As DCMA does not have Raytheon network access, the process is currently handled with paper forms and signatures, which can be time intensive and introduce unnecessary delay for exchange of the forms.

The VBS team is working to develop a custom application that would allow DCMA to receive the data and provide the necessary approvals electronically. Since external access to VBS is not yet available, the application will use a "peer-to-peer" architecture. When Raytheon submits FRACAs and scrapping requests, the VBS system will send the file ether by email or by FTP to an internet-accessible mailbox. DCMA will have a specialized application installed on their system, not incorporating other VBS functionality, which will retrieve these files and allow DCMA to review them, electronically sign them as approved or denied, and return them to the Raytheon VBS system which would track their status.

7.5 What gaps remain – what needs are not being met?

7.5.1 Metrics

SRS is undoubtedly useful in evaluating suppliers, but from a supply chain coordination standpoint it has room for improvement. Just as metrics measuring and reinforcing lean behavior are key aspects of the metrics implemented with VBS at Raytheon, there is a need for required measurement of the process improvement efforts and of supply chain cooperation. "Optional" metrics that are definable in different ways will by definition sometimes not be used; when they are used they will not have consistent meaning, making them unreliable as a tool for comparing suppliers.

SRS is also not calculated often enough; timely feedback is one of the keys to reinforcement, and with the current monthly system a supplier liaison could wait up to a month before seeing that a supplier's delivery performance was beginning to dip, and after taking action would have to wait up to another month to see any improvement. Today's dynamic supply chains need near-real time reporting, and SRS should be updated to fill this need.

Finally, SRS shows Raytheon the performance of its immediate suppliers. However, in the defense industry world of tightly interconnected subcontracting, to manage risk Raytheon needs to be concerned about not just its suppliers, but their suppliers' suppliers, and so on up the supply chain. There is a need for Raytheon to have timely visibility of metrics for upstream partners to help ensure a robust chain without weak links and to be aware of developing problems before they become crises. There is also a need for more extensive classical operations information sharing, gaining visibility into suppliers' inventories and production plans in order to optimize the supply chain.

7.5.2 Communication

The basic problem with most of Raytheon's communication tools (with the notable exception of the web site) is that their use does not automatically or easily transfer into institutional knowledge for Raytheon, its partners, or for the supply chain as a whole. There is no standard process for documenting phone calls and teleconferences, or for relating them to the topics they addressed. Emails stay in the inbox, but users have to go to significant effort to organize them by topic addressed (and so most users don't). There is no currently no central problem solving database that has the history of issues that arose, how they were resolved, and what the cost was in time and money; without this data it is difficult to prioritize supply chain problems for improvement. There is a need for a database, common to all supply chain partners, documenting what issues have arisen, how they were dealt with, and what they cost, to allow continuous improvement of supply chain processes. There is also a need for a simple and convenient way to attach relevant emails and to document relevant phone calls and meetings so that a full history is available and the supply chain can learn from its mistakes.

The existing structured communication tools can only pass information about decisions that have been made. There is a need to communicate possible courses of action in a structured way as soon as it is apparent that a decision must be taken to allow as much time as possible for preparation by affected partners and feedback about possible consequences of each course of action. Such communication would substantially reduce the delay and expense associated with responding to supply chain changes.

7.5.3 Data Access and Collaboration

As noted previously, the classic example of information sharing is the distribution of end-user demand data to allow better upstream forecasting and reduce the "bullwhip effect" of alternating inventory feast or famine. Unfortunately, even this is not implemented. Although Arrow receives a weekly file showing expected MRP need for their products in weekly buckets, an Arrow representative requested of the author if it would be possible for Arrow to receive a schedule of Raytheon's contractual delivery dates to the customers because the MRP expected need data for a given week varied tremendously as it approached. Arrow is in a better position than most suppliers, who do not receive direct MRP feeds with forecast usage. Still, it is clear that there is room for improvement in the types of data shared. Ideally, this would be resolved by providing access to near real-time data as opposed to received in weekly communications.

The other major complaint expressed by the Arrow representative was that there was extensive delay involved in getting engineering drawings for new or changed parts from which to quote prices. Once Arrow received a list of items to quote, the representative would need to contact a person in engineering and request the drawings. That person would review the request and manually move each of the several hundred drawings in a typical request to iCenter and make them available to Arrow. The delay in acquiring drawings accounted for the majority of the elapsed time in loading new parts into the Proximity Warehouse. Because of the volume involved, it would seem to make sense to have a system that tracked the suppliers involved in supplying each part and provided on-demand access to the engineering drawings for those suppliers, automatically controlling access appropriately. By removing human interaction, the process could be made much shorter, and both Raytheon and Arrow personnel could spend more time on value-adding work.

