THE DIFFUSION AND IMPACT OF RADIO FREQUENCY IDENTIFICATION IN SUPPLY CHAINS: A MULTI-METHOD APPROACH

by

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ABSTRACT

XIAORAN WU. The diffusion and impact of radio frequency identification in supply chains: A multi-method approach (Under the direction of DR. CHANDRASEKAR SUBRAMANIAM)

As a promising and emerging technology for supply chain management, Radio Frequency Identification (RFID) is a new alternative to existing tracking technologies and also allows a range of internal control and supply chain coordination. RFID has generated a significant amount of interest and activities from both practitioners and researchers in recent years. However, the factors important for its diffusion in supply chains and the impact on supply chain performance have not been well understood. Many organizations are reluctant to participate in supply-chain level RFID projects because of this lack of understanding. My dissertation proposes to help understand RFID's use in supply chains through a multi-method approach - an empirical study to understand the diffusion and impact of RFID and a simulation study to understand RFID's impact on inventory accuracy in supply chains. My first study on the factors influencing RFID adoption decision showed that compatibility, trading partner's RFID capability, trading partner power, competitive pressure, transaction volume and financial resources are significant factors for RFID adoption in a supply chain context. The second study which looked into the post-adoption use of RFID for supply chain has found that adoption cost, complexity, organizational readiness, external pressure and trading partner readiness significantly influence RFID infusion, which finally improves firm's supply chain process performance. The third study used a simulation model to examine RFID's impact on inventory management in supply chains. The key findings

were that the benefits reaped from RFID heavily depend on product type which implements RFID. The above findings indicate that organizations have to carefully evaluate their RFID project with different factors identified in this dissertation to successfully implement RFID and derive its full benefits. My dissertation has contributed to RFID research in particular, and supply chain technology adoption in general, by showing the importance of trading partner issues for supply chain technology diffusion and use.

ACKNOWLEDGMENTS

A wise man said that history, big or small, is made during the process. It is the moment to appreciate all the experiences that have made and shaped me during this long journal. I am indebted to many who have made these experiences invaluable.

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CHAPTER 1: INTRODUCTION

1.1 Background

Businesses always require information about the properties of goods or other entities involved in their operational processes. An effective and efficient information tracking and tracing system enables a decision maker or an automated system to rapidly respond, in order to reduce operational cost and increase productivity (Piramuthu 2005). Radio frequency identification (RFID) is a technology that can dramatically increase organizations' capabilities to acquire data about entities and their locations in real time (Chatterjee et al. 2005).

RFID technology can be implemented in different contexts. For example, RFID can be used within a single firm to track and trace their expensive assets and improve asset management. RFID can be applied in tracking animals to optimize the livestock's value. RFID is also used to speed up tolling service. However, the most promising area for RFID technology is supply chain management (SCM). RFID can be deployed in SCM from very common activities such as moving goods through loading docks, to complex ones, such as managing in real-time information about millions of goods on hand. RFID has the promise to help indentify container, pallet, case and items being manufactured, shipped and sold along supply chains, provide customers the right product at the right place at the right time, and consequently maximize sales and profits for every part of supply chains. RFID application for SCM can be found in the sectors of logistics, retail, healthcare, automotive and textile.

RFID is usually compared with another scanning technology—barcode, the commonly used identification technology. However, RFID technology can provide much more useful information than barcode can, such as product identification number, price and cost, manufacture date, location, inventory on hand, etc (Chao et al. 2007). RFID can help increase efficiency, accuracy, and visibility of supply chains operations, which in turn lead to many benefits, for instance, lower labor costs, shorter cycle times, lower inventory and improved customer service (Matta and Moberg 2006).

In 2005, a survey of 500 companies, conducted by AMR Research-RFID Journal found that RFID related spending represented 9.1% of IT budgets, with the spending projected to increase 16% by 2006, and another 20% by 2007 (Reilly 2005). Bagchi et al. (2007) predicted that growth of RFID will be very quick, from $1 billion in 2003 to $4 billion in 2008. Despite a global economic recession, RFID market keeps a steady growth rate. Based on a report from ABI Research in 2010, global RFID market is estimated to grow to $5.35 billion in 2010, a 15 percent increase over the total for 2009. The RFID market is also expected to see steady growth over the next five years, reaching over $8.25 billion in 2014. As ABI's practice director, Michael Liard says "To 2014, the greatest growth will be found in RTLS (Real Time Location Systems), baggage handling, animal ID, and item-level tagging in fashion apparel and retail." Hence, RFID is being viewed as one of the most exciting technologies for SCM (Scott 2005).

The growing literature on RFID continues to provide valuable insights to many RFID topics, such as RFID applications and impact on business operations. Most studies, though, analyze RFID from a case-study approach to study specific instances in which this technology is used or could be used to create value for the businesses. Some studies address RFID diffusion from a customer's perspective, focusing on privacy and security issues. The diffusion of RFID in a supply chain is a complex process due to the feature of the technology and the interactions of technology adoption decisions among the supply chain partners. RFID adoption in one organization within a supply chain may have impacts on the rest of the supply chain, so the adoption and infusion decisions need to be addressed in a more thoughtful manner (Dutta et al. 2007). In addition, research findings on RFID diffusion have remained fragmented (Whitaker et al. 2007) and do not provide a comprehensive understanding of this phenomenon in supply chains.

I identify the following as gaps in the current RFID literature: (1) lack of a theoretical framework for RFID adoption and infusion in supply chains; (2) lack of understanding of critical factors for RFID diffusion; (3) lack of empirical assessment of RFID diffusion with large sample data; and (4) lack of research that can help practitioners to use RFID technology in SCM, as well as to solidify the quantification of RFID benefits for supply chain gains. Moreover, because of the unique characteristics of RFID, companies face a series of obstacles in adopting and using RFID to overcome significant technical, managerial and economic issues (Kapoor et al. 2009), especially related to supply chain issues and technology development status for RFID diffusion studies. In some industry reports and white papers, the development status of RFID is often mentioned as a major concern for current RFID adoption; however, the development status of RFID has not been investigated in academic literature.

From practitioner perspective, organizations and industries which have been considering RFID adoption, implementation, and use are interested in knowing what antecedents are critical to motivate RFID diffusion and how RFID creates value for organizations. On the other hand, organizations which have been involved in creating, standardizing and integrating RFID technology are eager to know which factors they can highlight to their customers in order to promote RFID diffusion and use in supply chain applications. The lack of good answers to the above issues poses a challenge for scholars and managers in IS field given that RFID is such a promising technology for SCM. An insufficient understanding of RFID diffusion and value will result not only in missed business opportunities but also lead to inefficient business operations.

This dissertation seeks to address the gaps in RFID literature discussed above by exploring RFID diffusion phenomenon in supply chains and its impact on firm performance and a higher level, supply chain performance, respectively. This dissertation attempts to make important contributions to existing literature.

Since there are numerous studies on diffusion and use of electronic data interchange (EDI) and E-business in IS literature, one might ask why we still need to study RFID diffusion and its impacts in supply chains. The unique characteristics of RFID diffusion and use can help answer this question. First, RFID can be implemented at various granularity (pallet-level, case-level, or item-level) and it can be used at different levels of sophistication (breadth and depth). Second, in addition to the initial adoption costs, using RFID also involves relatively high variable costs; however variable costs can be ignored for EDI or Internet use. Third, partner coordination and readiness are more important for RFID implementation than with other technologies because of the complexity of RFID implementation in a supply chain context. Fourth, RFID supports its adopters to quickly identify business issues and respond to those issues along the supply chain.

