RFID TECHNOLOGY: A ROADMAP FOR INTEGRATION

INTO THE SUPPLY CHAIN

THESIS

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ABSTRACT

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Organizations have begun to examine the pros and cons of implementing Radio Frequency Identification (RFID) technology into the supply chain. RFID systems have the potential to improve supply chain coordination; however, many firms have experienced significant barriers when incorporating RFID technology into the supply chain. Through research and analysis of firms that have implemented an RFID system, this research work proposes a long-run strategy to integrate RFID into the supply chain. The aforementioned strategic roadmap is recommended because it reduces the likelihood of encountering barriers to RFID adoption and implementation; which in turn, presents the best opportunity for successful RFID integration into the supply chain.

CHAPTER I

INTRODUCTION

Today, world-class businesses are constantly searching for tactical methods to improve operational efficiency, minimize costs, and simultaneously, maximize shareholder wealth. To achieve these ends, many organizations have bought into the concept of supply chain management (SCM). Thus, the goal of the organization is not to simply maximize company profit, but "to maximize the overall value generated" in the supply chain network. This goal can be quite challenging for firms to attain. It is not uncommon for a business to appear very successful when looking at their net income statement; yet, insiders will freely admit the firm could potentially be much more profitable if its SCM was more efficient and cost effective.

There are many factors that contribute to an elite supply chain. Some of the most important are highlighted and discussed in the work of Lee (2004). He explained that "Triple-A Supply Chains" have three primary qualities: agility – firms in the supply chain are able to quickly react to sudden changes in demand or supply; adaptability – firms in the supply chain have the ability to change as market structures and strategies evolve; and the interests of all businesses in the supply chain are aligned – firms work to optimize the performance of the chain (Lee 2004). The term "Triple-A Supply Chain" was coined by Lee et al. (1997). If one were to follow Lee's assertion, and a business wished to maximize the overall value generated in their supply chain, logic would predicate that the supply chain should be agile and adaptable with interests aligned. Members of academia and business are currently doing their part to evolve the application of SCM; many have turned to information technology (IT) to help align businesses interests while improving the agility and adaptability of the supply chain (The Economist 2003).

One particular technology has been dubbed to have the potential to help businesses achieve "Triple-A Supply Chain" status. This technology is radio frequency identification (RFID) and the physical objects are known as RFID tags. The tags are placed on products; these tagged products allow firms to gain visibility as to the location of either incoming materials, products in storage, or finished goods that are to be shipped to a customer. RFID technology is important because it allows businesses to better track the movement of materials, products, and finished goods. Better tracking and increased visibility present the opportunity to improve demand forecasting, management of inventories, communication, and information sharing to name a few (Bose 2005). In essence, RFID could potentially improve agility, adaptability, and better align the interests of all involved in the supply chain.

RFID technology's vast potential has prompted many businesses to publicly announce their intention to implement RFID systems. Probably the most well-known, Wal-Mart, announced that their top suppliers would be required to ship pallets and cases equipped with passive RFID tags beginning in 2004 (Sullivan 2004). Others, such as the United States (US) Department of Defense (DoD), Tesco (a British supermarket chain), Hewlett-Packard, Proctor & Gamble, Best Buy, and European retailer Metro AG, are among the early adopters that were the first to test and implement the technology

(Murphey-Hoye et al. 2005). The US DoD was the first to issue a mandate to suppliers and vendors requiring item level tagging and the use of active tags for certain goods (United States DoD 2003). These actions have prompted hardware manufacturers and technology firms to produce cheaper tags, more reliable readers, and "new software to process data read from RFID tags and use to improve supply chain operational control" (Murphey-Hoye et al. 2005).

Even though the technology has evolved significantly, the application of RFID in supply chain context is still in the infancy stage of the product-life-cycle. There is still much speculation as to the most productive method of adoption and utilization of RFID systems. To date, a countless number of businesses have begun to either research, pilot-test, or partially implement RFID systems (Hardgrave et al. 2005, Murphey-Hoye et al. 2005, and Dighero et al. 2005). Many organizations are experimenting with the technology. Some have been extremely successful with implementation and pilots, others, not so much.

Firms such as Wal-Mart and Metro have already reported that RFID has helped to reduce out-of-stocks by 16% and 11%, respectively, at pilot stores (Hardgrave et al. 2005). Some organizations, though, have not been as successful with RFID pilots, and many have found the return on investment (ROI) does not justify the cost. There is a well-documented approach to RFID implementation that some businesses have taken which might explain such mixed results. This method of implementation, known as "slap and ship", has become prevalent among some Wal-Mart and DOD suppliers to merely adhere to compliance mandates (Faber 2006). Patrick Sweeny, CEO of ODIN technologies, an RFID software firm, explains that his firm works with a number of Wal-

Mart's top 100 suppliers, and he estimates that almost 70% adhere to "slap and ship" (Wailgum 2004). Firms that "slap and ship" only attach the required RFID tags to the pallet, case, or item before it is shipped to the customer. They do not try to take advantage of any of the technology's potential benefits, and more importantly, they leave the retail supply chain blind to product movement. If a large number of businesses apply RFID through "slap and ship" this practice might explain the conflicting reports as to the effectiveness and value of the technology. One has to question, why are businesses applying a technology such as RIFD and ignoring all the potential benefits?

Apparently, some businesses may not have a clear understanding of the potential benefits of RFID technology. Furthermore, businesses may not even realize how or where to use RFID to optimize the supply chain. Thus, the purpose of this study is to advance the understanding of RFID in a broad sense. To accomplish this goal, the main obstacles firms encounter were identified during the process to adopt and apply RFID into a supply chain network. Obstacles were specifically associated at different stages of the RFID implementation process. In the future, this study may serve as a guideline to help businesses formulate a long-run RFID integration strategy to minimize obstacles that might prevent the successful application of RFID into the supply chain.

Two separate models were uncovered during the research process which appear to work together to achieve the specific goal of this research. One pertains to various strategic pathways for RFID adoption (proposed by Murphey-Hoye et al. 2005). The other relates to particular stages of an innovation (Dighero et al. 2005). When combined, the two models appear to spotlight a long-term strategy to integrate RFID into SCM. The validation of the strategy depends on the identification of barriers to RFID technology.

The encountered frequency was analyzed for some of the most common barriers to RFID integration. The results of the analysis are twofold: 1) A strategic path for RFID adoption is identified; 2) A long-term strategy for RFID implementation is identified. The two were merged to formulate a long-run strategy least likely to encounter the most common barriers of RFID systems. If businesses have an RFID strategy that minimizes the impact of barriers to RFID integration, they will be more likely to incorporate a successful RFID campaign and maximize the potential benefits of the technology.

RFID technology appears to have the potential to streamline the coordination of supply chains. Granted, the technology may not be a panacea, but proper application of RFID systems could allow organizations to maximize the efficiency and cost effectiveness of their supply chain. Through maximization of the chain, firms have a greater potential to be agile, adaptable, and work cohesively with members of the network. Pundits, though, offer many valid arguments: the technology is too expensive; it does not generate revenue; there are significant security concerns; application is too complex. This is where the aforementioned models come into play. The strategic model for RFID integration can be used to bridge the gap between early adopters and pundits by providing a roadmap to successfully incorporate RFID into supply chains. An explanation of the research objectives, then research questions, and lastly, thesis organization can be found next.

Research Objectives

The main objectives of this research are:

- To study businesses' use of RFID technology and advance the understanding of RFID into SCM.

- To determine organizational perceptions on adoption, long-term implementation, industry standards, potential barriers, and the overall usefulness of the technology.
- To use "The Pathways to Adoption Model" to identify the predominate pathway for adoption, determine who bears the majority of the investment and benefits the most, and identify problems that occur in the process.
- To use the "Stages of Innovation" model to classify firms' RFID campaign into one of three stages – Substitution, Scale, and Structural Effect, and examine the benefits in each stage, and identify problems that occur in the process.
- To combine the two models to form a long-run strategic model for RFID integration into SCM that minimizes the impact of barriers to the technology.

Hypotheses

Based on the literature research on RFID, the following hypotheses are formulated:

i. Due to the technology's stage in the product-life-cycle, unified industry standards have not been widely accepted and most firms will be in the *Substitution* Stage of Innovation.

ii. Organizations that use Gen 2 UHF RFID tags with EPC technology will be less likely to experience failures of the technology (read failure, hardware failure, and software failure).

iii. Firms that share the RFID investment will be less prone to barriers that may impede the technology.

iv. The *Solo Drive* pathway will be the most prevalent method of adoption undertaken by firms in the sample.

v. The lack of a quantifiable return on investment, coupled with the technology's cost, will be the most prevalent barriers of RFID technology.

vi. Firms in a *Structural* stage of long-term implementation will encounter barriers of RFID technology less frequently than those in *Substitution* and *Scale* stages.

Organization of the Thesis

- *Chapter 2* – defines supply chain management, addresses the complexity of supply coordination, examines the bullwhip effect, and discusses information technology's (IT) role in SCM.
- *Chapter 3* – pertains to RFID technology, namely: the history of the technology, the advantages of RFID compared to barcodes, additional benefits, and barriers to widespread implementation.
- *Chapter 4* – presents the framework of the two models – ***the stages of innovation*** and ***pathways to adoption***.
- *Chapter 5* -- covers the methodology of the research project.
- *Chapter 6* – provides the results of the data and analysis is provided.
- *Chapter 7* – provides the results of the proposed strategic analytical RFID models
- *Chapter 8* – presents the conclusions and recommendations.

CHAPTER II

SUPPLY CHAIN MANAGEMENT

The supply chain often serves as the backbone for doing business and can be the key differentiator for a successful organization. Thus, supply chain management (SCM) has become a major focus of organizations that want to optimize operational efficiency and overall profitability. A textbook definition is as follows:

> *Supply Chain Management is a set of approaches utilized to efficiently integrate suppliers, manufacturers, warehouses, distributors, and stores, so that merchandise is produced and distributed at the right quantities, to the right location, and at the right time, in order to minimize system-wide costs while satisfying service level requirement (Simchi-Levi 2003).*

A traditional supply chain (see Figure 1) begins with the extraction of raw materials. The supply chain takes into consideration every facility that has an impact on cost and plays a role in making product conform to customer requirements. This includes the movement of materials, products, information, and funds to suppliers, manufacturers, distributors, retailers, and, ultimately, the end-consumer (Macvittie 2005).

Today, supply chains exist under the same premise of the traditional model; however, they are much more dynamic and complex. Consider a customer who decides to buy a laptop from Dell Computers. The supply chain in this instance begins with the customer's need for a computer. Since the individual chose Dell, let us assume a telephone call was made by the customer to a Dell call center to place the order. This

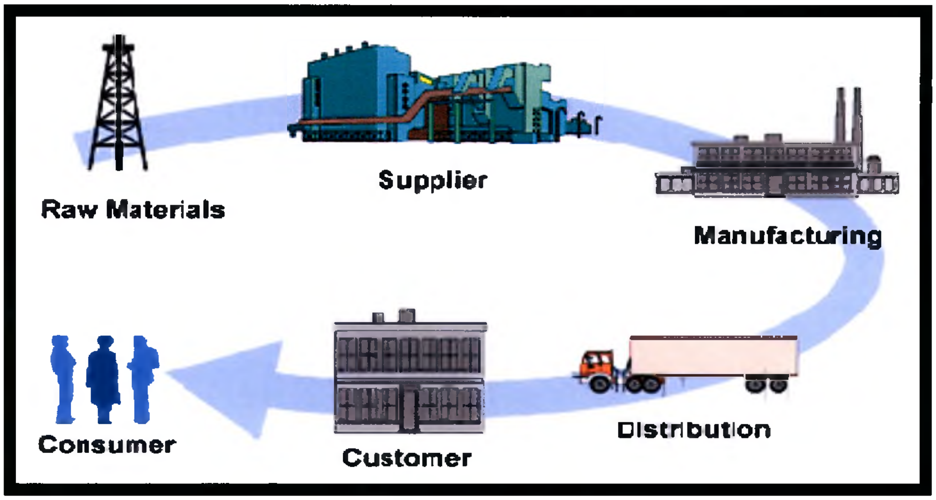

Figure 1: Stages of the Supply Chain.
(Source: The Progress Group)

supply chain is illustrated in Figure 2, and the arrows correspond to the direction of the physical product flow. There is not a retailer or wholesaler involved in the supply chain because Dell sells directly to its customers. There would be, however, a distributor such as UPS or FedEx that served as the linkage between Dell and the consumer. The next stage of this supply chain is one of Dell's manufacturing facilities. There are a number of components that go into a Dell laptop: microprocessor, video card, wireless network interface card, software, etc. These components come from manufacturing plants / warehouses which are delivered by trucks supplied by third-party distributors. A component manufacturer (for example, Intel) receives parts for its finished-good (microprocessors) from outsourced semiconductor manufacturers. The outsourced manufacturer, in turn, receives raw materials for the fabrication of semiconductor wafers.