The last and most significant gap is somewhat difficult to identify conclusively. Raytheon has a number of systems at its disposal that would seem to enable excellent information sharing including the Supplier and Customer Connections web sites, Exostar, iCenter, WISDM, and Supplier Portal. The literature for each suggests enormous flexibility and power. However, when the author inquired with the supply chain systems staff about using existing tools rather than modifying VBS to act as a supply chain integration system, he was told by several people that these systems could not easily provide the kind of data access and analysis available in VBS. This suggests several possibilities: 1) That the various systems have significant gaps in terms of flexibility and ease of implementation for new functionality, 2) that Raytheon has an opportunity to take better advantage of its IT assets by more widely publicizing their capabilities, or 3) that the priority of developing such data access functionality seemed to the supply chain systems personnel to be lower than other projects in their queue.

8 Why use VBS for supply chain integration?

8.1 What are the characteristics of a good solution?

As noted above, Supply Chain Information Technology (IT) has four primary goals: 1) Collect information on each product from production to delivery or purchase point, and provide complete visibility for all parties involved; 2) Allow access of any data in the system from a single point of contact; 3) Partially or fully automate the process of analyzing, planning activities, and making trade-offs based on information from the entire supply chain; 4) Facilitate collaboration with supply chain partners (Simchi-Levi et al 2008 pg 414). An additional important characteristic would be a relatively short development time.

8.2 What makes VBS a good candidate to fill the gaps? Namely, which characteristics of a good solution does VBS have? Lack?

VBS is an attractive candidate to fill these gaps for many reasons. Foremost is that VBS has successfully been used internally to Raytheon for purposes very similar to those required to fill Raytheon's external supply chain integration needs. The modularity and code reusability of VBS also would make it relatively easy to bring functionality on line for supply chain participants without having to re-program entire applications.

VBS also fully meets all four Supply Chain IT goals. VBS can collect information from any and all systems, and provide visibility to all users. All functionality can be easily found and reached from the launchpad application. VBS has been programmed on multiple occasions with business logic for automating processes, such as the overtime allocation dashboard for hourly workers. VBS has also facilitated collaboration between people in different departments through use of the project book and communication tools.

There are two potential contra-indications for use of VBS. The first is that it was not originally designed to be a secure system, and would need security to protect any sensitive Raytheon data added before it could be opened to suppliers. The second is that while VBS *can* be a single point of contact system, as discussed in section 7.3.3 there are other potentially redundant supply chain integration systems currently being used. For VBS to be effective as a supply chain integration tool it will need to be integrated with the other tools to avoid redundancy and establish the single point of contact.

9 Method: How VBS was adapted to fill the supply chain integration role.

In this chaper, we will discuss details regarding how VBS was modified to create "Supplier VBS," a working prototype supply chain coordination system. After briefly reviewing design characteristics of VBS that are relevant to the discussion and summarizing the changes, we will discuss technical and organizational issues that were encountered in the process and how they were resolved. These will be discussed in the context of the three requirements for supply chain IT that were discussed earlier: connectivity, security, and compatibility.

9.1 What were the characteristics of VBS?

- Designed for free sharing of information
- Includes performance display, metrics, lean tools, communication tools, data retrieval and analysis, and applications
- Based on a programming language familiar to many users (National Instruments LabView)
- Designed with reusable code modules, to accelerate prototyping and make learning easy
- Client server model, leaning heavily on client-side logic
- Self-updating
- Automatically retrieves the latest data from its sources and caches it locally for distribution.
- Allows near-real time data analysis.

9.2 What did we have to change?

- Added security checking by group membership
- Modified user ID method to check employee or contractor ID number as opposed to network logon.
- Created a new data structure for suppliers separate from the Raytheon internal data

- Created a special, non-self-updating, launchpad for Citrix. Citrix is set up to prevent users from modifying files or running unapproved programs, and therefore satisfies the security concerns of the Raytheon network administrators.

9.3 Connectivity

Most people are connected to the internet – but through gateways and firewalls to protect the network from hackers, viruses, and other online attacks.

Raytheon IT rules prohibit database servers from being exposed to the internet because they are hard to secure. The VBS server is a MS SQL database server, so creating an internet-accessible VBS server was out of the question.

Other options included VPN (virtual private network). Typically, VPN software only allows connection to one network at a time. So people connecting to Raytheon by VPN to use VBS would not be able to access their local network resources at the same time, a considerable inconvenience.

Labview has web applets that allow remote control of applications, but this only works for one user at a time. Likewise, remote interface software would require computers to be dedicated for use by remote users and may allow users too much access – they could work around the client-side security.