More specifically, while RFID and EDI have some features in common like building the links between trading partners, there are significant differences between them. First, RFID technology has a wide spectrum of potential applications for upstream manufacturers like Intel and Ford for internal production and deliveries (O'Conner 2004). RFID can improve entire supply chain operations along the supply chains from manufacturing, distributing, to retailing; however EDI can only influence part of supply chain operations, specifically facilitating standardized documents and its exchanges. Second, although use of EDI is a one-to-one relationship between trading partners, RFID can be implemented as a one-to-many or many-to-many relationships, which makes RFID adoption and infusion more complicated than EDI implementation. Third, cost issue also differentiates the two technologies, in terms of diffusion process. After adopting EDI, there is very low variable cost for using it, but the cost of RFID tags would amount to hundreds of millions of dollars for a multi-billion-dollar manufacturer if it attaches RFID tag on each product. These features make RFID diffusion more complex than and different from EDI diffusion. Thus, it is desired to study RFID diffusion separately.

For e-business, which is based on open standard protocol and public network, its cost is relatively cheaper and its usage is often driven by balanced considerations (Zhu et al. 2003). RFID adoption is currently influenced by some large trading partners. E-business is a very broad concept, "business activities conducted over the Internet" (Zhu et al. 2003, pp.251) and involves electronic purchasing, processing order electronically, handling customer service, and cooperating with business partners. RFID technology can be viewed as part of E-business but its unique features positions RFID in a more complicated context. The scope of RFID applications is narrower than E-business but greater than EDI.

Overall, while we can borrow what we have learned from previous technology diffusion studies, the unique features of RFID leads me to propose the current studies in my dissertation to provide better understanding of RFID diffusion in supply chains and its impact on performance at both firm level and supply chain level, especially considering its huge promise for SCM.

1.2 Research Objectives and Research Questions

The main objective of this dissertation is to examine the diffusion and use of RFID in supply chains. This dissertation first focuses on investigating what factors are important for the diffusion of RFID in supply chains. In this dissertation, RFID diffusion includes multiple stages: RFID adoption and RFID infusion, which are investigated in Chapter 3 and Chapter 4, respectively. Chapter 4 also examines the consequence of RFID infusion on firm performance from a supply chain perspective. In Chapter 5, I explore the impact of RFID technology on supply chain performance using an analytical model and simulation approach to unlock the value of RFID for SCM.

The study in Chapter 3 identifies and examines critical factors for managers to make a decision to invest resources in RFID technology in their supply chain activities (Cooper and Zmud 1990). Drawing on the literature in technology diffusion and SCM, an integrated model of RFID adoption is proposed and examined with empirical data, which is collected from industry supply chain or IT professionals. Specifically, Chapter 3 explores the following research question:

(1) What framework can be used as theoretical basis for studying RFID adoption in a supply chain context?

(2) Within this framework, what factors facilitate or inhibit organizations' RFID adoption decision?

For researchers, the answers to this question provide better understanding of RFID adoption in a supply chain context and the integrated RFID adoption model examined in the study provides a relatively comprehensive view of RFID adoption factors from four dimensions: technological, organizational, environmental and inter-organizational. The results in this research also enables RFID advocates to understand the important factors which impact organization's RFID adoption decision in its supply chain activities, so they can analyze their own conditions and then highlight positive factors to elicit more organizations to adopt this technology.

Chapter 4 takes one step further to study RFID diffusion by examining its infusion. In this dissertation, infusion is defined as any stage after RFID technology has been implemented or piloted and is being regularly used for business processes, so different levels of RFID use can be captured. A comprehensive RFID infusion model is proposed and is validated with data collected from 169 supply chain and IT professionals from industries. Since a lack of evidence of business value has been cited as one of the most challenging aspects of RFID adoption (GMA and IBM 2006), this dissertation also extends infusion study to investigate performance gains by using RFID. The specific research questions addressed in Chapter 4 are:

(1) What are the important factors for RFID infusion after adopting it?

(2) How does RFID infusion impact firm performance from SCM perspective?

The answers to these questions help researchers explain the current status of RFID infusion and the impact of RFID on firm performance. More importantly, this study addresses the challenges that IT and supply chain professionals face every day when they are implementing RFID or any other similar innovations in their supply chains. The understanding and knowledge obtained from this study can be applied in their daily work. This study is another attempt that intends to increase the relevance to practice in IS research.

In this dissertation, Chapter 5 focuses on the impact of RFID on supply chain performance from an inventory accuracy perspective since RFID has a direct impact on the accuracy of inventory information in a supply chain. It is desirable to investigate RFID value at supply chain level because supply chain trading partners should work cooperatively to reap the full benefits of RFID. The main research question explored in Chapter 5 is:

(1) How does RFID help eliminate or reduce inventory inaccuracy, and consequently improve supply chain performance?

Answering this question helps fill the gap in the literature for RFID value research and provides better understanding of RFID value creation in a supply chain.

This study develops a simulation model for RFID impact that links the underlying operating characteristics to control decisions and ultimately to supply chain performance. This detailed operational model can describe where and how RFID can affect the inventory management, so that the quantification of its impact is understood more precisely.

In the dissertation, the three studies are related because they investigate RFID issues in supply chains. However, every study has its own concentration: RFID diffusion's early stage-adoption, RFID diffusion's later stage- infusion and firm performance, and RFID impact at supply chain performance level.

1.3 Contributions

This dissertation investigates RFID diffusion and use phenomenon in supply chains. The first two empirical studies broaden our view in what factors are critical for RFID adoption and infusion and the third study helps unlock the value of RFID in supply chains. Therefore, the dissertation has made several contributions to academic literature on technology diffusion and IT value. At the same time, it also provides managerial implications for industry practitioners.

First, while there are a number of theoretical studies on the diffusion of interorganizational system (IOS) technologies, such as EDI and E-business, our understanding of technology diffusion is still limited from a comprehensive way, especially for complicated technologies, such as RFID. Besides what had been studied in literature, there is very limited research that empirically examined how the development status of innovative technology influences its adoption and infusion and how high level organizational features such as absorptive capabilities drive innovation diffusion in IS literature. In this dissertation, the first two empirical studies propose two comprehensive models for RFID adoption and infusion, respectively. Each model not only extensively evaluates possible important factors for RFID adoption and infusion from existing technology diffusion literature but also identifies other possible factors which may be important but have not been investigated yet in literature. Specifically, this study provides a more complete view for technology diffusion and helps gauge the roles of these new factors in RFID adoption and infusion. Because of the larger data set compared to those in the existing literature, improved generalizability of the results is also expected.

Second, this dissertation extends the existing literature of network technology by indicating the importance of supply chain trading partner issues for supply chain technology diffusion. Compared to the literature on network technologies such as EDI and Internet, the dissertation highlights the roles of supply chain trading partner issues in RFID diffusion, because RFID has broader impacts on the activities which are beyond organizations' value chains. The results from this dissertation shed light on a broader scope of stakeholders that contribute to network effects.

Third, this dissertation consolidates isolated findings from RFID infusion into a more comprehensive model by integrating innovation diffusion theory, IT business value, and SCM literature. It provides a deeper understanding of RFID diffusion and its impact on supply chain performance. Researchers have pointed out that solely depending on innovation diffusion theory is not sufficient to study the diffusion of network technology (Damsgaard and Lyytinen 1998).

Finally, this dissertation also contributes to literature on inventory management, in particular to better understanding technology-enabled inventory management in supply chains. The study in Chapter 5 considers detailed operating characteristics of an RFID enabled supply chain, which enables researchers understand the value of RFID from an analytical perspective. The study also investigates a multi-echelon supply chain with different products, which is a relatively complex supply chain configuration for RFID value research. Developing technologies improve over time, so this dissertation takes this feature of RFID into account by modeling RFID as an imperfect technology. Perfect visibility of an RFID-enabled supply chain is only viewed as an extreme case because of the immature feature of current RFID technology in SCM area. So the result from the study will be closer to the reality. In addition, the study captures RFID cost when it investigates RFID value in the given supply chain, so the model can be a step towards concretely measuring the value of RFID, or any other technologies which can help eliminate or reduce inventory inaccuracy.