Additionally, the Intel manufacturing plant receives raw materials from a variety of suppliers, who may have been supplied by lower-tier suppliers (Chopra 2007).

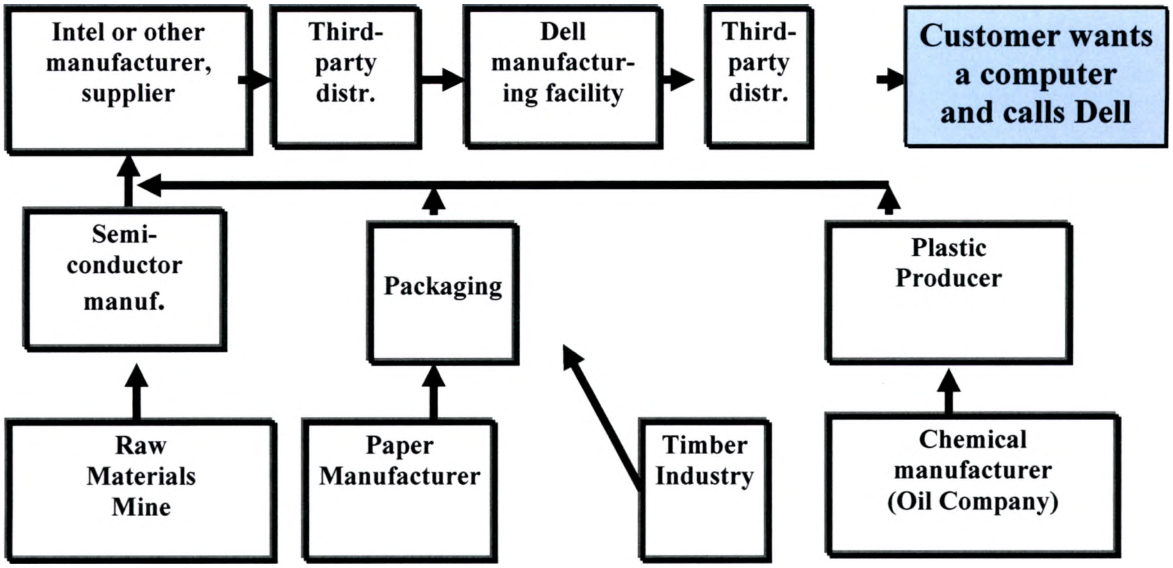

Figure 2: Stages of a Laptop Supply Chain.
(Adapted from: Chopra 2007)

This example demonstrates how an abbreviated supply chain might function. In reality, a manufacturer may receive material from several suppliers or vendors and then supply several distributors (Chopra 2007). Also, it is important to note that products, information, and funds are dispersed in both directions in the chain after the customer places an order. The key player in this process, though, is the end-consumer. If there is no customer, there is no need for the computer and no potential to generate a profit by Dell and its supply chain. Thus, the objective of every supply chain should be to maximize the overall value generated, which will likely be strongly correlated with supply chain profitability (Chopra 2007).

Coordination of the Supply Chain

Supply chain coordination between different stages has great importance due to the complexity of the process. As one might expect, it is not uncommon for supply chains to have problems coordinating the flow of goods, information, and funds with the increased intricacies encountered. A lack of coordination usually occurs either because members of the supply chain have objectives that differ or due to delays and distortion of information as it travels in the supply chain (Chopra 2001). For example, a firm that is only worried about maximizing its own profitability would have objectives that likely conflict with the supply chain as a whole. Likewise, information may be distorted as it moves within the supply chain if complete information is not shared between stages, and distortion can be exaggerated due to variables such as: demand signal processing, order batching, price variations, shortage gaming and the production of a wide product variety (Lee et al. 1997). A consequence of distorted information is called the bullwhip effect which is presented next.

The Bullwhip Effect

A lack of coordination in a supply chain can lead to a phenomenon known as the bullwhip effect (see Figure 3). In this scenario, moving up the supply chain from end-consumer to the manufacturer, each supply chain participant has greater observed variation in demand and a greater need for safety stock. Fluctuations in orders increase as they move up the supply chain away from the end-consumer, and the result can be a complete loss of supply chain coordination. Consequences of the bullwhip effect are increased costs, longer lead-times, increased out-of-stocks, and negative effects on relationships with strategic partners (Lee et al. 1997). All of these factors have detrimental effects on supply chain profitability; thus, supply chain partners constantly search for ways to coordinate supply chain processes so that the bullwhip effect is held to a minimum. Lee, Padmanabhan, and Whang (1997) considered the bullwhip effect in several case studies and recognized four separate tactics to counteract its impact: avoid multiple demand forecasts, break-down order batches, offer stable prices, and eliminate shortage gaming. Today, many businesses have turned to information technology (IT)

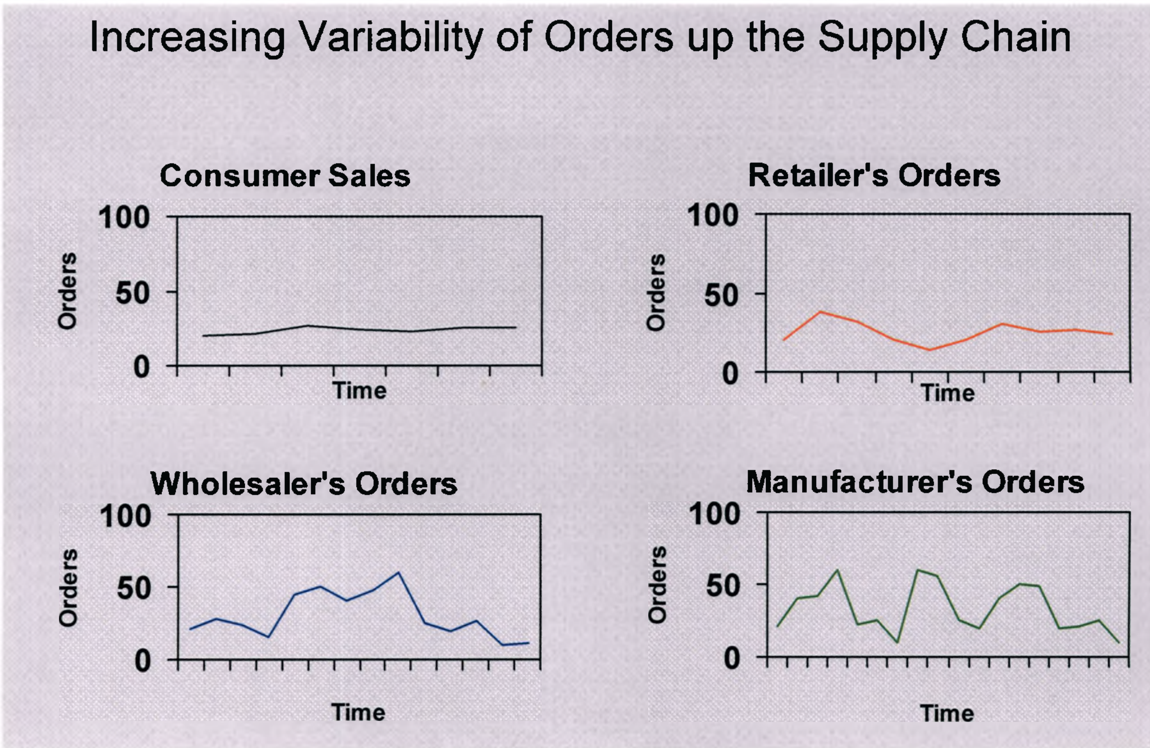

Figure 3: Bullwhip Effect Illustration.
(Adapted from: Lee et al. 1997)

because certain technological applications have proven to improve supply chain coordination and reduce the bullwhip effect (Wikipedia 2006). A discussion of IT's role regarding tactics to minimize the bullwhip effect can be found next.

The Role of IT in SCM

IT has opened the door to refine supply chain coordination despite multiple ownership, information distortion, and product diversity (Simchi-Levi 2003). For example, technologies such as electronic data interchange (EDI) and enterprise resource planning (ERP) software coupled with vendor managed inventories (VMI) have helped improve the accuracy of information, made it more accessible, and more useful. These applications and processes are suppose to reduce fluctuations in orders as they move up the supply chain because they eliminate multiple demand forecasts, break down order batches, stabilize prices, and reduce shortage gaming (Lee et al. 1997). Firms like Wal-Mart, Dell, and Intel have experienced tremendous success with ERP software and VMIs. Others such as Hewlett-Packard and Volvo have experienced significant problems with the application of ERP into SCM (Koch 2004).

RFID is one of the latest applications of IT, and many believe the technology has the potential to further refine SCM (Bose 2005). A number of businesses have already begun to apply RFID to supply chain processes with mixed results. This research examines the application of RFID technology in a supply chain context. Specifically, this work analyzes alternate methods of RFID adoption and long-term implementation. Barriers of the technology are also identified to measure the effectiveness of the alternate methods. This analysis allows for the identification of a strategic method of adoption and long-term implementation which avoids frequent barriers of the technology. The proposed model provides a strategic framework that allows businesses to capitalize on the theoretical benefits of RFID in a real world context.

CHAPTER III

RFID TECHNOLOGY

RFID is not an entirely new technology; sources trace the origins of RFID to the 1920's (Dargan et al. 2004). One of the first documented applications of technology was in 1948 to identify aircraft (Thomson 2006). Since that time, RFID has been used in various settings, and notably, the technology gained retail interest in the 1980's (Dargan, et al. 2004). RFID technology has evolved over time, but the technology did not spur serious attention until the mid-1990s. Advancements in integrated circuit assembly lowered the price of the technology, which brought forth interest and adoption of the technology in a number of industries (Dargan et al. 2004). Visionaries realized the utilization of RFID systems could potentially re-define how goods are tracked, improve operational efficiency, and increase a company's bottom line.

The application of RFID in a supply chain context, also known as Electronic Product Code (EPC) technology, began as pilot in 1999 between Proctor & Gamble (P&G) and Gillette with the Massachusetts Institute of Technology forming the Auto ID lab (Atkinson 2004). The stated goal was as follows: "to generate the intellectual fire-power to develop an open standard architecture infrastructure that would make it possible for computers to identify any object anywhere in the world" (Shister 2005). Simply put, the purpose was to create an "internet of things" which products communicate with machines and other products, shelves track their own inventory, and signal for replenishment when necessary. RFID evolved from that beginning and experts have boasted that RFID systems can track assets of any type (Johnson and Lee 2004).