One alternative is that a web front end could be created. This would have to be made from scratch, and would prevent reuse of the existing application base.

Virtualization software such as Citrix Metaframe can allow users to log in to a 'virtual pc' and run programs from there. Users have limited access, so administrators can control what programs and files are accessible. The firewall can be configured to allow the Citrix server to access the VBS server in such a way that the Citrix server acts as a secure gateway. One major advantage compared to VPN connectivity is that using Citrix allows a user to run VBS in a web browser with standard add-ons, avoiding the need to install proprietary software on their machine. Unlike VPN, Citrix does not interfere with local network use; users can even be allowed to use local IT resources such as printers and local drives with the Citrix application.

The downside is that this solution becomes expensive when scaling up. Each Citrix server can support a limited number of users at a time; depending on intensity of usage, generally 20-25 users. One can easily imagine that if VBS was used as a primary supplier and customer integration system that hundreds of users might be on the system at once, requiring substantial investment in hardware and software licenses.

One very minor downside had to do with aesthetics. When viewed using Citrix, the dashboard window appeared to be smaller and of poorer resolution than the same dashboard viewed using the VBS client on a local computer. This may be remediable using Citrix configuration, and in any case it did not affect the functionality of the system.

Both Citrix and web solutions can use Exostar's security solution to allow identification of users by "2-factor" security, which include a password and a key-tag generated passcode.

9.4 Security

This has to do with the issue of what data can be shared over this system, with whom, and how to make sure that confidentiality is maintained where necessary.

9.4.1 Client-Side Security

The most significant security concern had to do with the client-side security scheme that VBS uses. As noted previously, VBS was originally intended to be an open system and user-based security was not a significant concern. To avoid the need to administer user accounts on the database, the VBS client applications all use the same passwords to log on to the VBS database. VBS Access control, when necessary, was programmed into the client dashboard applications which run on the users' computers – hence the name "client side security." Since users need to log on to their computers using passwords, the dashboards could identify the user by querying the operating system for the current user's identity.

Since the database configuration changes from time to time, the dashboard applications retrieve the appropriate passwords from a different database using a built-in password. The problem with this arrangement is that it is conceivable that a clever person could manage to find out these passwords. If they did, they could use any SQL client to access the database, bypassing the client-side security built-in to the dashboards.

The preferred security method would be to control security on the database side; each user would have a database account which controlled his/her privileges. Unfortunately, to implement server-side security would require modifying all existing dashboards and take more time and effort than is currently feasible.

Fortunately, the solution to our connectivity issues also solves our security issue. As noted above, when users connect to Citrix the programs run on Raytheon's Citrix server; input data is relayed to the server, and the user interface image relayed back and displayed in a window. Furthermore, Citrix can be configured to restrict users to running specified programs and can prevent users from accessing the actual code for those programs. Without access to the code, a hacker cannot reverse-engineer the database password. Since the dashboards run on Raytheon machines, the passwords are not sent over the internet and cannot be intercepted. If an outsider somehow had the password, they would not be able to use it because the Raytheon firewall was configured such that the Citrix server is the only system outside the firewall that can communicate through to the VBS server. Therefore, use of Citrix solves the problem of client-side security from a supplier-access point of view. Because only trusted persons are given access to the Raytheon network, the potential vulnerability to tampering by insiders is considered less of a concern.

9.4.2 Sensitivity of information on the system

ITAR compliance requires that any technical data cannot be shared with non-citizens. We either need to ensure that users are all citizens, make sure no technical data is on the system, or have a good way to make sure that ITAR data is properly identified and access restricted to properly cleared users. Our solution for the prototype was to be conservative and restrict access to US citizens.

Classified Data was not an issue because classified data is kept on separate computer systems and networks.

There was definitely some concern on the part of the participating suppliers that they did not want other participating (sometimes competing) suppliers having access to information pertaining to them – whether this included performance metrics, problem solving records, production plans, etc. Since VBS was originally designed to share information freely among all users, applications to be used with the "supplier VBS" needed to have different user ID checking and permissions added on. To ensure that only Raytheon personnel with "need to know" have access to supplier data would be possible but more involved, and was not resolved for the prototype.

Getting permission to share Raytheon information with non-employees was tricky, because data administrators were reluctant to take responsibility for releasing it. Despite compliance with all published policies and fulfilling the Information Technology and Security departments' requirements, we found that data administrators could effectively veto our usage by declining to give the VBS server access.