CHAPTER 2: RADIO FREQUENCY IDENTIFICATION IN SUPPLY CHAINS

2.1 Radio Frequency Identification

RFID is a general term for a technology that uses radio frequency waves to transfer data between a reader and a movable item for the purpose of identifying, categorizing, tracking and monitoring products. (Columbus 2005). A typical RFID system is comprised of tags, readers, and software and related infrastructure. Figure 1 provides an image showing the basic components of an RFID system.

Figure 1: An RFID System in Retail Supply Chain
Source (http://www.foodylife.com)

RFID tag is placed on the entity (e.g. items, cases, pallets, or a track) that is identified as a data carrier. RFID tag typically consists of a silicon chip that holds a certain amount of data (e.g. a unique identification number) and an antenna that is used to communicate with remote reader devices. Typically, there are two types of RFID tags. Active tags have batteries and wider read/write ranges, but passive tags have shorter read/write ranges without batteries (Hassan and Chatterjee 2006). Passive tags are much cheaper than active ones and have much broader applications in SCM. Active tags can provide more power to collect and transmit data. While RFID cost has being decreased dramatically, the cost of the passive tags is still at least 0.1 to 0.2 dollars per tag (Asif and Mandviwall 2005). The cost has an important role in influencing RFID applications in supply chain contexts. Readers can read/write the data on tags and transmit the data between readers and tags. Readers can be fixed on certain equipment or on mobile devices, as shown in Figure 1. The third part, RFID software integrates the entire RFID system, which usually includes a front end managing readers and tags and a middleware routing RFID information to servers to run back-end database applications such as enterprise resources planning (ERP), SCM (Asif and Mandviwall 2005).

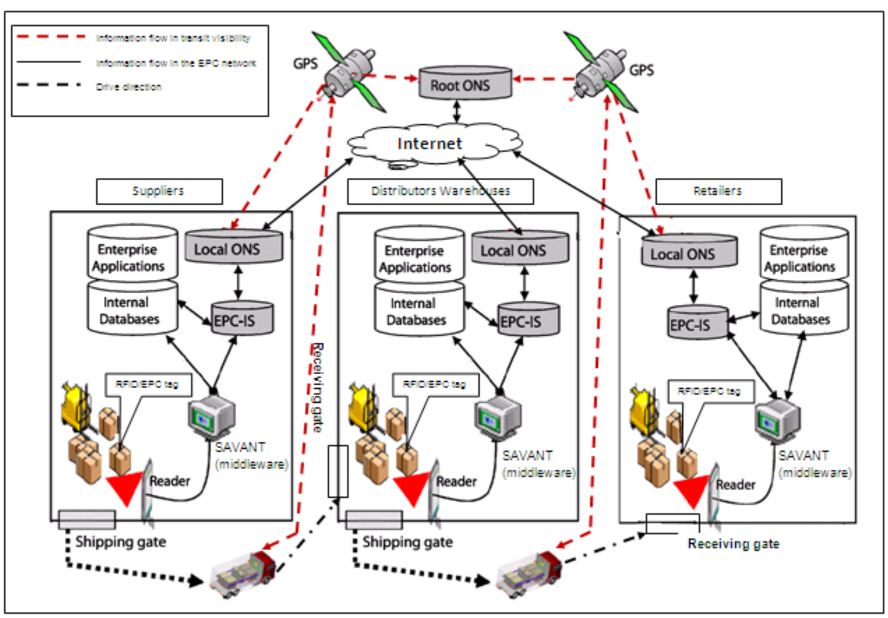

Figure 2: An RFID/EPC Network
(adapted from Wamba et al. 2008)

Figure 2 shows an RFID/ EPC (electronic product code) network which integrates RFID technology into a specific supply chain and shows how they work together. This RFID/EPC network is considered as a standard for RFID infrastructure for SCM (EPC global 2004; Srivastrava 2004). There are six components in the supply chain system (Wamba et al. 2008): (1) RFID/EPC tag is attached to a physical object (e.g. product) and provides information such as the manufacturer, the product category and size, the manufacturing date, expiration date, final destination, etc. (2) The RFID reader indentifies and reads any RFID tags within its interrogating field, and then forwards information to the SAVANT. (3) The SAVANT is the middleware system between RFID readers and enterprise systems. The SAVANT is responsible to filter and aggregate data and interacts with EPC information service (EPC-IS) and the local object name service (ONS). (4) The EPC-IS is a gateway between any request of information and a firm's enterprise applications and internal databases. (5) The local ONS is an authoritative directory of information sources to describe all RFID/EPC tags used in the supply chain. Each firm in the given supply chain hosts a local ONS to communicated with root ONS within the RFID/EPC supply chain network. (6) The root ONS is the authoritative directory of firms whose products may have information on the EPC/RFID network. Shipments between firms in the supply chain are also located with global position system (GPS) and location information is transmitted to corresponding local ONS and the root ONS. Information exchange among the firms in the supply chain is enabled by Internet.

In some ways, RFID is similar to barcoding which is the other identification technology commonly used in retail supply chains. Both RFID and barcode technologies use labels and scanners to collect the information on the labels and both depend on information system that relates the labels to an object or a class of objects. However, because of the four important features of RFID (No line of sight needed, multiple parallel reads, individual items, and read/write capability), RFID has much more advantages over barcode. The comparison between RFID and bar codes is presented in Table 1. For example, RFID reader does not need line of sight to read the information on products however barcode does. RFID reader can read multiple entities simultaneously but barcode cannot. RFID can identify individual product but barcode can only identify a SKU. RFID technology can automatically track products but barcode needs people manually to track products.

Table 1: The Comparison of RFID and Bar code
(source: Jones et al. 2005)

	RFID	**Bar Codes**
Line of sight	Not needed	Needed
Entities read simultaneously	Multiple	Single
Tag or code conditions	Harsh and dirty environments	No dirty or damage
Visible to be logged	Not needed	Needed
Identify level	Specific entity	Type of entity
Updated ability	Yes	No
Track	Automatically	Manually
Human Error	No	A concern

2.2 RFID in Supply Chain Operations

RFID is a contactless interrogation method for identification of objects and it can be applied in many areas, such as ID cards, windshield-mounted toll tags, animal tracking; however, this dissertation focuses on RFID applications in supply chain operations. This section discusses the main benefits and concerns of RFID use in supply chain operations.

2.2.1 RFID Benefits

There are three main benefits from RFID in retail supply chain operations. First, labor and time savings is the first benefit from RFID. A RFID system can potentially remove many of stopping points in the supply chain processes, such as shipping and receiving. RFID can also reduce labor cost such as for inventory counting. A white paper reports 96% labor reduction of RFID cycle counting compared to barcode (Patton and Hardgrave 2009). A well-known grocery store in the southeast of U.S. reported that they do physically account of their entire stock every week. If they have an RFID system, it will be much easier to track and trace their goods in stock.

Second, retailers can benefit from increased visibility of supply chain. Smart shelf is one of RFID applications at retail stores in retail supply chains. The purpose of smart shelves is to prevent out-of-stock situations from occurring at the shelf in retail stores. A study reports that RFID can lead to 30 percent out-of-stock reductions on RFID tagged items (Hardgrave et al. 2005). Smart shelves application in Metro AG is one of the most advance RFID implementations in retail sector (Metro AG 2006). At the same time, with RFID technology, employees can keep aware of backroom inventory levels continually, so they can re-order products in a more timely fashion.

RFID technology can help companies improve supply chain planning through enhanced information visibility and increased information accuracy (Sellitto et al. 2007; Twist 2005). Inventory inaccuracy refers to the difference between inventory record in information systems and physical inventory. RFID can help improve the accuracy of inventory record in the systems through automation of scanning process. After a three month pilot program, an apparel company reported that RFID tagging improved store inventory accuracy from 85 percent to 99.9 percent (Blossom 2005a). Based on product tracking information from RFID, inventory management system and warehouse management system can be integrated, and delivery processes will also be improved (Daw 2003; Kelley and Brooks, 1988). With a complete or greater supply chain visibility, organizations can reduce forecast error and inventory discrepancy, which lead to inventory reduction. Booth-Thomas (2003) cites an Accenture study which shows 10-30% inventory reduction. RFID can have dramatic impact on organization operations with both top and bottom-line business results.