RFID Systems

The primary components that make up an RFID system include: antennas, transponders, readers, personal computers, servers, and application software. Figure 4 illustrates the components of a basic RFID system. The RFID tag itself usually is a few square inches and contains a microchip with an antenna that acts as a transponder to communicate wirelessly with radio frequency readers when in range (Bose 2005). The

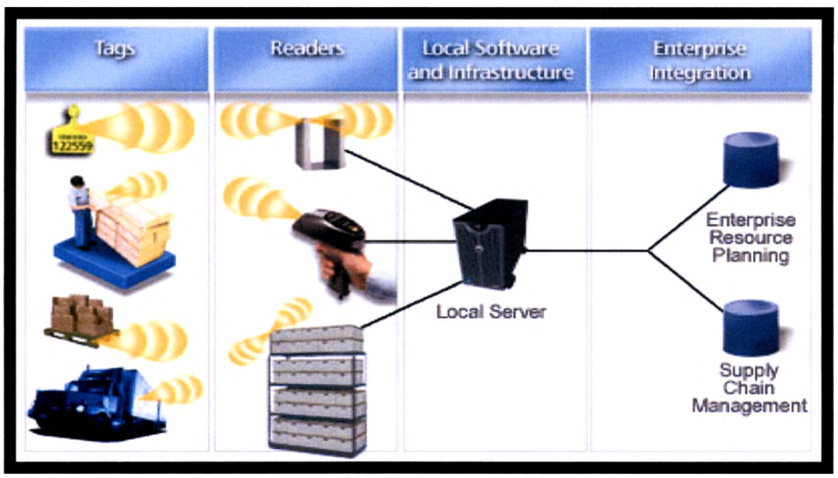

Figure 4: RFID System.
(Source: iDA Singapore)

wireless readers are capable of tracing a particular item within the supply chain. Strategically placed readers allow organizations to obtain real-time information that is transmitted over the Internet by a host computer and communicated to suppliers, manufacturers, retailers, and logistics providers through application software (Atkinson 2004).

There are multiple frequencies over which RFID can function; these frequencies have different purposes, distance capabilities, and cost (Dighero et al. 2005). Examples of applications, typical frequency ranges, and system characteristics are displayed in Table 1. The specific application dictates the RFID system specifications, and some of the key

Table 1: Characteristics of RFID.
(adapted from Laran 2004)

	Low frequency	High frequency	UHF	Microwave
Frequency	< 135 KHz	13.56 MHz	869-930 MHz	2.45 GHz
Read range	<1.64 ft	< 3.28 ft	~ 13-23 ft	<= 32 ft
Power	Passive	Passive	Active, Passive	Active, Passive
Cost	< 5 ¢	50 ¢	50 ¢	$'s
Applications	Access control Animal tags Auto immobilizers	Smart cards Access control Item tags Baggage control Biometrics Libraries	Supply chain Item tags Pallet/case tags Baggage control Toll collection	Supply chain Item tags Toll collection
Read rate	Slower ← → Faster			
Metal/wet	Better ← → Worse			
Tag size	Larger ← → Smaller			
Cost	Lower ← → Higher			

characteristics for various applications are given. The area of focus for this research work is the application of RFID to coordinate the supply chain; thus, the assumption should be made that this discussion incorporates the specifications of Ultra-High Frequency (UHF) tags in the range of 869-930 megahertz (Mhz). Note on Table 1 that frequencies above 869 Mhz have a faster read rate and are usually smaller in size; however, the cost per tag is higher and functionality is reduced by metals and moisture.

Benefits of RFID

Barcode technology has long been the standard when it comes to tracking products. RFID tags have been identified as a possible replacement and upgrade of the current bar code system. A summary of the advantages and disadvantages – from Atkinson 2005, Johnson and Lee 2004, Dargan et al. 2004, and Thomson 2006 – are presented in Table 2. Barcode technology faces several disadvantages compared to RFID: each item (unit, pallet, batch, truck, etc) must be scanned manually – extensive labor hours are required; barcodes store a limited amount of information; once a tag is printed – the information cannot be changed; and a barcode tag can be easily damaged - making it unreadable (Atkinson 2005). The aforementioned disadvantages of barcode technology are reasons RFID may eventually replace the use of barcodes.

Table 2: Barcodes Compared to RFID.

Characteristic	Bar Codes Disadvantage	RFID Advantage
Reading	Line of sight only Label must be clean / not deformed	Various angles Through some materials Functions in harsh environments
Storage	Limited amount of information Information cannot be changed	More data storage Data can be changed / updated
Scanning	Manual	Automated Instantaneous
Tracking	Limited – slow, costly	Real time
Processing time	Seconds / minutes	Milliseconds
Labor costs	Significant	Minimal

There are several advantages of using an RFID system to track products. RFID does not require line-of-sight to be functional, and it only takes milliseconds for the read process to occur; thus, multiple pallets can be scanned when passing through a dock door (Johnson and Lee 2004). Once fully functional, an RFID system would be primarily automated. An automated tracking system could significantly reduce labor costs and make the overall system more reliable. Also, RFID tags can be read in virtually any environmental condition which allows inventory to be tracked at any point within a supply chain (Dargan et al. 2004). Lastly, more data can be stored on an RFID tag than a barcode, and depending on the implemented technology, data could be changed and/or updated (Johnson and Lee 2004).

In a supply chain context, RFID has the potential to provide benefits in the following areas:

- advanced shipping notices,
- reduced shrinkage,
- better logistics for returned goods,
- improved anti-counterfeit,
- increased traceability with a reduction in the number of discrepancies,
- superior supply chain efficiency and stock management,
- improved demand forecasting,
- inventory reduction,
- automated replenishment, and
- reduced labor costs (Thomson 2006).

Overall, RFID technology presents the opportunity to open communication lines and increase supply chain visibility. Improved communication and vision could lead to more effective management of the flow of materials since RFID has the potential to provide a precise view of how long it takes a product to move from its point-of-origin all the way to its customers (Shister 2005). Also, strategic partnerships could be due to steady communication which might lead members of the supply network to increase their overall level of trust. In all, RFID technology has the potential to have a revolutionary impact on SCM.

Barriers of RFID Technology

RFID systems are not without a number of concerns that seem to be inherent with the technology. Since RFID is a relatively new technology in the introductory stage of the product-life-cycle, there are a number of barriers that must be overcome to gain industry-wide acceptance. The most significant barriers to adoption and successful implementation include: (1) the cost of RFID tags and readers; (2) RFID system failure; (3) environmental factors; (4) EPC standards and security; (5) supplier non-compliance; and (6) the lack of return-on-investment (ROI) generated by RFID systems – each barrier is discussed next.

The Cost of the Technology

The largest hurdle is the price of the microchips which is estimated to be 40 times greater than the cost of the barcode (Bose 2005). P&G has focused on including RFID technology in its business model since 1999, originally budgeting for tags to cost less than a nickel per case or pallet. Currently, P&G estimates that homogeneous pallets can be tagged for approximately ten cents per case; however, mixed pallet requirements can run as high as fifty cents a case (Shister 2005). Smartcode Corporation, a manufacturer of EPC RFID hardware, offers EPC Gen2 tags for 7.5 cents for quantities of 1 million and 7.2 cents for orders exceeding 10 million.

Although chip price is likely to decrease, there is a considerable additional cost that must be absorbed in the short-run. According to a Forrester Research study on the cost of implementation for a Wal-Mart supplier, a company can expect to spend around 9 million dollars – depending on the size of its distribution network and Wal-Mart volume (Wikipedia 2006). Granted, this figure could be subject to much debate; though, for small to medium-sized businesses, the return-on-investment (ROI) may not be justifiable.

RFID System Failure

Another obstacle to successful implementation has been read failure. Passive UHF tags at 869-930 Megahertz (MHz); commonly used in supply chain context, have a read range of approximately thirteen to sixteen feet (Thomson 2006). Under theoretical conditions, the read or write process should occur when tags pass within the radio frequency (RF) field of the wireless readers. Manufacturers have found significant differences in read rates, ease of use, and consistency of data in the actual production environment compared with test labs (Shuster et al. 2006). In test labs, firms have been able establish relative stability of the preceding factors; whereas, in production environments, operators often have to continually jiggle pallets until they get a full read or write function (Dighero et al. 2005). This type of problem requires additional time to obtain the necessary data capture – if accurate data is captured at all – and reduces many of the intended benefits of RFID systems.

Environmental Factors

A significant concern among manufacturers and suppliers is that certain liquids and metals block the ultra-high frequency (UHF) radio waves used with some RFID tags. Mike Oshea, Kimberly-Clarks Director of AutoID/RFID strategies, noted that "the environment has an influence on how radio waves perform" (Shister 2005). He states concrete and steel can block radio waves and humidity absorbed in packaging tends to decrease read rates. Due to the importance of accurate read rates, additional frequencies have been developed. West pharmaceuticals use a 13.56-MHZ high frequency active tag which adds significant cost, but many pharmaceutical manufacturers are willing to incur increased costs to guarantee timely delivery and product authenticity (Koroneos 2005).

Researchers (Dighero, Kellso, Merizon, Murphey-Hoye, and Tyo 2005) note that firms should take a holistic view and take a close look at every aspect of the physical environment to maximize accuracy and reliability of an RFID environment. The primary factors that should be analyzed are as follows:

- On the object – placement, orientation, form factor and materials, and spacing, along with other labels on the boxes;
- Around the object – casings, carriers, transport materials, structure, and hierarchy;
- With the object – the physical proximity and relationship associations.

Each environment, box type, product, and tag type needs specific testing in the environment to define the particulars of the circumstance (Dighero et al. 2005).

EPC Standards and Security

EPC Global, responsible for the development of RFID standards, must take a number of different precautions into account that relate to RFID technology. Jeannie Tharrington, P&G spokesperson, echoes that "there must be industry wide standards" for RFID to become viable on the global level (Shister 2005). EPC Global released the UHF Generation 2 protocol (Gen2) in December 2004. Gen2 incorporates worldwide frequency and performance requirements in the following areas: read rate accuracy is improved (through bit mask filtering), speed is increased, chip size is reduced by 20%, tag security is increased to 32-bit, and additional write schemes and memory are available (Porter 2005). Although EPC specifications theoretically allow for great performance improvements, the majority of the above benefits are yet to be fully realized in supply chain operations.

Product security is also a concern because, "what would stop counterfeiters from hacking into RFID chips and randomly placing fake product into the supply chain" (Koroneos 2005)? The Black Hat conference – an annual event in Las Vegas that details security exploits in emerging technology – had experts who demonstrated how a voltage-controller oscillator could act as a disrupter by shooting a frequency beam at a RFID reader to jam the device (Messmer 2005). The demonstration, although extreme, illustrated how the elimination of comprehensive reading could play havoc within supply chain operations. EPC Global has the burden of devising secure standards that will undoubtedly be demanded by businesses that implement RFID systems.

Supplier Noncompliance

As standards are developed for RFID systems, which have already been implemented by Wal-Mart (and Wal-Mart's top 100 suppliers), European retailers, the U.S. Defense Department, Hewlett-Packard (HP), and numerous pharmaceutical manufacturers, organizations may have to alter operations to conform with new standards that are applied in the future (Wilks 2005). HP already uses RFID for components that go into its printers which usually come from Taiwan and China (Wilks 2005). For RFID to serve its purpose, companies like HP must convince or possibly even provide an incentive for their suppliers to conform to industry standards. The challenges of RFID compliance are magnified when implementation involves a supplier that is a small business located in a town in Asia. This would especially be true when the Asian supplier who provides parts for HP out-sources microchips for its parts to be made by a third-party.