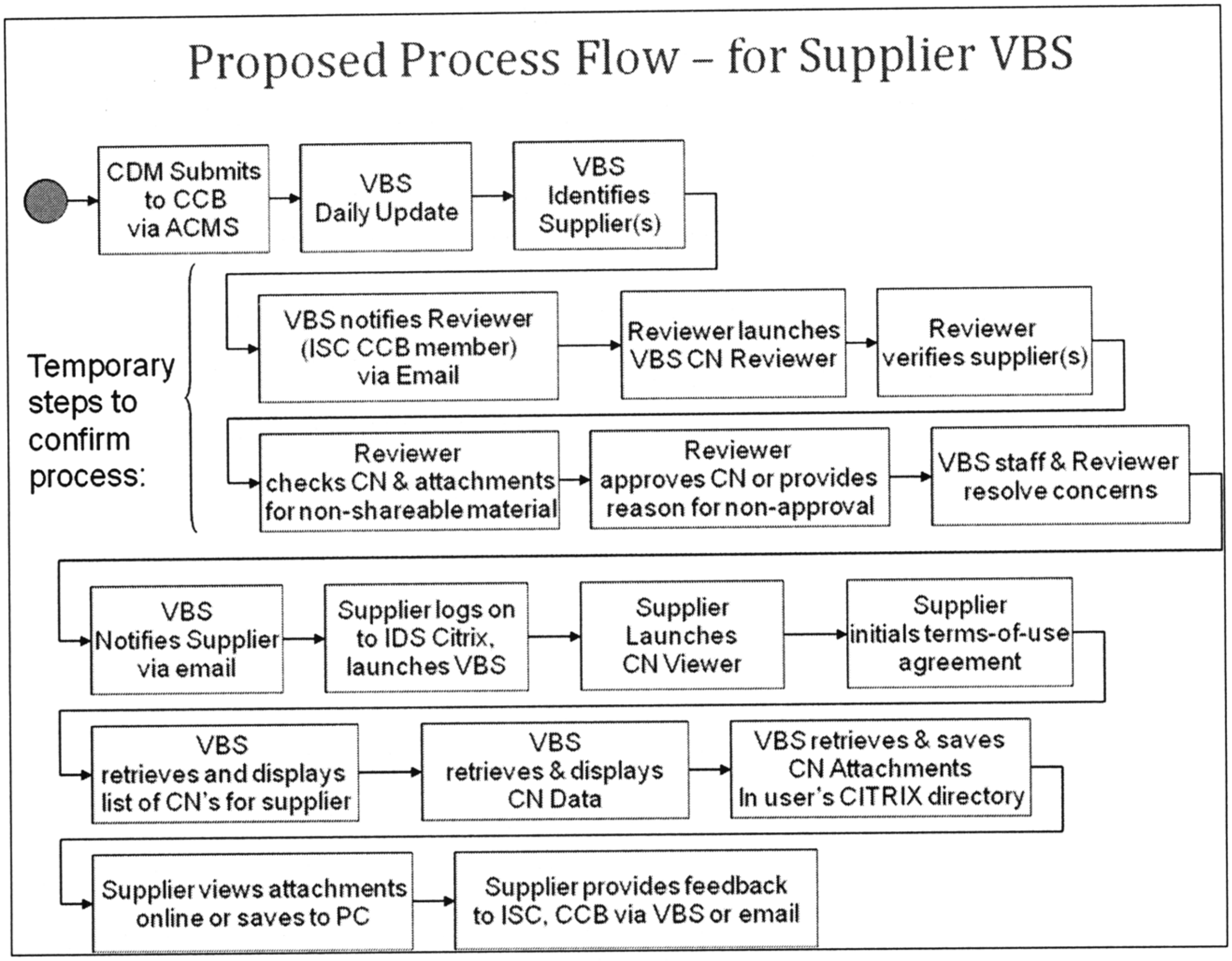
One concern expressed was that suppliers might take inappropriate actions based on the data. For example, if an engineering change was being considered, a supplier might see this and postpone production. If the change was not made, production might be delayed because of the suppliers' actions. The second main concern was that although there was not supposed to be any company confidential data in the system, there may nevertheless be some data in the systems that was confidential.

These concerns were addressed by creating a process for an introductory period to manually clear the data being loaded into the system to ensure that it was safe for release to suppliers, and by adding a user agreement at system logon agreeing that the data was information only, and that any change to contractual agreements had to be authorized by the procurement specialist in purchasing. A diagram of this process appears in the figure below:

9.5 Compatibility

Since this prototype was designed as a system-to-human process, compatibility with the suppliers' IT systems was not an issue. In addition, user compatibility was not a problem because the suppliers would connect to the Supplier VBS Citrix system using a normal web browser and a well-supported plug-in that could be downloaded freely.