RFID technology can greatly reduce shrinkage, which is the financial loss attributable to a combination of employee theft, shoplifting, administrative error, and vendor fraud (Daw 2003; Wilding and Delgado 2004). According to the National Retail Security Survey (NRSS) in 2005, the total percentage of shrinkage in the retail industry in the United States was 1.6% of sales. Considering the retail base of $2.334 trillion in 2005, it means approximately $37.356 billion annual loss from shrinkages to retailers (NRSS 2005).

2.2.2 RFID Concerns

There are also some major concerns which are limiting RFID diffusion in supply chain operations. RFID cost is considered as the first major concern (Jones 2005). The cost of RFID includes the cost of tags, readers, and IT infrastructure. Typically, the costs of reader and infrastructure are viewed as fixed costs; however tag costs are variable costs. While the costs of RFID tags continue declining, it is still high compared to the major competitor, bar codes. The lack of a globally agreed standard is the second concern (Curtin et al. 2007). Without a globally agreed standard, the uncertainty for adopting an innovation technology is increased. The last concern is the complexity of RFID implementation and use (Spekman and Sweeney 2006). The inter-organizational features and unique technological characteristics of RFID system make it more complicated.

Although no one guarantees that RFID will spread throughout the economy, the potential benefits from RFID suggest a strong future for RFID use (Niederman et al. 2007). Many leading retailers such as Wal-Mart (USA), Target (USA), Tesco (UK) and Metro (Germany) have required their major suppliers to implement RFID on every case or pallet shipped to their docks (Boyle 2003, Vijayaranman and Osyk 2006). Many manufacturers such as Toyota, Proctor and Gamble, and Gillette have also implemented or piloted RFID systems in their supply chains and are actively sponsoring research on testing and deploying RFID systems (Prater et al. 2005, Spekman and Sweeney 2006). In addition, some big companies such as SAP, Oracle, IBM, Microsoft, HP, and Sun Microsystems are working on RFID technology to provide the technology solutions as RFID venders (Lei and Hutchinson 2005).

2.2.3 A Type III Innovation

According to the classification of innovation proposed by Swanson (1994), there are three types of innovations: Type I innovations are technical innovations, related to technical tasks (e.g. CASE); Type II innovations use information technologies to support business administration (e.g. payroll system); and Type III innovations need to be integrated with the core of business where the whole business is potentially influenced. Based on the classifications of technologies, RFID in a supply chain context is considered as Type III innovation. The nature of RFID technology makes its adoption decision more difficult to reach and its infusion more difficult to be understood. The complicated nature may partially explain the lack of clear understanding on RFID diffusion and use in supply chains in literature. This dissertation seeks to bridge this gap in literature.

2.3 RFID vs. IOSs

RFID system can be implemented within a single firm, however it is predicted that many benefits will emerge when the RFID system is implemented along supply chains. To pursue the full potentials of this technology, organizations should span the supply chain partners' boundaries to gather and share the real time RFID information captured by RFID systems. This dissertation treats RFID system as an IOS-enhancing technology, which shares some common characteristics of IOSs, such as cross organizational boundaries, automated information sharing, and integration across multiple business processes.

However, RFID system is also very different from other established IOSs such as EDI. First of all, RFID technology has a much broader application potential than EDI does. It can improve entire supply chain operations including manufacturing, distribution, transportation and retailing (Rutner et al. 2004), rather than only a part of the supply chain operations as is the case with EDI, which only facilitates standardized documentations and transaction sets exchange (Curtin et al. 2007). RFID systems can enable real-time decision making for higher effectiveness and efficiency of business operations. For instance, by using RFID technology, vehicles and cargoes can be identified as they drive in a compound warehouse and then be automatically directed to the right locations to be unloaded or loaded. This application can reduce or even eliminate human errors, and at the same time it can increase processing speed and save labor costs.

Secondly, RFID implementation is much more complicated than other IOSs. Organizations need to decide scope and scale of their RFID adoption. First, because of RFID features, organizations can decide only to adopt RFID tags without any applications within its organization if the only reason for them to adopt RFID in their supply chains is the pressure from their powerful trading partners. They can only receive RFD information from its trading partners. When organizations intentionally plan to adopt RFID, they need to decide that where they need to install RFID readers along their supply chains in order to capture and exchange information with RFID tags. These locations may be across their organizational boundaries so they need their trading partners to cooperate with them, in terms of costs allocations, data ownership and sharing, etc. Moreover, RFID system can generate a huge amount of RFID data, so it is challenging to address, integrate and share RFID data into existing application systems within their organization boundaries and among trading partners.

Finally, the current development status of the RFID technology makes its diffusion even more complicated. RFID is still an emerging and maturing technology for supply chain applications, and it perfects over time. The lack of a commonly agreed standard and the relatively low readability rate show its immature status (Curtin et al. 2007). This issue leaves uncertainty for RFID adopters to benefit from the technology.

In sum, these differences between RFID and other IOSs make its diffusion challenging to fully understand for researchers and practitioners. Because RFID diffusion is currently on-going in supply chain operations in different industries, it is desired and valuable to investigate RFID diffusion and impact, so this dissertation can provide better understanding about RFID diffusion phenomenon and help clear confusions about RFID in supply chain contexts.

2.4 Research Scope of the Dissertation

In Chapter 3 and 4, this dissertation focuses on RFID adoption and infusion in a supply chain context. RFID will be adopted or is currently used for identifying, categorizing, tracking and monitoring products in a supply chain and supporting decision-making. Figure 3 shows the examples of the supply chain relationships considered in the chapters. In Chapter 5, the dissertation investigates RFID impact in supply chains which includes a retailer, a distributor and a supplier with different products. The dashed red box in Figure 3 shows the scope of RFID use in Chapter 5.

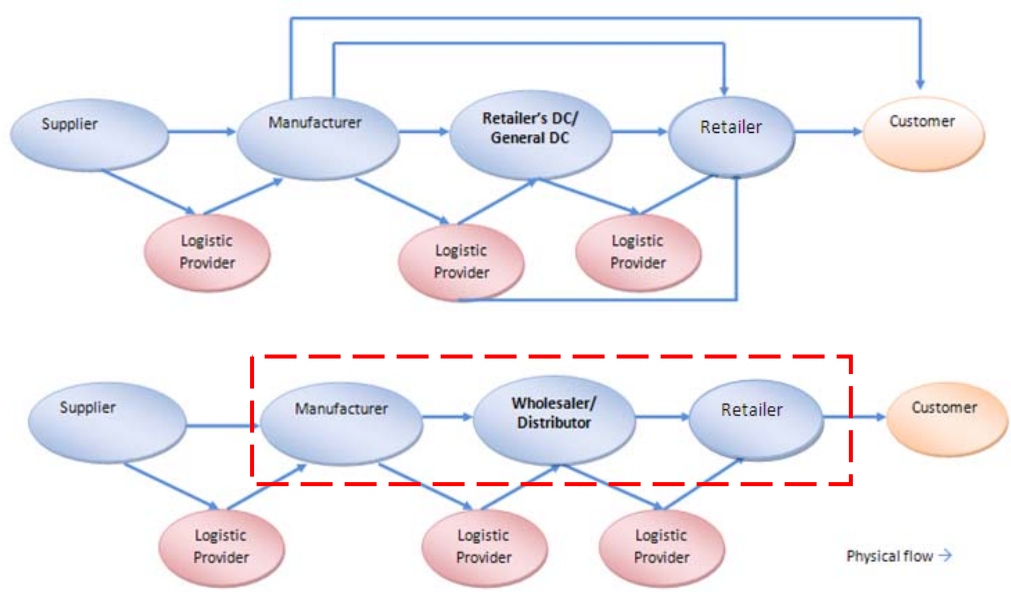

Figure 3: Research Scope of the Dissertation

CHAPTER 3: A MODEL OF RFID ADOPTION IN SUPPLY CHAINS

3.1 Introduction

While the advantages of RFID have been extensively discussed, uncertainties in value creation from RFID still prevent its adoption. Vijayaraman and Osyk (2006) found that in warehousing industry only 5 % of warehousing firms surveyed were implementing RFID, 9% on the pilot testing stage, 42% considering RFID implementation, and up to 44% not considering RFID technology when their study was conducted.