A Lack of ROI

A number of businesses have found the ROI from RFID implementation in supply chain operations to be minimal (Faber 2006). Others adhere to "slap and ship" by tagging their pallets, cases, or products as they leave distribution centers and eat the cost. A few firms have managed to quantify their ROI and can at least measure their return or cost savings (Hardgrave et al. 2005). Clearly, firms need a better framework to analyze ROI and measure the value RFID systems could potentially provide.

Murphy-Hoye et al. 2005 note that there are three ways to assess the value of a new technology. Experts or practitioners could subjectively give their best estimates. Obviously, this method would have the highest likelihood for error and there would be much speculation into subjective measurements. Second, in-depth case studies could be used to analyze early pilot initiatives and determine value by observing the results. Intel and Wal-Mart are both currently engaged in ongoing pilots, and have either published initial results or had members of academia publish working papers. The University of Arkansas published that Wal-Mart was able to reduce out-of-stocks, which would be quantifiable to a ROI. The question is: does a 16% reduction of out-of-stocks in Dallas test stores justify implementation worldwide? Intel, on the other hand, is not even sure how to successfully apply RFID in manufacturing operations. The last approach is to gauge RFID's value is to use analytical models that link the underlying operating characteristics to control decisions and performance measures (Murphy-Hoye et al. 2005). This is an area where research and analysis is most lacking, and this research will build on prior models – found in Chapter IV – to develop a proposed strategic model for RFID adoption and long-term implementation.

CHAPTER IV

ANALYTICAL RFID MODELS: PROPOSED MODEL

The search for the most effective strategy to integrate RFID into supply chain management (SCM) led to two separate existing models: *The Pathways for RFID Adoption* – proposed by Murphey-Hoye, Lee, and Rice, Jr. 2005 and *The Stages of Innovation* – proposed by Lee (2001). The Pathways for Adoption model identifies four unique methods of initial deployment; each method is identified using taxonomy based on two key dimensions – investments and benefits. Theoretical advantages and disadvantages of each method of adoption – *Internal Use/Closed Loop, Solo Drive, RFID-ready, and Collaboration* – are discussed later in the chapter. The Stages of Innovation model follows (the Pathways for Adoption), and it focuses on the various phases of sustained implementation. Businesses that have applied RFID technology in the work environment could potentially be grouped into one of three phases: substitution, scale, and structure. Each category (henceforth, *phase of implementation*) has independent characteristics which are different; thus, a firm's application of RFID technology can be grouped into one of the three phases of implementation. The two models are separate, but their combined application may serve to help firms better comprehend the strategic and tactical advantages of incorporating RFID into supply chains. The combined effects of the models are used to provide a clear understanding of the potential benefits of RFID and illuminate a strategic map for integration and long-run application of the technology. A complete explanation of grouping, characteristics, and analysis is found next.

Pathways to RFID Adoption

There are various pathways to integrate RFID into supply chain operations. Murphey-Hoye et al. (2005) explain that it can be a major challenge to develop and productively apply a new technology because so much about the technology itself is uncertain. This statement seems to be true because many firms are facing an impasse; they have not yet identified a concrete strategy to use RFID to optimize supply chain efficiency. The identification of four pathways begins to provide strategic direction, but which provides the path of least resistance? Some of the most common barriers of RFID were identified (refer to Chapter III); the goal is to spotlight the pathway that is least affected by barriers of the technology.

Figure 5 illustrates a summary of the four proposed pathways – Internal Use/Closed Loop, Solo Drive, RFID-ready, and Collaboration. Firms that adopt RFID either pay for the technology on their own or look to divide the investment among members of the supply chain. Independent of the investment outlay, the beneficiary of an RFID system can be a single firm or members of the supply chain. Thus, the identification of four pathways is based on investment and benefits:

- *Internal Use/Closed Loop* occurs when a single firm invests in an RFID campaign and bears the vast majority of the benefits. This is the most direct path; it allows a company to enjoy significant control and freedom, avoiding costly and time-consuming coordination with others in the supply chain (Murphey-Hoye et al. 2005).

An example of this pathway would be a firm that incorporates an RFID system to track inventory in their warehouse. This proprietary solution limits the investment; consequently, benefits are limited due to isolation of the RFID system.

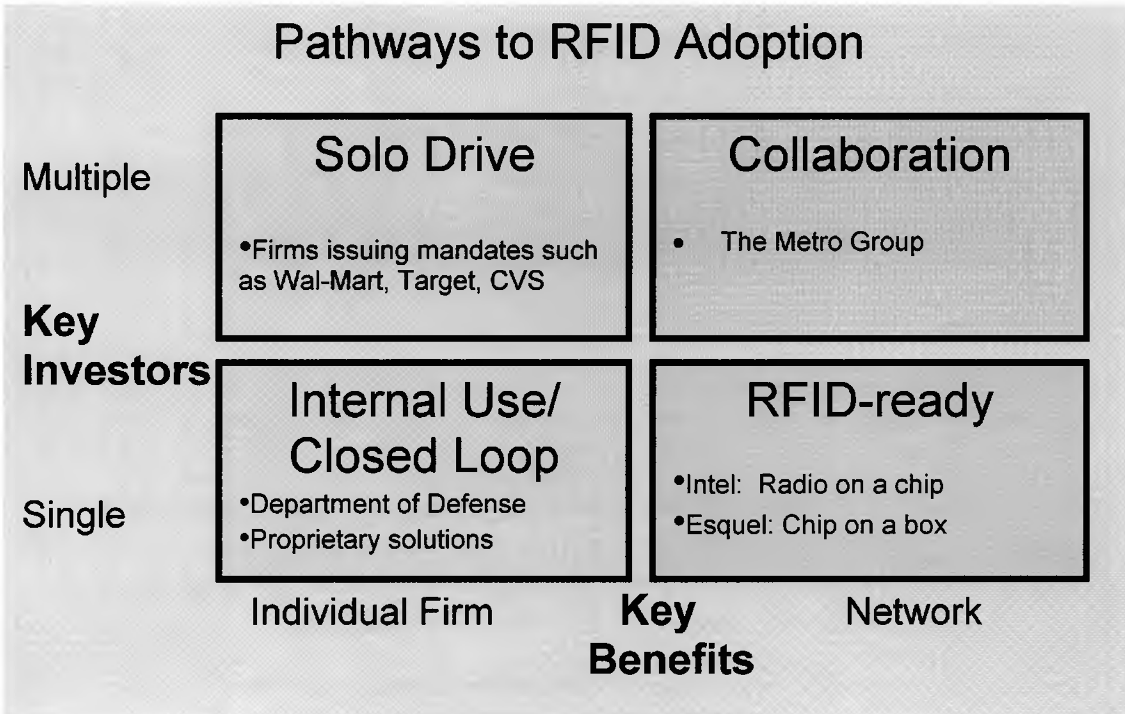

Figure 5: Pathways to Adoption.
(Adapted from: Murphee-Hoye et al. 2005)

- *Solo Drive* occurs when multiple firms invest in an RFID system; however, the majority of the benefits are gained by a single organization. Firms that issue mandates would be a prime example of Solo Drive. Wal-Mart requires many of its top suppliers to ship pallets of goods with RFID tags. Due to the complexity RFID systems, many of these suppliers have opted to "slap and ship" products with RFID tags. The businesses that "slap and ship" invest in the technology, but are not gaining any benefits from applying RFID technology. Wal-Mart, however, has experienced early successes by reducing the following: out-of-stocks, picklists, and employee hours restocking shelves (Hardgrave et al. 2005).

- *RFID-ready* occurs when a single firms invests in the technology and is able to gain immediate benefits from implementation. Upstream and downstream partners can make use of the investment to add value due to RFID enabled products (Murphey-Hoye et al. 2005). Partners may either benefit from trickle down effects or decide to take advantage of materials which are already tagged and implement their own system. An example of the former would be a firm that has sound business processes and focuses on operational efficiency is able to streamline inputs received or outputs delivered if a direct link – upstream or downstream – in the supply chain employs an RFID network. This would be the result of an organization which has implemented an RFID-ready system where a directly linked organization is able to benefit. Whether the benefit is improved forecasts, increased product availability, or more cohesive coordination, directly linked firms may be able to improve efficiency as a result of a partner firm with an RFID. The important thing to note is that the supply network has the potential to benefit from RFID-ready adoption.
- *Collaboration* occurs when multiple firms in the supply chain jointly invest and collectively share the benefits of the technology. German retailer Metro and Hewlett-Packard have "both invested in RFID adoption in cross-supply chain applications, and have actively involved their strategic supply chain partners to help create a successful system of application that is expected to benefit all parties" (Muphey-Hoye et al. 2005). Adoption through collaboration best fits the ideology of SCM, but this method requires absolute dedication to the initiative. Firms must make sure that long-term goals and objectives of the supply chain run parallel to their RFID initiative, which is easier said than done.

Stages of Innovation

It has been claimed that great innovations take place in three stages – substitution, scale, and a structural effect (Lee 2001). The Internet would be a prime example of an innovation that has moved through the three stages. In the early 1990s, businesses began to use Internet email as a form of communication in place of telephones, faxes, and mail – *substitution*. During the mid-1990s businesses as well consumers started to use the Internet to browse the web for information, communicate through email, and conduct limited financial transactions. This would be a *scale effect* that occurs when the benefits of a new technology cause it to grow. Today (circa 2006), the Internet has changed the way society conducts business and lives life – *a structural effect*.

RFID may not have an impact equivalent to the Internet, but the technology has the potential to have a significant impact on SCM. Murphey-Hoye et al. (2005) note that RFID is still largely in the substitution phase, which means barcodes are being replaced with RFID technology. Substituting RFID tags for barcodes have obvious advantages, but does substitution justify RFID implementation? Feedback from manufacturers of personal computers (PC) identified that their studies found the cost of RFID application is too much to justify substitution. The same Original Design Manufacturers (ODM) believe that high margin items such as high-definition (HD) televisions (TV) may justify the substitution of RFID for barcodes.

A scale effect would be similar to substitution except RFID would be installed across a wide range of products or processes (Dighero et al. 2005). Wal-Mart would be the most prominent example of an organization that progressed to scale application of RFID. The company has enabled almost all pallets and / or cases with RFID at specific locations (Hardgrave et al. 2005). Best Buy would be another example because the company set a mandate that its major suppliers tag cases and pallets in January 2006 (Roberti 2004). Economies of scale would provide a greater opportunity for savings, but how much is the supply chain benefiting if firms achieve RFID compliance through "slap and ship"? Scale effects may not provide justification for RFID implementation either.

A structural RFID effect, which changes the processes of SCM, would appear to provide the most value to businesses. In this scenario, there would be an end-to-end application of an RFID system and the supply network would function similar to the chain on a bicycle. As a product moves off a retail shelf, and a final read occurs as the product leaves the store; the aforementioned read triggers a product to be brought from the warehouse to the shelf that was emptied. Likewise, the operations manager at the product's raw materials mine, furthest upstream, has visibility into product movement at the retail level. Synchronization of the supply chain network provides the best opportunity to minimize the bullwhip effect and maximize supply chain profitability. Structural application of RFID systems would appear to provide the greatest value to businesses.

Proposed Model – Effective Pathways for RFID Adoption and Implementation

The primary objective of this research is to explore the most significant barriers regarding the adoption and long-term implementation of RFID systems into SCM. Due to the newness of the technology, a *strategic method of RFID integration* has yet to be identified. This research work proposes a strategic method for RFID integration; two steps were required to build the model. First, businesses were classified into one of four pathways to identify the most advantageous method of adoption; each pathway was analyzed based on the following barriers: read failure, cost of technology, security concerns, software failure, hardware failure, supplier and/or customer noncompliance, lack of standards, and poor ROI. These barriers were defined in Chapter III. Analysis of the above barriers determines the most effective pathway to RFID adoption. The barriers observed least will facilitate the selection of an RFID adoption strategy – Solo Drive, Internal Use/Closed-Loop, RFID-ready, or Collaboration.