We did encounter some compatibility issues in importing data from the engineering change database. As noted earlier, one of the main constraints for maintaining integration systems is the availability of expertise with legacy systems. The engineering change database operates in Lotus Notes, a format that had not been previously encountered by the VBS team.



Creating a near-real-time link to the database proved difficult, and required the services of a local expert who was not available until after the author's internship was completed. After PRISM is implemented engineering changes will be handled as part of the PDM software, and so should be easier to access.

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10 Discussion and Conclusion

10.1 What the prototype achieves, and what it doesn't

The prototype system successfully achieved connectivity, security, and compatibility, allowing suppliers to access certain VBS tools, including the communication suite, the project book, and the "cause and effect" diagramming lean tool from their own computers over the internet.

Since VBS dashboards are built using templates, the security changes required needed to be applied to each dashboard separately to prevent suppliers from seeing Raytheon data not authorized for release to them. The changes were applied to a few dashboards as a demonstration, but the majority of the VBS functionality is off-limits to suppliers until it can be modified.

This prototype successfully allows suppliers to see Raytheon data, but does not address the issue of allowing Raytheon to see supplier data, a logical next step in development. This is a much more complicated issue because it is more organizational than technical; as difficult as it sometimes was to gain permission to connect VBS to Raytheon systems, suppliers were clearly hostile to the idea of giving a Raytheon system direct access to their own.

Ideally, a supply chain integration platform would enable two-way information sharing, as well as allowing system-to-system communication. This is not achieved by the prototype and will have to be developed at a later time.

10.2 What's next: a pilot run of the system.

Since the prototype is functional, the next step is to use it in a pilot program. Two suppliers, Banneker Industries and Arrow Electronics, have agreed to participate and have voiced positive impressions from a first introduction to the software. The internal clients—the supply chain staff who will be coordinating with Arrow and Banneker—need to be introduced to the system and trained on its use. Ideally, some additional functionality would be enabled to make the supplier VBS as useful as possible.

Once the training and functionality are complete, the VBS team will use its normal user feedback and development cycle to make the system as useful as possible: The users will try it in practice and give comments to the VBS team in regular meetings; the VBS team will identify needs from those discussions and modify functionality to meet needs. Metrics will be put in place to ensure that the system is being used. At the regular meetings with the internal and external users, the team will assess results and start the cycle again. In this way, the continuous improvement program will be applied to the Supplier VBS system and it will become a tool that meets most of the users' needs and be a good basis for future work.

10.3 Answering the Research Question: Does extending VBS to suppliers satisfy Raytheon's needs for supply chain integration and coordination?

The Supplier VBS prototype was successful in demonstrating that VBS information sharing functionality could be extended to suppliers. While the prototype does not meet all the criteria for a full integration system, one of the benefits of VBS is that as a "home grown" system it can be made to do anything. Once a pilot implementation provides information about what functionality is really needed, the VBS team can work to find solutions and implement the iterative development process to create a full-featured solution.

In particular, additional development will most likely be necessary in the areas of security and user interface. The use of Citrix which satisfies the security requirements may prove to be cost-prohibitive when scaled for use by all (or even most) suppliers. As use of the system expands, it may be worthwhile to switch to a server-side security scheme or to a web-based interface.

National Instruments, publishers of the Labview platform used to write VBS, is in the process of developing a fully web-enabled version of the software, even including the development environment. When this becomes available, it will certainly be worth exploring.

The other aspect of VBS that needs to be further developed is a way to decentralize it – to provide supply chain partners with their own VBS systems that would be able to communicate with Raytheon's and others' systems on a peer-to-peer basis to enable true multi-tier integration.

Finally, the VBS team will need to continue building support and sponsorship among the Raytheon IDS executive leadership. To make Supply Chain integration work, one needs to change business processes, not just information systems; one needs sponsorship not only from supply chain executives, but also from general management of the company. Supplier VBS was driven mainly by the Author supported by the VBS team, not the supply chain systems group. A successful system implementation will require gaining senior executive sponsorship to make change happen. According to Day, this necessary executive support is beginning to coalesce among the IDS vice presidents of operations and supply chain.

10.4 What lessons can be drawn about the ideal supply chain integration design?

VBS has been very successful in meeting Raytheon's internal alignment needs, and the prototype shows promise of being able to meet many of Raytheon's supply chain integration needs as well. From VBS's success and from the internship experience, the author suggests the following lessons that may help others developing supply chain integration systems.

10.4.1Users must be able to maintain control of their data

As observed in the literature, trust issues make it difficult for an information sharing system to work if it is controlled by one partner in the supply chain. EDI systems have been effective because each party controls the information that they "push" to the other. Hub systems maintained by a trusted third party work because the hub is trusted to implement security rules as defined by the users. Even so, the hub is rarely allowed to connect directly to enterprise systems, but instead connects to an external database that each user maintains as a liaison between their system and the hub, and that holds the subset of data cleared for publishing to the hub.