While the growing literature on RFID continues providing valuable insights on RFID topics, such as RFID applications and impact on business operations, research findings on RFID adoption in SCM are rare and remained fragmented (Whitaker et al. 2007). RFID adoption in one player of a supply chain may have impact on other parties along the supply chain and the adoption decision needs to be addressed in a more thoughtful manner (Dutta et al. 2007). Thus, there appears to be a gap in literature providing a comprehensive understanding of RFID adoption in supply chains.

This chapter attempts to examine RFID adoption in a supply chain context. Specific research questions are: What framework can be used as theoretical basis for studying RFID adoption in a supply chain context? Within this framework, what factors facilitate or inhibit organizations' RFID adoption decision?

Based on the previous IOS research, this study proposes a conceptual RFID adoption model and tests the model with the data collected from supply chain and IT professionals through an online survey. This study extensively screens existing variables for technology adoption studies and identifies the most important factors for RFID adoption in a supply chain context. Moreover, a new factor, technology maturity is introduced in the study. This factor is ignored totally in existing technology adoption studies. Overall, the proposed RFID adoption model is more comprehensive and robust, compared to other RFID adoption studies. Our findings also benefit to practitioners through managerial implications.

3.2 Theoretical Foundations and Literature Review

3.2.1 Theoretical Perspectives

In this chapter, this dissertation focuses on RFID adoption which is a milestone for RFID diffusion study or any technology diffusion. Research model proposed in this study draws on two research perspectives: Diffusion of innovation (DOI) theory and Technology-Organization-Environment (TOE) framework, which help identify important factors for RFID adoption in supply chains in this study.

DOI is a fundamental theory to guide technology adoption studies at an organizational level (Rogers 1995; Tornatzky and Klein 1982). This theory focuses on the impact of "perceived characteristics of the innovations" on its diffusion. There are five most investigated characteristics. (1) *Relative advantage* refers to the degree to which an innovation is perceived as serving better than previous one. Relative advantage can be viewed as a predictor of *intent to adopt* in a study of the property and causality insurance industry (O'Callaghan et al. 1993). (2) *Ease of use* (inverse to *complexity*) represents the degree to which an innovation is perceived to be simple to understand and use. Previous study found that the ease-of-use, as the reversed vision of complexity is not easy to judge in RFID adoption (Brown and Russell 2007). (3) *Compatibility* refers to the degree to which an innovation is perceived to be consistent with the current habits and practices of potential adopters. Prior studies showed that the more compatible a technology, the more likely the potential adopters will adopt it. (4) *Trialability* represents the degree to which an innovation may be experimented before its adoption. (5) *Observability* refers to the degree to which the results of an innovation are observed by its adopters. DOI theory can be used in both individual and organizational level for technology adoption study. In our research, we include the first three innovation characteristics because these three had been indicated as having consistently positive relationships with technology diffusion (Parthasarathy and Bhattacherjee 1998).

TOE framework is also widely applied in technology diffusion research at the organizational level (e.g. Chwelos et al. 2001; Teo et al. 1995; Tornatzky and Klein 1982). The framework allows researchers to assess innovation diffusion problem across three dimensions: technological, organizational, and environmental. *Technological dimension* includes both internal and external technologies issues associated with a firm. Externally, this dimension deals with how the characteristics of available technologies impact a firm's technology adoption activities. Internally, this dimension addresses how a firm's existing technological base influences its technology choices. *Organizational dimension* refers to several descriptive measures of a firm, such as firm size, the quality of human resources, the amount of available slack resources, managerial structure, and top management strategic behavior. *Environmental dimension* is the arena in which a firm conducts its business and includes firm's industry, competitors, access to resources and government regulations (Tornatzkey and Fleischer 1990, pp152-154).The technological dimension in TOE framework is consistent with the DOI theory.

3.2.2 Literature Review

As discussed in earlier chapters, RFID system is viewed as an IOS-enhancing technology because it shares the common characteristics of IOSs, such as cross organizational boundaries, automated information sharing, and integration across multiple business processes. This view supports us to review RFID adoption and IOS diffusion literature for the present study.

While prior research on IOSs emphasized more on the characteristics of technologies, interorganizational and environmental perspectives are also examined in technology diffusion literature. Saunders and Clark (1992) focused on the interorganizational linkage on EDI adoption. They not only studied the impact of technological factors including perceived benefits and perceived costs and but also the interorganizational factors including trust and dependency on an organization's intention to adopt or not adopt EDI. Competitive pressure, exercised power, customer power and customer support as interorganizational factors were investigated in a few studies. (Hart and Saunders 1997; Premkumar and Crum 1997; Premkumar and Ramamurthy 1995).

Iacovou et al. (1995) proposed a theoretical model for EDI adoption by sampling seven small businesses. The model includes three main factors: perceived benefits, organizational readiness and external pressure, all of which are viewed as the main causes for small business to adopt EDI. Based on their adoption model, Chwelos et al. (2001) empirically tested a modified model with the data collected from only buyer side and found that all three main factors were statistically significant in predicting an intention to adopt EDI. These two studies set up a base for the present study.

Since RFID deployment involves significant changes to existing processes and development of new business processes, it can be viewed as a discontinuous innovation, based on Tornatzky and Fleischer (1990). RFID implementation will involve a large range of applications, significant investments, and process redesigns, so it is challenging for a firm to adopt RFID within or across their organizations boundaries. Most current research has focused only on a limited set of interesting factors for RFID adoption (e.g. Lu et al. 2006; Matta and Moberg 2006; Schimitt et al. 2007; Vijayaranman and Osyk 2006).

By discussing seven possible RFID applications in manufacturing, Lu et al. (2006) implicitly emphasized that adoption costs, technological performance, standards and needs of interaction between partners have important impacts on RFID diffusion; however, they did not provide empirical evidence to support their statements. Matta and Moberg (2006) first identified various factors significant to RFID adoption and then only proposed a research agenda of RFID study. Vijayaraman and Osyk (2006) empirically studied RFID implementation in warehousing industry and found that the mandate from leading retailer, foreseeable benefits and the costs of adoption are the main factors for firms when considering adopting RFID. However, they did not build a theoretical model to better explain RFID adoption in warehousing industry.

Based on IOSs adoption research (e.g. EDI), Sharma et al. (2007) proposed a RFID research model in which two dependent variables: RFID adoption and level of expected integration were examined and eleven relevant independent variables were grouped into technological, interorganizational, organizational, and environmental dimensions. They tested their model with the data collected through semi-structured interviews of RFID managers from 10 organizations and found that perceived benefits of RFID technology, dominant supply chain partner pressure, and perceived costs are the most important factors for the intention of RFID adoption. Their study provided some insights on RFID adoption but small sample size gave the findings a relatively weak support for generalization. A similar problem in another RFID adoption research also exists (Brown and Russell 2007). Most of other RFID studies still stay on discussing the applications or the challenges of the technology (e.g. Angeles 2005; Jones 2005; Sellitto et al. 2007).