Widespread RFID implementation has yet to occur; however, organizations that have applied RFID technology to their supply chain may be in different stages of implementation. In the second step firms were grouped into a stage of implementation: substitution, scale, or structural – the same barriers were applied to the three stages to determine which phase of implementation is least affected by barriers of the technology. The end result is the identification of the pathway for adoption and method of implementation that minimizes the most significant barriers to RFID application.

Problems that may occur in these environments – pathways for adoption and stages of implementation –have not been examined in prior research. This research work incorporates such analysis. For instance, obstacles might have been encountered in a number of various situations (refer to Table 3 for a complete breakdown).

- If firms adopt RFID through Solo Drive and apply the technology through Scale applications, what obstacles have they encountered?
- Which problems have firms that collaborate encountered if they structurally apply the technology?

Previously, answers to these questions did not exist. In Chapter VII the answers are provided through detailed examination and analysis of barriers encountered by firms in each pathway to adoption and phase of implementation. The analyses reveal a strategic model which integrates RFID into SCM while reducing the impact of barriers of the

Table 3: Long-Run Strategies for RFID Integration.

Method of Adoption		Long-Term Implementation
Solo Drive	→	Substitution? Scale? Structure?
Internal Use/Closed Loop	→	Substitution? Scale? Structure?
RFID-ready	→	Substitution? Scale? Structure?
Collaboration	→	Substitution? Scale? Structure?

technology. The model highlights the most advantageous method of adoption and implementation; which together, formulate a strategy to integrate RFID technology into the supply chain.

CHAPTER V

METHODOLOGY

This study examines businesses' use of RFID technology and attempts to advance the understanding of RFID into SCM through the assessment of organizational perceptions on adoption, long-term implementation, industry standards, potential barriers, and the overall usefulness of the technology. The primary objective of this research was accomplished by gathering secondary data from archive literature on supply chain terminology, RFID history and technology, and other topics related to this research. Supplemental data on the application of analytical models were obtained at the proceedings of the International Conference on Supply Chain, Logistics, and Information Systems (ILS) 2006 in Lyon, France. Collected secondary data were used to improve the pilot survey instrument which was originally sent to 35 businesses by email. Primary data were obtained from organizations that utilize supply chain management and/or RFID systems.

A vast majority of the pilot survey sample agreed that RFID improved communication and visibility which in effect refined coordination of the supply chain. Consequently, most of the pilot sample was not familiar with Electronic Product Code (EPC) Global's initiative to apply world-wide RFID standards. Also, responses indicated that the benefits of RFID were outweighed by the cost of the technology (Barnes and

Temponi 2006). Refer to the Appendix D for summary findings of the pilot survey. The overall results of the pilot survey led to the conclusion that businesses may not have a clear understanding of how to apply RFID to optimize the supply chain. An explanation of the survey instrument is found next.

Sampling

A list of firms that had implemented RFID systems was developed based on the examination of current RFID literature. Firms were selected from industries such as: distribution/transport, energy/utilities, manufacturing, telecommunications, electronics, and retail. A list of 30 firms was compiled; executives from each firm were identified through Hoovers Online database. Executives from operational divisions were only considered. A total of 248 employees from the 30 firms were selected to participate in the study.

Survey

The examination of secondary data led to the decision to gather primary data through a survey instrument. Subject content, wording, and response strategy was considered in drafting investigative questions. The majority of responses were on a five-point Likert scale to avoid centrality. The formats included: simple category scale – nominal data, Likert scale summated rating – interval data, numerical scale – interval data, and multiple-choice scale – nominal data.

Critiques and comments were solicited from the thesis supervisor and committee members. Then, the pilot survey was conducted to gauge the effectiveness of the investigative questions. Ineffective questions were eliminated, and the scope of the instrument was refined. After multiple revisions, the final survey was sent by email on

August 25, 2006. It was requested that the survey be completed within two weeks. The sample survey is attached in Appendix A.

The survey presented administrative and target questions to address research questions derived from RFID literature. The first two questions addressed organization size and industry type. The third question dealt with the impact of out-of-stocks in the supply chain. Question four identified if the respondent worked with RFID technology. Questions five and six were used to build the "Pathways to Adoption" model. The seventh question gauged the impact of barriers to RFID adoption and implementation. Question eight served to build the "Stages of Innovation" model. The final question addressed the incorporation of unified RFID standards. See Appendix A for a sample of questions sent to the participants.

Survey Administration

The survey was administered by email over the Internet. Survey Monkey's (www.surveymonkey.com) web-based software was used to design the instrument and collect the results. All respondents were informed that there participation would remain anonymous; a message in the introductory email message reassured each person that their identity and responses would not be published (refer to Appendix C to view the introductory email message). On September 10, 2006, the responses were exported from Survey Monkey into a coded Microsoft Excel spreadsheet.

Response Rate

The rate of response was highest at the onset of the distribution of the survey. Approximately 77% (32 responses) of all the responses were received within 72 hours of distribution. A follow-up email message with a reminder of the due-date was sent a week after the survey was emailed. A total 42 responses were received, and the response rate for the survey was approximately 16.9%. Since there were 14 surveys returned due to invalid addresses, the adjusted response rate came to 17.95% (~18%). Appendix B gives the counts for each survey question.

Data Analysis

Data collected from the surveys were organized to make it more manageable and exported into spreadsheet format. The analyses were performed using Microsoft Excel and SPSS ™ data analysis program. The exported data were double-checked to make sure the surveys were coded correctly. The analyses were performed using frequencies, means, students' t-tests, and analysis of variance (ANOVA). The results of these analyses are discussed in Chapter 6 and 7.

Limitations

The research has some limitations that should be considered in the examination of the results.

1) Since time and resources were an issue, the data sample was limited. The uniqueness of the technology and database constraints did not help much in overcoming the sample size limitation.

2) A convenience sample was used and the sample only represents businesses in the aforementioned industries that could be found in Hoovers Online database.

CHAPTER VI

DATA ANALYSIS

This section presents the analysis of results from the data collected for the research, and the analyzed data follows in Chapter VII. Two administrative questions were presented at the onset of the survey instrument to observe the size and industry of the firms. A small business was defined as 500 employees (or less) based on the specifications (for a manufacturing firm) set forth by the U.S. Small Business Association (SBA, 8888). The responses from the survey indicated the size the organizations were distributed as follows: small businesses 12% (5 responses) and large organizations 86% (36 responses). There was one response (about 2%) without a size declared. The most widely represented industry in the sample was the electronics industry with 45% response. Distribution/transport and manufacturing industries garnered 17% respectively. Retail, telecommunications, and energy/utilities each accounted for 7% of the sample – a total of 21%. A discussion of out-of-stocks in the supply chain is presented next.

Out-of-Stocks in the Supply Chain

The effect of out-of-stocks on supply chain productivity and revenue were measured in the survey instrument by collecting data which measured level of agreement with a statement about out-of-stocks. Refer to Appendix A for questions contained in the survey instrument. Results on distribution are presented in Table 4. The distribution of out-of-stocks indicates that about two-thirds of the companies experience reductions in productivity, and in turn, revenue, due to out-of-stock goods that come from members of

Table 4: The Impact of Out-of-Stocks – ***Percent (Counts)*.**

	Significant	Some Impact	Insignificant
Supply Chain	67% (28)	5% (2)	29% (12)
Suppliers	64% (27)	2% (1)	31% (13)
Manufacturers	33% (14)	31% (13)	36% (15)
Distributors	43% (18)	21% (9)	36% (15)

the *supply chain*. Specifically, *suppliers* were the most likely source of out-of-stocks; suppliers had a significant impact on productivity and revenue of the supply chain by 64% (27 responses). Manufacturers were the least likely source of out-of-stocks by 33% (14 responses). There was one response (about 2%) out of all the returned surveys without an impact assigned to the "Supplier" category.

A one-way ANOVA test (95% confidence) was also performed to analyze whether a statistically significant difference existed between the supply chain, supplier, manufacturer, and the distributor. A p-value of 0.0912 indicates there is not a significant statistical difference between the groups. The impact of out-of-stocks, which decreased productivity and caused losses in revenue, were approximately the same when comparing the supply chain, suppliers, manufacturers, and distributors.

It should be noted a one-way ANOVA test (90% confidence) indicates there is a significant statistical difference; one of the groups is different – the supply chain, suppliers, manufacturers, and distributors. To determine which group was different a Tukey correction method was applied. The Tukey analysis indicated that none of the groups were significantly different, so the results at a 10% significance level were somewhat inconclusive. Refer to Appendix E for the summary output.

RFID Technology

The application of RFID technology by businesses was captured by asking if *RFID is currently used at my organization or I have experience working with the technology*. A vast majority of the sample (approximately 88%) either worked with RFID at their firm or had experience working with RFID technology. Those who did not work or have experience with RFID technology (five, approximately 12%) were asked to "submit" the survey instrument at this juncture. One respondent answered that the technology was not used; however, the respondent answered the remaining questions – those responses were not included since they were invalid.

RFID Investment

To ultimately build the pathways for RFID adoption model, information regarding the monetary investment and the main beneficiary of RFID needed to be captured. The beneficiary of the RFID system is addressed in the next section. To determine who bore the investment, participants were asked if they agreed, were unsure, or disagreed with the statement: "the monetary investment for my company's RFID campaign is shared by members of the supply chain". Table 5 reports the distribution for each category. Approximately half of the sample population, nineteen (51%) reported that the cost to implement the organization's RFID system was dispersed among the supply chain; whereas, 38% of the respondents indicated that the monetary investment for their company's RFID campaign was not shared. About 11% (4 responses) were potentially unsure of whether (or not) their organization's RFID investment was shared.

Table 5: Collected Data on RFID Systems.

Categories	Frequency (%)[1]
A. ***RFID Investment***	
Shared	51%
Not Shared	38%
Neutral	11%
B. ***The Beneficiary of the RFID System***	
The Supply Chain benefits	100%
Manufacturers benefit	76%
Retailers benefit	73%
Distributors benefit	70%
Suppliers benefit	65%
C. ***Barriers of RFID Technology***	
Read failure	57%
Software failure	54%
Hardware failure	54%
Cost issues are a barrier	49%
Supplier and/or customer noncompliance	38%
Poor return-on-investment	35%
Security issues	8%
D. ***Phases of RFID Implementation***	
Used for specific products/locations	41%
Pilot program(s)	32%
Used on all products – firm specific	8%
Implemented across the supply chain	8%
Being researched only	5%
To replace barcodes	5%
E. ***Unified RFID Standards***	
Gen 2 RFID tags with EPC technology	63%
Unified standards not applied	37%

The Beneficiary of the RFID System

The second component of the pathways for RFID adoption model – the beneficiary of the RFID system – was determined with the following statement: *the RFID initiative of my organization benefits the company business and members of the supply chain.* All responses indicated that an RFID initiative benefited the company business and members of the supply chain (100%, 37 responses). Approximately 76% of

[1] Percentages do not add up to 100% in categories B or C because respondents were allowed to choose more than one answer.

the sample agreed that manufacturers benefit from an RFID system. Likewise, 73% and 70% agreed that retailers and distributors, respectively, benefited from an RFID system. Lastly, about 65% agreed that suppliers benefited from an RFID system.