A third possible architecture would be a peer-to-peer "pull" model, in which each user maintains a liaison database with access control implemented and partners would query data from each other's databases as needed. These databases could be connected by VPN. In such a situation, most people would connect to their own company's system, and the number of active VPN links and users would be minimized, while still maintaining the integrity of each partner's network and data security.

10.4.2Sharing functionality is almost as important as sharing data

One reason EDI is so complicated to implement is because the firms on each end of a transaction often have to write not only their own "translators" to import the data to their systems; they also often need to create custom interfaces that allow users to view, analyze, and modify the data being received. VBS has created value by wherever possible making dashboards meet a client department's needs but yet are still generic enough to be used by other departments. In this way, development time is leveraged for the benefit of the entire firm.

Similarly, if one firm has a good functionality for dealing with a certain kind of data, it is wasteful and expensive for their partners to have to reproduce that functionality to make use of the data. This is one appeal of web-based systems, but the same objective can be met by having partners use a common platform other than the web. For example, if all partners had compatible VBS servers then dashboards could be exchanged and that development leveraged.

10.4.3Coordination and Information Sharing include improvement processes

Supply Chain Coordination, and the information sharing that enables it, tends to focus on the business processes themselves. In the same way that VBS has improved alignment at Raytheon by improving the business process and by encouraging lean behavior, supply chain coordination must improve not only the business process links between firms but the improvement process links as well. Improvement processes that share information and are well coordinated will be much better equipped to support supply chain coordination.

Improvement processes work best when they generate institutional knowledge. Supply Chains need to build an institutional knowledge about how to work well together just as companies do. To build this, a supply chain integration effort should include easy to use knowledge management tools shared by all members. To maximize the chance of adoption, the knowledge should also be integrated into the internal knowledge management system of each partner.

10.4.4Plan for Change

The business world is always changing, and the integration needs of supply chains will change with it. In the same way that VBS is always a work in progress, a supply chain coordination system needs to be easily and quickly adapted to meet new needs. When existing tools inside Raytheon didn't meet people's needs, the people worked around the tools and created new ones. Likewise, an information sharing system needs to be adapted to the supply chain partners' needs or employees will work around it, reducing its effectiveness further.

A key enabler of this responsiveness is to grow the pool of people who are capable of modifying and improving the system to be as large as possible, and include many members of the user base. This is not to say that development should not be coordinated or controlled; a central group has to be responsible for maintaining standards of security, performance, and style. However, allowing client groups to use some of their own resources to help themselves improves development speed, reduces frustration, and results in stronger user commitment to the system.

10.5 What other lessons can be learned?

One of the unique aspects of VBS is its entrepreneurial nature and culture, and that it has managed to succeed within the larger Raytheon corporate culture. One of the hallmarks of the VBS team is its responsiveness to customer needs. The team really believes in the evolutionary, iterative approach and this responsiveness may be one of the biggest drivers of their success. Entrepreneurial groups which have no budget need to be responsive to their customers to keep them happy and to get referrals for additional work. This is a pressure that an institutional department does not typically feel. It would be worthwhile to research whether entrepreneurial groups in large corporations can consistently succeed in introducing innovative, responsive solutions.

Eventually, if "the shadow becomes more solid than the tree" and the group succeeds, there needs to be a way to institutionalize that success; to bring it back into the mainstream while not losing the lessons about what enabled it to succeed. The challenge that faces Raytheon now is how to institutionalize VBS, retaining not only the software but the important cultural aspects that are as important as the code.

Other firms can quite possibly benefit from allowing entrepreneurship within the company to generate innovation, provided that they can effectively re-integrate that innovation when the time comes.

10.6 What further areas of research should be pursued?

A pilot implementation program using the prototype should be run to verify conclusions, quantify benefits, and learn additional lessons. Additional prototypes incorporating these conclusions might be created and tested for comparative purposes. For example, a peer-to-peer network of VBS systems connecting a supply chain might be developed and tested. If such a model was successful, then it would be demonstrated that VBS can in fact serve as a primary information sharing system for enabling supply chain integration.

BIBLIOGRAPHY

Antoniou, C. (2008). *Using visual analytics to drive lean behavior in the program management office.* Unpublished masters thesis, Massachusetts Institute of Technology,

Arshinder, S., Kanda, A., & Deshmukh, S. G. (2008). Supply chain coordination: Perspectives, empirical studies and research directions. *International Journal of Production Economics, 115*(2), 316-335.