More recently, special RFID issues in journals have appeared, such as Communications of the Association for Information Systems (CAIS), European Journal of Information Systems (EJIS), Production and Operation Management (POM) and International Journal of Production Economics. In 2008, the special issue of CAIS focused on the novel use of RFID in retailing and CRM and provided some interesting insights to successful RFID adoption and use in retailing and CRM. One study investigated the opportunities of RFID to enhance business to customer (B2C) marketing of apparel retailers, one of the sectors which have implemented RFID technology very early (Uhrich et al. 2008). Six out of seventeen developed RFID applications that support marketing relationships of apparel retailers were discussed. A value analysis framework was proposed to develop decision support tools for RFID adoption decision in retailers in China (Luo et al. 2008). For EJIS special issue on RFID in 2009, it focused on discussing various applications for using RFID, challenges and issues surrounding RFID use, and some success strategies for the value of RFID projects. However, these studies still stay on discussing RFID application in different settings.

On the other hand, most of empirical studies on RFID are case-study based (e.g. Lee et al. 2008; Loebbecke and Huyskens 2008; Wamba et al. 2008), and there are very few quantitative empirical studies on RFID adoption (e.g. Bendoly et al. 2007; Chang et al. 2008; Goswami and Teo 2008; Lee and Shim 2007). Bendoly et al. (2007) explored how the infrastructural capabilities of a firm impact a firm's RFID adoption commitment. Their study demonstrated that the complementary effects of infrastructural capabilities, such as cross-functional knowledge and procedural flexibility significantly influence both perceived benefits from RFID and commitments to RFID. From a real option perspective, Goswami and Teo (2008) studied how manager's recognition of the real option from RFID adoption influences their adoption decision. They found that recognition of different real options can mediate the effect of strong institutional forces on manager's adoption decision making. Lee and Shim (2007) investigated underlying motivations and driving forces behind RFID adoption by using theory of technology-push and need-pull. The findings from their study showed that in addition to technology factors and organizational factors, performance gap and market uncertainty are also important to help understand RFID adoption.

Based on our knowledge, Chang et al. (2008) provides a relatively complete set of factors for RFID adoption. They also applied TOE framework to examine fifteen factors for RFID adoption in logistics industry in Taiwan, China and found that competition in market place, pressure of transaction partners, supplier's industry environment, cost, integration of supply chain strategy, complexity of RFID, and mutual standard are critical for RFID adoption. However, their study has its own limitations: first, the sample size is small, 81; second, they surveyed the professionals only from the logistics industry in Taiwan, China; third, the measurement applied in their study is not very clear and it is not easy to follow their work to gain a clear understanding of their results.

While each study discussed above has contributed to our cumulative knowledge in RFID adoption decision, they are either lack of strong data support for their findings or only examining RFID adoption from one dimension or two dimensions. There is no single study that has tested a comprehensive model of RFID adoption by incorporating all major existing factors and the current development status of RFID in supply chain applications. More importantly, these existing studies attempted only to focus on a specific sector such as logistics industry or healthcare industry. For achieving full potentials of RFID in supply chains, it is important to consider its adoption along the different sectors of supply chains in order to provide better understanding of the nature of RFID adoption phenomenon.

Based on the literature review, it is desirable to explore drivers and obstacles for RFID adoption in supply chain activities because of the current situation of RFID diffusion and the limitations in existing literature.

3.3 Research Model and Hypotheses

Consistent with our research objective of studying RFID adoption in supply chains, our research model is illustrated in Figure 4. The dependent variable is RFID adoption in supply chains, which refers to an organization either having made the adoption decision or initiated a pilot implementation of RFID.

The TOE framework has been consistently applied in innovation diffusion research at the organizational level (e.g. Cooper and Zmud, 1990; Iocovou et al. 1995; Premkumar and Ramamurthy 1995). This framework allows assessing innovation characteristics across three dimensions, and thus it provides a relatively complete coverage of technology diffusion issues. It appears it is appropriate to apply TOE framework as a starting point to investigate RFID adoption in supply chain contexts.

As discussed in Chapter 2, RFID is an IOS enhancing technology and its adoption shares some characteristics of those of IOSs; however, it also has unique features which differentiate RFID from others. For example, RFID implementation may not only involve one trading partner but very likely need to coordinate with multiple supply chain trading partners. Besides the three dimensions in TOE framework, it is worthy to consider factors from an interorganizational perspective to capture a more complete set of important factors for RFID adoption. Moreover, in the research model technological dimension takes technological maturity into account, which has been ignored in technology adoption literature. Complexity and compatibility of IOSs adoption are further explored in our study, because RFID unique features such as more complicated implementation process enable us to posit that these two factors may have greater impact on RFID adoption at an interorganizational level.

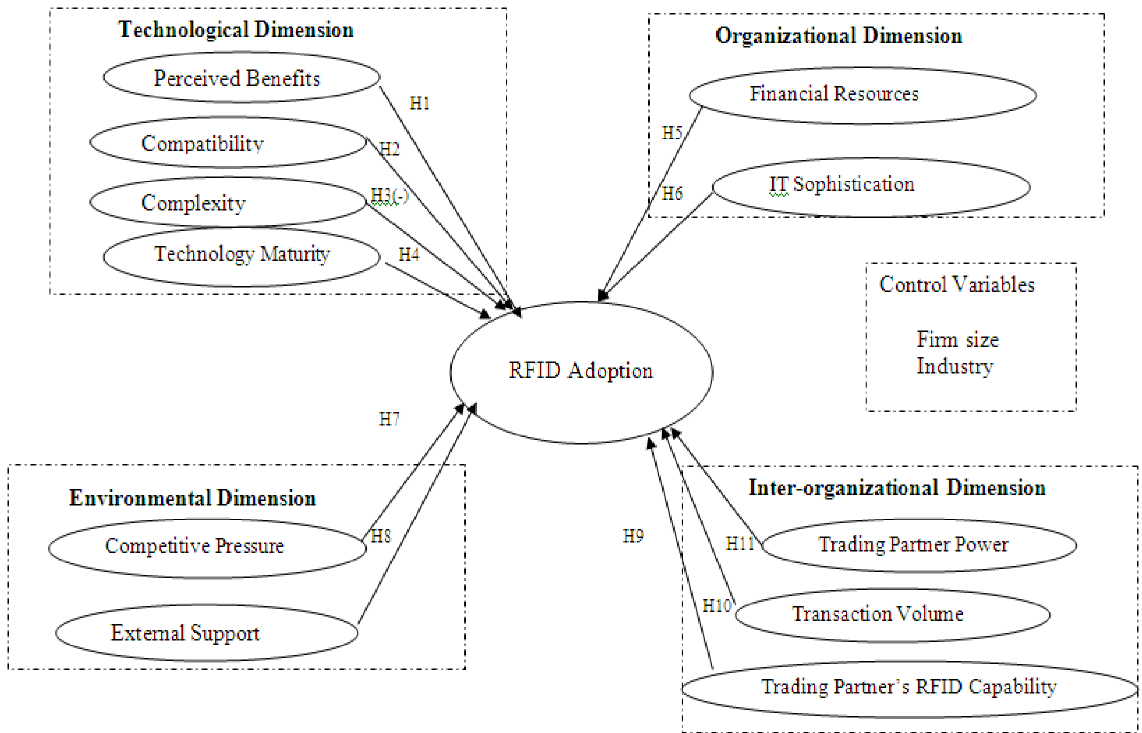

Figure 4: RFID Adoption Research Model

There are two basic approaches to select adoption factors in a specific context. One approach is to establish a certain number of factors and examine if there is empirical support. The second approach is to ask research subjects to provide the factors (Tan and Humter 2002). In our study, we incorporate the two approaches for identifying RFID adoption predictors. Scanning prior literature for key factors is the first step and helps us cover most of significant factors in general IOS adoption literature. While we did not directly ask practitioners to provide their own factors, we reviewed a number of industry publications to identify important predictors of RFID adoption in supply chains from a practitioner perspective. In our research, we indentify eleven predictors for RFID adoption within an extended TOE framework, and control for firm size and industry.