Barriers of RFID Technology

Businesses that encountered problems with their RFID system indicated that barriers exits. The potential barriers of RFID were: read failure, hardware failure, software failure, the cost of the technology, supplier and/or customer noncompliance, poor return on investment (ROI), and security issues. The breakdown of the barriers – found in Table 5 – which reduced the intended benefits of the RFID system were read failure (57%), hardware and software failure (54% each), the cost of the system (49%), supplier and/or customer noncompliance (38%), poor ROI (35%), and security issues (8%). Failures of the technology – read, hardware, and software – accounted for more than 50% of the sample each. Overall, these three factors – *failures of the technology* – were the most frequently encountered problems which reduced the intended benefits of RFID systems.

Phases of RFID Implementation

Businesses were in various phases of RFID implementation (see Table 5); the various phases of implementation are used to classify the sample into one of the three stages of innovation in Chapter VII[2]. The largest portion of the sample (41%) noted their firm applied RFID technology to specific products and/or locations. Approximately 32% were engaged in RFID pilots. A total of about 16% of the responses either used RFID on

[2] The three stages are defined in Chapter IV.

all products (firm specific) or applied RFID across the supply chain – 8% each. Using RFID to replace barcodes and researching the technology were each represented by 5% of the sample.

Unified RFID Standards

To ascertain whether (or not) unified standards are being applied to RFID systems, respondents were asked: *my company uses Gen 2 UHF RFID tags with EPC technology.* RFID tags with Generation 2 Ultra-High Frequency (UHF) Electronic Product Code (EPC) technology were used by the majority of the sample (63%). About 37% did not use tags with the aforementioned technology; thus, unified standards were not applied to the firms' RFID system. The bulk of the sample, though, would appear to understand the importance of applying unified standards to RFID systems that may span across the globe.

A two-sample t-test with unequal variances (95% confidence) was performed to analyze whether a statistically significant difference existed between the two groups (see Appendix F for the summary output). *Failures of the technology* served as the basis for comparison – read, hardware, and software – analysis revealed that there was a statistically significant difference between the two groups (p-value = 0.017). Thus, businesses that do not employ unified RFID standards are more likely to encounter failures of the technology based on the sample. Firms that adopt and implement RFID systems should apply unified standards to reduce the likelihood of failures of the technology.

CHAPTER VII

ANALYTICAL RFID MODELS

The first step in the development of a long-run strategy to integrate RFID into the supply chain requires the selection of a pathway to adopt the technology. Research has identified four alternate pathways – solo drive, collaboration, internal use/closed loop, and RFID-ready; in the proceeding sections the pathways are analyzed. Ultimately, the pathway least affected by barriers of RFID technology is identified. *Step One* plots the strategic method of adoption. The second step is to determine the long-term method of application (henceforth, *implementation*) which is most beneficial. The stage of implementation that is least affected by barriers of RFID – the result of *Step Two* – plots the strategic method of long-term implementation. Together, the method of adoption and implementation form a roadmap for the formulation of a long-run strategy for RFID integration into the supply chain – the proposed model can be found at the end of this chapter.

To build the models, multiple data sorts and classifications had to be made. These classifications were based on the responses to *RFID investment, the beneficiary of the RFID system*, and *the stages of implementation.* The pathways for adoption model was constructed first, and then the stages of implementation model was built, and lastly, both models were combined with the barriers of RFID technology. The models were separately analyzed based on the frequency of the various barriers of RFID technology discussed in Chapter III. These analyses serve as foundation for the proposed strategic model that minimizes the barriers of supply chain RFID systems. The classification processes and analyses are detailed in the next sections.

Pathways to RFID Adoption (Step 1)

The pathways to adoption are based on two dimensions – investment and benefits. Thus, the sample should be sorted by investment and benefits. It does not matter which sort occurs first. In this case, the investment sort was performed first. For this sample, the sort yielded three groups instead of two: shared investment (51%), investment not shared (38%), and those "unsure" (11%) – refer to Table 5 in Chapter VI. The responses that were "unsure" – a total of four – had to be omitted from the model because a key component for adoption (the investment) was not specified. This reduced the sample size to thirty-three; where *shared investment* was 58% (19 responses) and *investment not shared* made up 42% (14 responses). The *shared investment* group consists of two pathways –refer to Table 6: Solo Drive and Collaboration. The *investment not shared* group consists of the following: Internal Use/Closed Loop and RFID-ready.

Table 6: Monetary Investment for the Pathways.

Shared Investment	Investment Not Shared
Solo Drive	Internal Use/Closed Loop
Collaboration	RFID-ready

To divide the *shared investment group* into two specific pathways – Solo Drive and Collaboration – a second sort was performed based on the beneficiary of the RFID system. Once this sort was performed, the determination was made that the entire *shared investment group* (58%) believed the supply network benefited from the RFID system.

All responses indicated that the whole supply chain benefits – rather than the individual firm. In this case, none of the sample adopted an RFID system through Solo Drive (0%). Collaboration (58%) was the dominant method of RFID adoption for this sample.

The *investment not shared group* was likewise sorted based on the beneficiary of the RFID system to identify whether the firm adopted RFID through an Internal Use/Closed Loop or an RFID-ready method. This sort revealed that the entire *investment not shared group* (42%) believed the supply chain network benefited -- rather than the individual firm. Thus, none of the sample adopted an RFID system through Internal Use/Closed Loop (0%) and approximately 42% adopted RFID systems through an RFID-ready approach.

The Three Stages of RFID Implementation (Step 2)

The three stages model was constructed by grouping the responses to the various *Phases of RFID Implementation* (see Table 5 in Chapter VI). According to the specifications of the stages of innovation set forth by Dighero et al. (2005), a substitution stage of implementation would consist of firms that are either *researching RFID*, *using the technology to replace barcodes*, or *pilot-testing RFID systems.* Businesses in the **substitution stage** made up 43% of the sample. Firms that have applied RFID technology to specific products/locations have engaged in the **scale stage** of implementation – 41% of the sample. Firms progress to a **structural stage** of implementation once they apply RFID technology to all products across the supply network and supply chain processes change because of RFID – 16% of the sample. The largest portion of the sample (sixteen respondents) was in the initial phase of implementation – substitution; however, many firms engaged in scale applications of

RFID systems (fifteen respondents). The smallest portion of the sample (six respondents) had progressed to final stage of implementation – structural.

Barriers Encountered

A summary of the barriers of RFID technology can be found in Table 5 of Chapter VI; the most prevalent barriers of RFID according to the sample proved to be read failure, hardware failure, and software failure. The proceeding sections determine (through cross tabulations, t-tests, and ANOVA analyses) the most prevalent barriers to adoption, and then, implementation of RFID systems – refer to Table 7 for summary findings.

Barriers of the Pathways to RFID Adoption (Step 1b)

Businesses that adopted RFID encountered barriers to adoption which reduced the intended benefits of the RFID system. The barriers encountered were read failure, software failure, hardware failure, cost issues, supply and/or customer noncompliance, poor return on investment (ROI), and security issues. The breakdown of barriers encountered can be found in Table 7. In the *Collaborative* pathway for adoption, the barriers were distributed as follows: cost issues and software failure (68% each), hardware failure (58%), read failure (53%), supplier and/or customer noncompliance (47%), poor ROI (32%), and security issues (8%). Cost issues and software failure were the most prevalent barriers. Also, more than half of the *Collaboration* pathway encountered read failure and hardware failure which reduced the intended benefits of the RFID system.

Table 7: RFID Barriers – Cross Tabulations.

Categories	Frequency (%)[3]
A. ***Pathways to RFID Adoption***	
Collaboration:	
Read failure	53%
Software failure	68%
Hardware failure	58%
Cost issues are a barrier	68%
Supplier and/or customer noncompliance	47%
Poor return-on-investment	32%
Security issues	11%
RFID-ready:	
Read failure	57%
Software failure	43%
Hardware failure	43%
Cost issues are a barrier	14%
Supplier and/or customer noncompliance	29%
Poor return-on-investment	29%
Security issues	0%
B. The Stages of RFID Implementation	
Substitution:	
Read failure	69%
Software failure	69%
Hardware failure	69%
Cost issues are a barrier	44%
Supplier and/or customer noncompliance	44%
Poor return-on-investment	44%
Security issues	13%
Scale:	
Read failure	53%
Software failure	47%
Hardware failure	53%
Cost issues are a barrier	73%
Supplier and/or customer noncompliance	27%
Poor return-on-investment	33%
Security issues	7%
Structural:	
Read failure	33%
Software failure	33%
Hardware failure	17%
Cost issues are a barrier	0%
Supplier and/or customer noncompliance	50%
Poor return-on-investment	17%
Security issues	0%

[3] Percentages do not add up to 100% because respondents were allowed to choose more than one answer.

Businesses that adopted an RFID system through an *RFID-ready* pathway encountered barriers in the following distribution: read failure (57%), hardware failure and software failure (43% each), supplier and/or customer noncompliance and poor ROI (29% each), cost issues (14%), and security issues (0%). Read failure was the most prevalent barrier in the *RFID-ready* pathway. Hardware and software failure followed, but there was less than a 50% chance that these factors would reduce the intended benefits of an RFID-ready pathway to adoption.

A two-sample t-test with unequal variances (95% confidence) was performed to analyze whether a statistically significant difference existed between the two pathways (the summary output can be found in Appendix G). Analysis of the cumulative barriers' means – *Collaboration* and *RFID-ready* – revealed that there was a statistically significant difference between the two groups (p-value = 0.0003). Based on the sample, a *Collaboration (investment shared)* pathway to adoption is more likely to encounter the preceding barriers of RFID technology than adoption through *RFID-ready (investment not shared)*. Thus, an RFID-ready pathway to adoption would be more likely to minimize the barriers which reduce the intended benefits of RFID systems. Firms that choose to employ an RFID system may want to consider adoption through an RFID-ready pathway because this method appears to reduce the impact of barriers associated with the technology – refer to Chapter 3 for a complete discussion of the *Barriers of RFID Technology*.

Barriers to the Stages of RFID Implementation (Step 2b)

Firms that have implemented an RFID system as a "*substitute*" for another technology – primarily barcodes – encountered the following barriers most frequently (refer to Table 7): read failure, hardware failure, and software failure (69 % each); cost issues, supplier and/or customer noncompliance, poor ROI (44% each); and security issues (13%). Failures of the technology – whether it is read, hardware, or software – were the most prevalent in the *Substitution Stage* of implementation. The cost of the technology, supply chain noncompliance, and the lack of a solid ROI reduced the intended benefits of RFID systems in at least four out of ten firms in the sample.

Firms that have applied RFID technology to specific products / locations – *scale applications* – encountered these barriers (found in Table 7) most frequently: cost issues (73%); read failure and hardware failure (53% each); software failure (47%); poor ROI (33%); supplier and/or customer noncompliance (27%); and security issues (7%). Almost three-quarters of the sample believed the cost of the technology was a barrier to implementation; and likewise, approximately one-half identified that failures of the technology (read failure, hardware failure, and software failure) reduced the intended benefits their RFID systems. The failures of the technology do, however, decrease in frequency when compared to the substitution stage of implementation.

Firms that "structurally" apply RFID technology across their supply chain encountered the following barriers – refer to Table 7: supplier and/or customer noncompliance (50%); read failure and software failure (33% each); hardware failure and poor ROI (17%); and cost and security issues (0%). Supply chain noncompliance was by far the most prevalent barrier in this stage of implementation. This makes sense because significantly more interaction amongst members of the supply chain would be required in this stage. It should also be noted that the failures of the technology – read, hardware, and software – significantly decrease in frequency as firms move to this stage of implementation (when compared to prior stages).