Ballou, R. H., Gilbert, S. M., & Mukherjee, A. (2000). New managerial challenges from supply chain opportunities. *Industrial Marketing Management, 29*(1), 7-18.

Beckman, S. L., & Rosenfield, D. B. (2008). *Operations strategy: Competing in the 21st century.* New York, NY: McGraw-Hill Irwin.

Buhalis, D. (2004). eAirlines: Strategic and tactical use of ICTs in the airline industry. *Information & Management, 41*(7), 805.

Byrnes, J. L. S., & Shapiro, R. D. (1991). *Intercompany operating ties: Unlocking the value in channel restructuring* Retrieved from http://jlbyrnes.com/uploads/Main/Intercompany%20Operating%20Ties.pdf

Chen, F., Drezner, Z., Ryan, J. K., & Simchi-Levi, D. (2000). Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information. *Management Science, 46*(3), 436-443.

Chen, T. H., & Chen, J. M. (2005). Optimizing supply chain collaboration based on joint replenishment and channel coordination. *Transportation Research Part E, 41*(4), 261-285.

Chen, F., Drezner, Z., Ryan, J. K., & Simchi-Levi, D. (2000). Quantifying the bullwhip effect in a simple supply chain: The impact of forecasting, lead times, and information. *Management Science, 46*(3), 436.

Chen, I. J., & Paulraj, A. (2004). Towards a theory of supply chain management: The constructs and measurements. *Journal of Operations Management, 22*(2), 119-150.

Cooper, M. C., Lambert, D. M., & Pagh, J. D. (1997). Supply chain management: More than a new name for logistics. *The International Journal of Logistics Management, 8*(1), 1-14.

Cost.(2009). *Merriam Webster Online Dictionary,* , March 22, 2009. Retrieved from http://www.merriam-webster.com/dictionary/cost

Cox, A., Hughes, J., & Ralf, M. (1995). Influencing the strategic agenda: The challenge for purchasing leadership. *Purchasing & Supply Management,* , 36.

Dorsch, J. (2009). *Raytheon Company.* http://www.hoovers.com/raytheon/--ID__11261--/free-co-factsheet.xhtml

Duke-Woolley, R. (2001). *B2B exchanges: Public or private?* http://www.e-principles.com/B2B.htm

Exostar LLC. (2009). *The Exostar vision.* http://www.exostar.com/about-1.aspx?id=526

Fisher, M. L., Raman, A., & McClelland, A. S. (1994). Rocket science retailing is almost here: Are you ready? *Harvard Business Review, 72*(3), 83-93.

Forrester, J. W. (1961). *Industrial dynamics.* Waltham, Ma: Pegasus Communications.

GlobalSecurity.org. (2008). *Joint Cargo Aircraft,* http://www.globalsecurity.org/military/systems/aircraft/jca.htm

Graves, S. C. (1999). A single-item inventory model for a nonstationary demand process. *Manufacturing & Service Operations Management, 1*(1), 50.

Grieger, M. (2003). Electronic marketplaces: A literature review and a call for supply chain management research. *European Journal of Operational Research, 144*(2), 280.

Ho, P. (2008). *Using virtual business systems to drive lean behavior in engineering design and support.* Unpublished masters thesis, Massachusetts Institute of Technology,

Horvath, L. (2001). Collaboration: The key to value creation in supply chain management. *Supply Chain Management, 6*(5), 205.

Hsu, C., Levermore, D. M., Carothers, C., & Babin, G. (2007). Enterprise collaboration: On-demand information exchange using enterprise databases, wireless sensor networks, and RFID systems. *Ieee Transactions on Systems Man and Cybernetics Part A-Systems and Humans, 37*(4), 519-532.

Kauremaa, J., Kärkkäinen, M., & Ala-Risku, T. (2009). Customer initiated interorganizational information systems: The operational impacts and obstacles for small and medium sized suppliers. *International Journal of Production Economics, 119*(2), 228-239.

Kent, J. L.,Jr, & Flint, D. J. (1997). Perspectives on the evolution of logistics thought. *Journal of Business Logistics, 18*(2), 15.

Kirby, M. (2003) Exostar remains optimistic in face of cordiem's demise. Retrieved from http://www.exostar.acom/news/pressrelease_view.asp?id=68

Lambert, D. M., & Londe, B. J. L. (1976). Inventory carrying costs. *Management Accounting (Pre-1986), 58*(2), 31.

Lee, H. L., Padmanabhan, V., & Whang, S. (1997). Information distortion in supply chain: The bullwhip effect. *Management Science, 43*(4), 546-558.