3.3.1 Technological Dimension

Extant RFID adoption literature addressed technological dimension focusing mainly on relative advantage and complexity but rarely examining compatibility. There is very limited literature examining impact of technology maturity on RFID adoption (Wu and Subramaniam 2009). However, RFID is an emerging and still-maturing technology for SCM and the perception of its development status may impact an organization's adoption decision (GMA and IBM 2006). By adding technology maturity to the technological dimension, this study richens the technology dimension of RFID adoption phenomenon. In the following section, we develop and discuss the hypothesis for each technology factor.

Perceived benefits refer to the degree to which relative benefits of an innovation are recognized by firms (Rogers 1995). Typically, there are two types of benefits, direct and indirect. Direct benefits include operational cost savings related to internal efficiency such as reduced labor costs (Loebbecke 2007) and improved information quality across the supply chain (Sellitto et al. 2007). Indirect benefits include the impacts of RFID on business processes and greater opportunities for competitive advantage, such as better customer service (Lin et al. 2006). This dissertation has already discussed three main benefits of RFID technology for supply chains in Chapter 2. The benefits should not be perceived only by a single firm in a supply chain but also by its supply chain partners—manufacturers, distributors or retailers, in order to maximize supply chain profits. Generally, perceived benefit is the most important driver for a firm to adopt a technology from a rational perspective (Venkatesh et al. 2003, Zhu et al. 2006a). A study showed that the lack of clear business benefits is one of the main challenges for RFID adoption in supply chain activities (GMA and IBM 2006). This concern may lower the perceived benefits of RFID. This study anticipates that if a firm perceives more RFID benefits from a SCM perspective, it may more likely reach a decision to adopt RFID in its supply chain activities.

HYPOTHESIS 1: *RFID adoption will be positively influenced by perceived benefits.*

Compatibility refers to the degree to which an innovation is consistent with the adopter's current infrastructure, practices and needs (Rogers 1995). Generally, IOS innovation involves the changes of existing work procedures. A wide range of applications, significant investments, and process redesigns are required for RFID implementation. As an IOS-enhancing technology, the implementation of RFID also needs identify the interfaces with suppliers, distributors and retailers to maximize benefits from RFID system. Compatibility should be evaluated before a firm makes a decision on RFID adoption.

Firms will not aggressively adopt a certain technology if they perceive the technology cannot be integrated with their other operations (Steele 2004). For obtaining full benefits from RFID, firms need integrate their RFID systems with other applications within their organization and those with their trading partners along their supply chains. Therefore, how RFID information can be meshed and integrated seamlessly with existing IS resources is a major challenge for its adoption (Loebbecke and Palmer 2006). The study predicts that if a firm perceives RFID has a higher compatibility, this perception will positively influence its decision to adopt RFID.

HYPOTHESIS 2: *RFID adoption will be positively influenced by compatibility.*

Complexity refers to the degree to which an innovation is perceived as being difficult to use (Rogers 1995). Because RFID does not need line of sight to read the information on RFID tags, it can make it much easier to manage inventory and other related business processes. However, this perceived characteristic of RFID is not that easy because from integration aspect RFID implementation in supply chain activities is very complicated (Brown and Russell 2007). Currently, some products, such as HP printers and GAP apparel, are tagged with RFID tags and bar codes together. Existing systems have been designed to store and process barcode data with its own structure and transmission. For the coexisting of RFID and barcode data, existing systems need to be updated to store and process RFID data. Given this situation, it may be difficult to seamlessly integrate and effectively use a large volume of RFID data with other applications. Thus, the potential benefits of RFID may not be easily reachable. This may be one of the main reasons that potential RFID adopters have not adopted it yet, according to the GMA and IBM report in 2006. This study posits that a lower complexity of RFID leads to a greater technology attractiveness which will have a positive impact on RFID adoption decision.

HYPOTHESIS 3: *RFID adoption will be negatively influenced by complexity.*

Maturity of technology refers to the degree to which a technology is perceived as being mature for widespread adoption. Technology maturity and widespread adoption are two emphases in this definition. Maturity concept was investigated more in the fields when studies qualify technology development and help make investment decisions. In IS literature, this concepts has been rarely investigated in previous technology adoption literature.

IS literature focuses more on the characteristics of technology but ignored the possible impact of technology development status on its diffusion. However, technology maturity is one of the critical sources of risk to an adopter's effort and benefits when an immature technology is adopted. Any technology should have reached an adequate maturity before it is widely used in practice. Therefore, technology maturity could be an important aspect of technological dimension. When a technology is perceived as mature, it should be perceived as having a low failure rate, being easily available in the market and able to demonstrate full potential after its adoption. A commonly agreed standard should be built if applicable, especially for its widespread adoption.

While RFID is being continuously improved, many limitations are still in existence. First of all, standards have a critical role in RFID adoption because RFID tags, readers, and backend systems may be provided by different vendors; thereby the importance of a common standard increases in that different tags need to be read by different readers, plus different RFID systems need to interoperate with one another. So far, there is no global unified standard for RFID technology. Without a commonly accepted standard, it is difficult for firms to communicate, interpret, and manipulate information gathered from RFID systems along their supply chains (Markus et al. 2006, Zhu et al. 2006a).

RFID involves two main types of standards: data standards and technology standards. Data standards specify what is contained in RFID tags and what format is used to store the data. Electronic Product Code (EPC) is the most important data standard in supply chain applications for fast-moving goods. Technology standards specify protocols used for communication between tags and readers. For supply chain applications, ISO 18000 standards family issued by the International Standards Organization (ISO) is the most common one. Although EPC has decided to align its proposed standards with those of the IOS, these standards have not reached a commonly agreed standard world widely. Different standards make interoperability a challenge for potential RFID adopters. Organizations rolling out RFID implementation have to face variability in standards, both in their designs and in associated business processes, particularly given the increased globalization. The current development state of RFID standards leaves a critical concern to RFID maturity and its adoption (Shapiro and Varian 1999).

Innovations involving standards are a primary driver of industrial productivity (David and Greenstein 1990). King et al. (1994) claimed that commonly agreed standards promote the use of innovative technologies and provide an incentive for potential adopters to adopt the technology that meets the standards. Potential adopters often worry about future technical changes. Specifically, they worry about the residual value of their investments and the upgrading path for future procurements (King et al. 1994). The potential adopters are normally reluctant to adopt innovations which lack a widely accepted standard. When it comes to RFID standards, the lack of a global standard creates uncertainties to both vendors and end users. It will put early adopters into a dilemma where they may gain some benefits from the current usage of RFID, however, they may not have enough trading partners adopting RFID to maximize the benefits. More importantly, they may also need to replace the technology when a commonly accepted standard emerges, which is not compatible to the one they have adopted early. The current status of RFID standardization poses a barrier to more aggressive adoption of this technology. Thus, if there is a globally agreed standard for RFID, the technology should be in a better situation for its adoption in supply chain activities and it will be easier for firms to reach its adoption decision.

Second, while signaling techniques have become more sophisticated to improve the accuracy of reading operations at readers and tags, stability issue still exists according to industry reports (GMA and IBM 2006). As to RFID in the retail environment, stability can be captured by readability and data quality, as well as tag failure rate, which are identified as key challenges for current RFID technology (GMA and IBM 2006), By surveying 100 Chief Technology Officers (CTO), Venture Development Corp. found that more than 50% of the CTOs expressed a concern about the quality and synchronization of data gathered by RFID systems (O'Connor 2004). False reads or multiple reads from same tags are two main sources for poor readability and data quality. However, the high level of readability and data quality is the basis for all RFID applications. In 2004, commonly reported RFID read rates still ranged from 80 percent to 90 percent. That means 10-20 percent of tags purchased from a tag vendor were not able to be programmed and read (Brandel 2004). In a recent study, read rate varies dramatically based on the contexts in which RFID tags are used (Crombout et al. 2009). The range can be from 30% to 100%, but for a certain combination of tags and readers, the read rate can stay between 90% and 100%. Therefore, the dissertation posits that low perceived readability will negatively contribute to RFID technology attractiveness.