A one-way ANOVA test (95% confidence) was conducted to attempt to differentiate between the groups – Substitution, Scale, and Structural. Analysis of the cumulative barriers' variance revealed that there was a statistically significant difference between the groups – refer to Table 8 for the summarized results. A p-value of 0.00001 was derived from a test of the variation between the stages; thus, at least one group is different. A Tukey correction method was also applied (see Table 8) to address the multiple comparisons. The confidence interval for *Substitution-Scale* reveals that there is not a significant difference between these two groups. The confidence intervals for *Substitution-Structural* and *Scale-Structural* reveal that there is a statistically significant

Table 8: One-Way ANOVA for the Three Stages.

Source	SS	df	MS	F	p-value
Between variation	*39.544*	*2*	*19.772*	*14.362*	*0.0000*
Within variation	*349.693*	*254*	*1.377*		
Total variation	*389.237*	*256*			

Confidence intervals for mean differences

Confidence level 95.0%

Tukey method

Difference	Mean diff	Lower	Upper	Signif?
Substitution - Scale	*-0.149*	*-0.527*	*0.230*	*No*
Substitution - Structural	*-1.116*	*-1.618*	*-0.614*	*Yes*
Scale - Structural	*-0.967*	*-1.475*	*-0.460*	*Yes*

difference between the *Structural Stage* compared to the others, *Substitution* and *Scale*. Firms that structurally implement RFID might be less affected by the barriers of the technology (refer to Chapter 3 for a complete breakdown of the *Barriers of RFID Technology*).

Proposed Strategic Model to Minimize Barriers of RFD Technology

Among the many insights from the analysis of the results, two major issues stood out in regard to barriers of RFID technology. These two issues are the foundation of a proposed model to minimize barriers to the integration of RFID into SCM. The proposed model is presented in Table 9:

1) An RFID-ready pathway to adoption minimizes the occurrence of barriers to RFID technology; firms should invest individually, but also present the opportunity for members of the supply chain to reap the benefits and/or link up to the existing RFID network.

2) Businesses should strive to structurally apply RFID to their supply chain network to reduce the impact of barriers to the technology; fundamental changes to supply chain processes might be required for successful long-term application of RFID into Supply Chain Management (SCM).

It should be noted that a number of growing pains – refer to the barriers in Table 9 – are likely to be encountered due to the newness of RFID technology. To work through these growing pains, businesses need to have a clear understanding of how to effectively adopt, and then continually apply, an RFID system within their supply chain network. Prior research has laid the foundation to provide these understandings, and this work has built on that foundation in an effort to provide clear roadmap for businesses to follow. This roadmap appears to identifies the most effective method of adoption and long-term implementation, which appears to yield the greatest prospect for success, because the probabilities of encountering the main barriers of RFID technology are decreased. Thus,

Table 9: Proposed Model for Long-Term RFID Application.

Categories	Likelihood of the Barrier (%)
Pathway to RFID Adoption	
RFID-ready:	
Read failure	57%
Software failure	43%
Hardware failure	43%
Cost issues are a barrier	14%
Supplier and/or customer noncompliance	29%
Poor return-on-investment	29%
Security issues	0%
B. ***Long-term Method of Application***	
Structural:	
Read failure	33%
Software failure	33%
Hardware failure	17%
Cost issues are a barrier	0%
Supplier and/or customer noncompliance	50%
Poor return-on-investment	17%
Security issues	0%

businesses can follow the recommended path to put themselves in a position to maximize the potential benefits of RFID technology. The recommendations and conclusion are provided in the forthcoming chapter.

CHAPTER VIII

RECOMMENDATIONS AND CONCLUSION

Businesses that have integrated RFID into supply chain operations definitely believe the technology benefits the company business and members of the supply chain based on the sample. These businesses would appear to understand that the benefits of RFID can be maximized if the supply network is engaged in integration of the technology. Responses from businesses indicate, regardless of the method of adoption (Collaboration or RFID-ready), that RFID adds the most value when partnering firms collectively share the benefits. Businesses would appear to understand the importance of collaborative efforts when adopting RFID technology.

Once an RFID system is in place (post-adoption), businesses were most heavily distributed between *substitution* and *scale* applications, which were more likely to encounter barriers of RFID than structural applications based on the sample. Approximately 84% of the businesses in the sample indicate they apply an RFID system in a manner that conflicts with the chosen pathway for adoption. This distribution indicates that businesses' RFID strategy might not be in line with the ideology of supply chain management (SCM). If businesses are aware that RFID provides the most benefits if applied to the supply chain, why are the majority of RFID systems being applied in a manner that does not capitalize on its potential benefits? Initially, it was believed this phenomenon might occur because businesses did not have a clear-cut strategy to apply RFID technology to the supply chain in the long-run. The results of the data collection seem to support this initial belief, and the application of the strategic model serves to provide a clear-cut strategy to successfully integrate RFID into SCM.

The key component of the model is the incorporation of barriers to RFID into the two prior proposed models – Pathways for Adoption and Stages of Innovation. Prior to this research work, these models mapped the theoretical pathways and stages and even provided advantages and disadvantages of each. The models were separate prior to this research work; thus, a gap existed between the two. During the research process it was discovered the two could be combined to form a single strategic model. Together, the models worked to cover initial adoption of a technology and long-term application of said technology. Independent variables were added (the barriers) to the models to identify a pathway for adoption and long-term stage of implementation least affected by common barriers of RFID. The responses in the sample indicated barriers exist (refer to Chapter IV for a summary of the barriers encountered); by plotting the various barriers into the models, a strategy for adoption and long-term implementation (henceforth, *long-run strategy for RFID integration*) was revealed.

In addition to providing a clear-cut strategy, this research highlighted that current RFID strategies were not reflective of a long-run strategy for RFID integration. If businesses adopt RFID through either Collaboration or RFID-ready, they should strive implement RFID in a structural manner based on the sample. Substitution and Scale implementation work against the businesses strategy for adoption – Collaboration or RFID-ready – when barriers of RFID technology are considered. Going forward, businesses can follow the proposed roadmap to better align their long-run RFID strategy, which should allow the supply chain to reap the greatest benefits, while avoiding barriers that reduce the intended benefits of the RFID system.

There is an additional component that should be considered when exploring the integration of RFID into SCM; an inclusive strategic alliance is needed to ensure the successful integration of RFID into SCM. Research suggests that businesses seem to understand that RFID can yield the greatest benefits through end-to-end application within supply chains (Murphey-Hoye et al. 2005). End-to-end application, though, requires businesses work together to coordinate the design and implementation of a single RFID network – a network of products whose movement is coordinated by RFID technology. To build an RFID network that spans the supply chain, a strong strategic alliance is needed, which is easier stated than accomplished. Large organizations must work with small to medium businesses which span the globe to guarantee the effectiveness of the RFID network. *A concerted effort by supply chain partners to incorporate RFID along with clear-cut strategy for integration is needed to transform this promising technology into revolutionary aspect of SCM.*

The prior statement brings up one last consideration. Are businesses within a supply chain network (end-to-end) capable of forming the type of strategic alliance that is needed maximize the benefits of RFID technology? Some would say yes; however, many would say no because the complexity of supply chain networks today is too great. This research work has led to an additional proposition that may reduce the need for an end-to-end all inclusive strategic alliance. A managed service provider might be able to build and integrate an RFID network that encompasses a supply chain from end-to-end.

A managed service provider can be viewed like an Internet Service Provider (ISP). A firm that specializes in RFID application, an RFID service provider (RFSP), might be more successful in the end-to-end integration of RFID into SCM. In this context, a RFSP would be responsible for providing RFID readers and initial setup of the network, similar to the setup done by an ISP. Once setup is complete, the businesses within the supply chain are linked through RFID technology. Would this method of RFID integration further reduce barriers of the technology? At this stage a concrete judgment cannot be made, but this postulation serves as a potential additional method for long-run strategic integration of RFID into the supply chain. Clearly, this method of integration is proposed and untested; however, integration through a managed service provider – an RFSP – might be an alternate strategic method of RFID integration. Further research is needed to explore the feasibility of RFID integration through an RFSP.

In closing, the strategic RFID model (provided in Chapter VII) assesses the impact of barriers of RFID technology. RFID adoption through an RFID-ready pathway and long-term structural application are least affected by barriers of RFID technology. Businesses that are looking to integrate RFID into the supply chain should adopt the technology through an RFID-ready strategy based on the sample. Once the technology is in place, a strategy to *structurally* apply RFID should be followed. Understanding that the pathway to adoption and stage of implementation are not mutually exclusive is a key to this strategy. The two were intertwined to form a long-run strategy for RFID integration into the supply chain. This strategy is recommended because it appears to minimize the impact of barriers of RFID that occur in real-world RFID systems. If applied correctly, the long-run integration strategy could help businesses transform

RFID's theoretical benefits into real-world capabilities which present the opportunity to achieve Triple-A Supply Chain status.

APPENDICES

A. Survey

A graduate student at the McCoy School of Business at Texas State University-San Marcos is conducting this survey to gather information on Radio Frequency Identification Tag's influence on Supply Chain Management. All participant information and responses will remain anonymous. Please fill out as much as you feel comfortable with and submit before **August 25, 2006**.

1. The number of employees at your organization.
   Less than 100   100 – 500   501-1000   More than 1000

2. I would classify my organization in the __________ industry.
   Distribution/Transport   Energy/Utilities   Manufacturing
   Telecommunications   Electronics   Retail

3 My organization experiences decreases in productivity and/ or loss of revenue due to out-of-stock goods that come from members of the supply chain. (Mark each) as applicable.

Strongly Agree	☐	☐	☐	☐	☐	☐	☐	Strongly Disagree
Suppliers	☐	☐	☐	☐	☐	☐	☐	
Manufacturers	☐	☐	☐	☐	☐	☐	☐	
Distributors	☐	☐	☐	☐	☐	☐	☐	

4 Radio Frequency Identification (RFID) technology is currently used in my organization (or I have experience working with the technology). _____ Yes _____ No

****If you marked "No" the survey is complete.****

5. The monetary investment for my company's current RFID campaign is shared by members of the supply chain.

Strongly Agree	☐	☐	☐	☐	☐	☐	☐	Strongly Disagree

6. The RFID initiative of my organization benefits the company business and members of the supply chain. (Mark each) as applicable.