Li, S. X., Huang, Z., & Ashley, A. (1996). Improving buyer-seller system cooperation through inventory control. *International Journal of Production Economics, 43*(1), 37-46.

Li, L. D., & Zhang, H. T. (2008). Confidentiality and information sharing in supply chain coordination. *Management Science, 54*(8), 1467-1481.

Liu, J., Zhang, S., & Hu, J. (2005). A case study of an inter-enterprise workflow-supported supply chain management system. *Information and Management, 42*(3), 441-454.

Martha C. Cooper, Douglas M. Lambert, Janus D. Pagh. (1997). Supply chain management: More than a new name for logistics. *The International Journal of Logistics Management, 8*(1), 1.

McAfee, A. (2002). The impact of enterprise information technology adoption on operational performance: An empirical investigation. *Production and Operations Management, 11*(1), 33-53.

McCaghren, N. (2005). *Enabling process improvement through visual performance indicators.* Unpublished masters thesis, Massachusetts Institute of Technology.

Mitra, S., & Singhal, V. (2008). Supply chain integration and shareholder value: Evidence from consortium based industry exchanges. *Journal of Operations Management, 26*(1), 96-114.

Moses, M., & Seshardri, S. (2000). Policy mechanisms for supply chain coordination. *IIE Transactions, 32*(3), 254-262.

Naylor, Ben J., Naim, M. M., & Berry, D. (1999). Leagility: Integrating the lean and agile manufacturing paradigms in the total supply chain. *International Journal of Production Economics, 62*(1-2), 107-118.

Ngai, E. W. T., & Gunasekaran, A. (2007). Knowledge and information technology management in supply chain integration. *International Journal of Production Research, 45*(11), 2387-2389.

Nucciarelli, A., & Gastaldi, M. (2008). Information technology and collaboration tools within the e-supply chain management of the aviation industry. *Technology Analysis & Strategic Management, 20*(2), 169-184.

Oliver, R. Keith and Michael D. Webber (1982), "Supply-Chain Management: Logistics Catches Up with Strategy," Outlook, cit. Martin G. Christopher, Logistics, The Strategic Issue, London: Chapman and Hall, 1992.

Power, D. (2005). Supply chain management integration and implementation: A literature review. *Supply Chain Management-an International Journal, 10*(3-4), 252-263.

Ramdas, K., & Spekman, R. E. (2000). Chain or shackles: Understanding what drives supply-chain performance. *Interfaces, 30*(4), 3.

Raytheon Company. (2006). *Mission support readlilog(tm) integrated solution sets: Integrated supply chain management.* http://www.raytheon.com/businesses/stellent/groups/rtsc/documents/asset/iscm_datasheet.pdf

Raytheon Company. (2009). *Connect with us.* http://www.raytheon.com/connections/index.html

Rogers, D. S., & Leuschner, R. (2004). Supply chain management: Retrospective and prospective. *Journal of Marketing Theory and Practice, 12*(4), 60.

Sanders, N. R. (2008). Pattern of information technology use: The impact on buyer-suppler coordination and performance. *Journal of Operations Management, 26*(3), 349-367.

Simatupang, T. M., Sandroto, I. V., & Lubis, S. B. H. (2004). Supply chain coordination in a fashion firm. *Supply Chain Management, 9*(3/4), 256.

Simchi-Levi, D., Kaminsky, P., & Simchi-Levi, E. (2008). *Designing and managing the supply chain : Concepts, strategies and case studies* (3rd ed.). Boston: McGraw-Hill/Irwin.

Tsay, A. A. (1999). The quantity flexibility contract and supplier-customer incentives. *Management Science, 45*(10), 1339.

van der Vaart, T., & van Donk, D. P. (2008). A critical review of survey-based research in supply chain integration. *International Journal of Production Economics, 111*(1), 42-55.

Vickery, S. K., Jayaram, J., Droge, C., & Calantone, R. (2003). The effects of an integrative supply chain strategy on customer service and financial performance: An analysis of direct versus indirect relationships. *Journal of Operations Management, 21*(5), 523-539.

White, E. (2003). *Lean enterprise distribution tactics with customer supply chain integration.* Unpublished masters thesis, Massachusetts Institute of Technology.

White, W. J., Ph.D., O'Connor, A. C., & Rowe, B. R. (2004). *Economic impact of inadequate infrastructure for supply chain integration* No. Planning Report 04-2)National Institute of Standards and Tenchnology, U.S. Department of Commerce. Retrieved from http://www.nist.gov/director/prog-ofc/report04-2.pdf

Wolbert, D. (2007). *Utilization of visual metrics to drive intended performance.* Unpublished masters thesis, Massachusetts Institute of Technology.