Strongly Agree	☐	☐	☐	☐	☐	☐	☐	Strongly Disagree
Suppliers	☐	☐	☐	☐	☐	☐	☐	
Manufacturers	☐	☐	☐	☐	☐	☐	☐	
Distributors	☐	☐	☐	☐	☐	☐	☐	
Retailers	☐	☐	☐	☐	☐	☐	☐	

7. My firm has encountered problems with its RFID system(s) which have reduced the intended benefits of the RFID campaign (Mark each problem) as it applies

Strongly Agree	☐	☐	☐	☐	☐	☐	☐	Strongly Disagree
Read failure.	☐	☐	☐	☐	☐	☐	☐	
Cost issues:	☐	☐	☐	☐	☐	☐	☐	
Security issues:	☐	☐	☐	☐	☐	☐	☐	
Software failure:	☐	☐	☐	☐	☐	☐	☐	
Hardware failure:	☐	☐	☐	☐	☐	☐	☐	
Supplier – noncompliance:	☐	☐	☐	☐	☐	☐	☐	
Poor return – on – investment:	☐	☐	☐	☐	☐	☐	☐	

8. RFID technology at my organization is currently __________. (Only circle one)
being ***researched*** ***replaces*** barcodes used for ***specific*** products / locations
used as a ***pilot*** used on ***all*** products used ***across*** the supply chain (all products)

9. My company uses Gen 2 UHF RFID tags with EPC technology.
_____ Yes _____ No

B. Counts of the Survey Responses

The number of employees at my organization

	Response Total
Less than 100	1
100 – 500	4
501-1000	2
More than 1000	34
Total Respondents	41
(skipped this question)	1

I would classify my organization in the __________ industry

	Response Total
Distribution/Transport	7
Energy/Utilities	3
Manufacturing	7
Telecommunications	3
Electronics	19
Retail	3
Total Respondents	42
(skipped this question)	0

My organization experiences decreases in productivity and/ or loss of revenue due to out-of-stock goods that come from members of the supply chain. (Mark each) as applicable

	Strongly Agree				Stongly Disagree	Response Average
	11	17	2	9	3	2 43
Due to suppliers	10	17	1	11	2	2 46
Due to manufacturers	6	8	13	8	7	3 05
Due to distributors	6	12	9	7	8	2 98
Total Respondents	42					
(skipped this question)	0					

Radio Frequency Identification (RFID) technology is currently used in my organization
(or I have experience working with the technology)

	Response Total
Yes	37

No	5
Total Respondents	42
(skipped this question)	0

The monetary investment for my company's current RFID campaign is shared by members of the supply chain

	Response Total
Strongly Agree	4
Agree Somewhat	15
Neutral	5
Disagree Somewhat	5
Strongly Disagree	9
Total Respondents	38
(skipped this question)	4

The RFID initiative of my organization benefits the company business and members of the supply chain (Mark each) as applicable

	Strongly Agree				Strongly Disagree	Response Average
My Firm Benefits	29	8	0	0	1	1 32
Suppliers Benefit	13	11	6	4	4	2 34
Manufacturers Benefit	17	11	7	1	2	1 95
Distributors Benefit	16	10	6	2	4	2 16
Retailers Benefit	19	8	3	1	6	2 11
Total Respondents	38					
(skipped this question)	4					

My firm has encountered problems with its RFID system(s) which have reduced the intended benefits of the RFID campaign

	Strongly Agree				Strongly Disagree	Response Average
Read failure	4	17	6	8	3	2 71
Cost issues	6	12	6	9	5	2 87
Security issues	0	3	12	11	12	3 84
Software failure	2	18	8	3	6	2 81
Hardware failure	0	20	5	6	6	2 95
Supplier and/or customer noncompliance	4	10	7	6	11	3 26
Poor return-on-investment	2	11	6	12	7	3 29
Total Respondents	38					
(skipped this question)	4					

RFID technology at my organization is currently __________

Response Total

being researched	3
being used to replace barcodes	2
used for specific products / locations	15
used as a pilot	12
used on all products	3
used across the supply chain (all products)	3
Total Respondents	38
(skipped this question)	4

My company uses Gen 2 UHF RFID tags with EPC technology

	Response Total
Yes	22
No	14
Total Respondents	36
(skipped this question)	6

C. Introductory Survey Greeting

Hello, my name is Damon Barnes, and I am a graduate student at the McCoy School of Business at Texas State University-San Marcos. I am conducting a survey to gather information on Radio Frequency Identification Tag's influence on Supply Chain Management.

All information gathered will remain completely anonymous. I would be very appreciative if you would take the time (about 5 minutes) to complete my survey. To participate in the survey, simply click on the link below. Please submit no later than September 1, 2006.

Please feel free to forward this message to anyone that may be interested in this subject.

Thank you,

Damon Barnes
MBA Candidate
Texas State University

D. Pilot Survey Results

The first survey question addressed the size of the organization. A small business was categorized as less than 500 employees and a large business was greater than 500. Of the fourteen respondents, 21% worked for a small business and 79% worked for a large organization. The breakdown by industry was captured through question two. The results were as follows: energies/utilities 30%, distribution and electronics 21% respectively, manufacturing 14%, and retail and telecommunications 7% each.

Supply chain management

Questions Three through Six were used to gain a perspective on the importance of SCM, whether the supply chain was global, and its effectiveness.

Question Three addressed the importance of SCM within the organization. This question was on a seven-point Likert scale with the strongest agreement being a 1 and the strongest disagreement being a 7. Responses marked a 1 or a 2 were "integral", 3 - 5 engaged in SCM (but not a focus), and 6 - 7 did not utilize SCM. Overall, 64% felt SCM was integral to their business whereas 36% engaged in SCM, but it was not a focus.

Question Four asked if a member of the supply chain was located in another country. This question was also on a Likert scale with the strongest agreement being a 1 and the strongest disagreement being a 7; however, responses of 1 -3 were classified global and 4 – 7 were classified to operate in a domestic supply chain. Almost 86% classified there supply chain as global and more 14% felt the supply chain was domestic.

Question Five asked how frequently the firm experiences decreases in productivity and/or loss of revenue from out-of-stocks due to members of the supply chain. An answer of 1 being the most frequent and 7 the least, responses marked 1 or 2 were classified as frequent, 3 - 5 were classified as occasional, and 6 - 7 were interpreted as infrequent. As an addition, suppliers, manufacturers, and distributors were listed below the question on the same scale. Each category contained its own seven point Likert scale that ranged form frequently to infrequently. None of the responses fell under the frequent category; Table 1 displays the responses by category. A vast majority of the

Table 1: Supply chain coordination

	Occasional	Infrequent
Supply Chain	79%	21%
Suppliers	86%	14%
Manufacturers	64%	36%
Distributors	71%	29%

respondents believed that their company experienced decreases in productivity and/or loss of revenue from out-of-stocks due to a supplier, manufacturer, distributor and/or the supply chain as a whole. Based on the sample, suppliers were the most likely source of occasional out-of-stocks, and manufacturers the most infrequent.

A one-way ANOVA test (95% confidence) was also performed to analyze whether a statistically significant difference existed between the supply chain, supplier, manufacturer, and the distributor. A p-value of 0.6 was derived from the test; thus, there was not a significant statistical difference in the frequency of out-of-stocks comparing the supply chain, suppliers, manufacturers, and distributors.

Question Six inquired whether the organization consistently meets the necessary level of demand, so retailers and/or consumers do not experience product/service shortages. Again, a seven-point Likert scale question with the strongest agreement a 1 and the strongest disagreement a 7, but responses marked 1 or 2 were classified as consistent, 3 - 5 were classified as somewhat consistent, and 6 - 7 were interpreted as inconsistent. Overall, 57% of the sample believed their organization consistently met the necessary level of demand and 43% stated their organization was somewhat consistent.

RFID

Questions seven through twelve addressed the use of RFID, potential benefits, current standards, and the cost of the technology.

Question Seven asked whether the individual used RFID at his/her organization or had experience working with the technology. The majority of the sample (approximately 57%) did not use or have experience with RFID. Six respondents (nearly 43%) worked with or had experience with RFID and answered questions eight through eleven.

Question Eight asked if RFID improved coordination of the industrial value chain. This was a seven-point Likert scale question with the strongest agreement being a 1 and the strongest disagreement a 7. Responses marked 1 or 2 were classified to significantly improve coordination, 3 - 5 somewhat improved coordination, and 6 - 7 were interpreted to have no impact. Approximately 33% believed the effect of RFID was significant whereas 67% thought RFID somewhat improved coordination.

Question Nine asked if RFID tags improved communication and visibility within the supply chain; and thus, improved inventory allocation and management of goods for participating organizations. This was also a Likert scale question that agreement started at 1 and disagreement ended with 7. Responses of 1 or 2 were classified to strongly agree, 3 - 5 somewhat agreed, and 6 - 7 did not agree. On the whole, 50% strongly agreed with the statement and 50% thought RFID somewhat improved communication and visibility; and thus, improved inventory allocation and the management of goods.

Question Ten asked whether the individual was familiar with the Gen2 UHF standard released by EPC Global. Nearly 67% of the sample was not familiar with Gen2 UHF. Respondents unfamiliar with Gen2 UHF were to skip to question twelve.

To gain greater insight into the data, respondents were spilt into two groups: familiar with Gen2 and not familiar. The basis for comparison was the surveyed responses to questions eight and nine. A two-sample student's t-test was used to test the difference between the means of the two groups. The variance between the groups was assumed to be equal, and led to a p-value of 0.058. At a 10% significance level, there proved to be statistically significant difference in the way the two groups answered the questions. Familiarity with Gen2 UHF may affect the perceived benefits of RFID.

Question Eleven asked if the features of Gen2 UHF had proven to increase overall performance and dependability of RFID technology. This was a Likert scale question which both respondents marked "4"; thus, agreement or disagreement was negligible.

Question Twelve asked if the benefits of RFID were outweighed by the cost to implement and sustain the technology. All respondents answered this seven-point Likert scale question that measured level of agreement. A 1 or 2 was classified as strongly agree, 3 - 5 somewhat agreed, and 6 - 7 did not agree. Overall, 71% at least somewhat agreed that the cost of the technology outweighed the benefits of RFID.

To determine if the size of the firm made a significant statistical difference, responses to question twelve were dived into two groups: large organizations and small businesses. A two-sample student's t-test was used to test the difference between means. Variance between the groups was assumed equal and a p-value of 0.14 was computed. At a 10% significance level, the size of the organization did not affect the individual's perception of whether the benefits of RFID were outweighed by the cost.

A second two-sample t-test was used to examine if RFID usage affected perception of whether the technologies benefits were outweighed by the cost. Two groups were formed from responses to question seven: usage/experience with RFID and non-usage. Variance between groups was assumed equal and a p-value of 0.14 was calculated. There did not prove to be significant statistical difference between the two groups.

E. Out-of-Stocks ANOVA

Results of one-way ANOVA

Summary stats for samples

	SC	Suppliers	Manuf.	Distr.
Sample sizes	42	41	42	42
Sample means	1.619	1.659	2.024	1.952
Sample standard deviations	0.909	0.938	0.841	0.882
Sample variances	0.827	0.880	0.707	0.778
Weights for pooled variance	0.252	0.245	0.252	0.252

Number of samples	4
Total sample size	167
Grand mean	1.814
Pooled variance	0.798
Pooled standard deviation	0.893

OneWay ANOVA table

Source	SS	df	MS	F	p-value
Between variation	5.240	3	1.747	2.190	0.0912
Within variation	130.005	163	0.798		
Total variation	135.246	166			

Confidence intervals for mean differences

Confidence level 95.0%

Tukey method

Difference	Mean diff	Lower	Upper	Signif?
SC - Suppliers	-0.039	-0.549	0.470	No
SC - Manuf.	-0.405	-0.911	0.102	No
SC - Distr.	-0.333	-0.840	0.173	No
Suppliers - Manuf.	-0.365	-0.875	0.144	No
Suppliers - Distr.	-0.294	-0.803	0.216	No
Manuf. - Distr.	0.071	-0.435	0.578	No

F. RFID Standards Two-Sample t-test

Two-sample analysis for RF-S minus RF

Summary stats for two samples

	RF-S	RF
Sample sizes	64	49
Sample means	2.547	3.051
Sample standard deviations	1.068	1.191

Test of difference>=0 versus one-tailed alternative

Hypothesized mean difference	0.000	
Sample mean difference	-0.504	
Pooled standard deviation	1.116	NA
Std error of difference	0.227	0.233
Degrees of freedom	101	74
t-test statistic	-2.225	-2.167
p-value	0.014	0.017

Test of equality of variances

Ratio of sample variances	1.243
p-value	0.219

G. Pathways Two-Sample t-test

Two-sample analysis for RFR minus C

Summary stats for two samples

	RFR	C
Sample sizes	98	130
Sample means	3.398	2.846
Sample standard deviations	1.225	1.138

Test of difference<=0 versus one-tailed alternative

Hypothesized mean difference	0.000	
Sample mean difference	0.552	
Pooled standard deviation	1.176	NA
Std error of difference	0.157	0.159
Degrees of freedom	226	200
t-test statistic	3.508	3.472
p-value	0.000	0.000316

Test of equality of variances

Ratio of sample variances	1.159
p-value	0.216

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