As one of the major barriers for the widespread adoption of RFID, costs had only been partially understood (Fontanella 2003, Roberti 2008). The costs of RFID hardware (i.e. tags) and software (i.e. middleware) are still high (Asif and Mandviwall 2005), although they have fallen down and will continue decreasing. The cost of individual RFID tag can vary from over $100 to less than 10 cents, depending on their capability (Jones et al. 2004). For addressing the large amount of data generated by RFID system, the adopters also need to invest in computing capability and IT infrastructure, especially in retailing industry (Levinson 2008). The cost of RFID system is expected to keep declining and reaching a reasonable level as it becomes more mature.

These features show that RFID technology is still under development for supply chain applications. Such a developmental status may play an role in RFID adoption and use (Curtin et al. 2007). In the study, it is expected to observe the impact of RFID maturity on a firm's adoption decision.

HYPOTHESIS 4**:** *RFID adoption is positively influenced by technology maturity.*

3.3.2. Organizational Dimension

In organizational dimension, factors reflect whether an organization is ready to adopt a technology from various organizational aspects. For example, financial resources show whether an organization has enough resources to implement a new technology (Chwelos et al. 2001; Iacovou et al. 1995).

Financial resources. Implementing RFID requires investment in hardware, software, system integration and training for employees. Financial resources can be used to pay the costs of installation and implementation of tags, readers and a database. Even though RFID may have lower fixed costs than other IOS technologies, its variable costs can become high because RFID tags have to be implemented on a large number of items to benefit supply chain applications. Since RFID is a new technology for SCM that causes large-scale changes to the work procedures, costs for employee training have to be incurred. Moreover, it is necessary to integrate RFID with other applications for a successful return. Sufficient financial resources help companies to obtain necessary resources and develop RFID applications into full scale functionalities. Hence, the financial capability of the organization can become an important driver of RFID adoption decision.

HYPHOTHESIS 5: *RFID adoption is positively influenced by financial resources.*

IT sophistication represents both the level of IT expertise available within an organization and the level of management's understanding of IT usage and management (Pare' and Raymond 1991). When an organization is sophistication on IT use, the organization should have a top-down planning process for linking IS strategy to business needs and a high degree of technology integration leading to an effective exploitation of IT within the organization, as well a wider spectrum of IT applications (Cash and Konsynski 1985; Premkumar and King 1992). IT sophisticated firms are more confident in managing IT applications, their IT applications dedicate to create economic benefits; and their IT managers are seek to manage the balance between short-term delivery and long-term investment. The more IT sophisticated a firm, the more likely the firm tends to use information technology to achieve its objectives (Bendoly et al. 2007). On the one hand, IT sophisticated organizations may be more likely to adopt RFID to meet their business needs because as a promising technology, RFID can help close some of information gaps in SCM and greatly improve supply chain performance. On the other hand, the high level of IT management and usage may also encourage these organizations to adopt new technology and achieve their goals. Thus, our study anticipates that higher IT sophistication will more likely lead an organization to adopt RFID.

HYPOTHESIS 6: *RFID adoption is positively influenced by IT sophistication***.**

3.3.3 Environmental dimension

External dimension includes factors from outside organizations for RFID adoption decision but focuses mainly on two factors which are not related to supply chain partners.

Competitive Pressure. Competitive pressure refers to the extent of RFID adoption in a firm's industry and more importantly to that of the firm's competitors (Iacovou et al. 1995). When firms face strong market force including competition, new market opportunity and changing customer needs, they may initiate changes, such as adopting new technology (Carr and Hard 1996). Competitive pressure among competitors causes an organization to change over time to turn itself more like to others in its environment (DiMaggio and Powell 1983). There are two aspects to explain the pressures on technology adoption placed on the organization: the prevalence of the technology in its industry and the perceived success of organizations in the industry that have adopted the technology (Haveman 1993). Technology diffusion literature has identified competitive pressure as an important factor for technology adoption (e.g. Chang et al. 2008; Grover 1993; Premkumar and Ramamurthy 1995, Teo et al. 2003). When more competitors in the same industry have adopted RFID (i.e. the prevalence of the technology) and have RFID capabilities (i.e. perceived success), organizations without RFID and corresponding capabilities may face more competitive pressure because those competitors stand in a better position in the same market. Thus, the potential adopters will be more likely to adopt RFID in order to compete with others in the same economic network when they perceive higher competitive pressure from its competitors for RFID adoption.

HYPOTHESIS 7: *RFID adoption is positively influenced by competitive pressure.*

External support refers to the level of RFID support from outside of a firm (Ungan 2005). Many potential RFID adopters may not have internal expertise to trail and implement RFID technology and would depend on external supports providers (Lee and Shim 2007). It may include RFID expertise from third parties. External support is critical for the adoption of a complex and disruptive technology because it can help organization overcome difficulties (e.g. setting up the equipments, troubleshooting and fixing technical and operational problems) for adopting the technology. When external support is sufficient, firms may feel more confident to adopt RFID since they believe they can access help from others when they need. Considering the complexity of implementing RFID system, the study anticipates that a higher level of external support leads a firm more likely to adopting RFID.

HYPOTHESIS 8*: RFID adoption is positively influenced by external support.*

3.3.4 Inter-organizational Dimension

While this dissertation has discussed environmental dimension, the factors from inter-organizational dimension cannot be missed because of the unique features of RFID in supply chains. Although an organization can implement RFID within its boundary, it is very likely it executes this technology in an inter-organizational context. Thus, the relationship between the organization and its supply chain trading partners becomes critical.

There are some overlaps between the environmental and inter-organizational domains since they both involve issues outside the organizations, but conceptually their focuses are different. Environmental issues are out of control of a firm; however, a firm has direct connection with its trading partners in terms of interorganizational relationships, so they can actively interact in the relationships.

Trading partner power measures the impact of dominant trading partners within a supply chain on its dependent trading partners' technology adoption decision. The trading partner power is identified as a major reason for firms to adopt RFID systems in literature (GMA and IBM 2006; Vijayaranman and Osyk 2006). A study found that the main reason for adopting RFID in the warehousing industry was from Wal-Mart's mandates (Vijayaranman and Osyk 2006). Wal-Mart even decides to apply penalty for its suppliers who did not attach RFID tags on the pallets shipped to its Sam's Club in order to push its suppliers to adopt this technology, according to InformationWeek news

(2008). Sharma et al. (2007) also found that the dominant supply chain partner pressure was one of the main drivers for technology adoption. In short, the study predicts that in supply chain contexts trading partner power has a positive impact on adopting RFID.

HYPOTHESIS 9: *RFID adoption is positively influenced by trading partner power.*

Trading Partner's RFID Capability. To achieve full benefit from IOSs such as RFID, organizations need to consider trading partner's capability for using this technology. Trading partner RFID capability is defined as the ability of trading partner along the supply chain to use RFID for conducting business with its trading partners. This capability is viewed as a necessary condition to maximize RFID benefits, so it may have significant influence on adoption decision of potential RFID adopters. If a trading partner is unready yet to adopt and use RFID and the partner is also an important node in the partners' supply chain network, other partners in the supply chain may not adopt RFID because they know they will lose some of perceived benefits from RFID adoption. Trading partner technology readiness has been found as a significant factor for EDI adoption (Iacovou et al. 1995); however literature has not reached technology capability of trading partner for the technology adoption studies. Plus, because RFID can be implemented within a single organization, so it is not necessary to have its trading partners ready and use RFID in a high level if the organization intends to adopt RFID only within its own boundary. These leave the impact of trading partner readiness for RFID adoption in supply chain activities unclear.

HYPOTHESIS 10: *RFID adoption is positively influenced by trading partner's RFID capability.*

Transaction Volume. According to the resource-dependency approach (Pfeffer and Salancik 1987), the opportunity to sell products is also considered as a resource. An organization's decision to adopt a technology which is related to its trading partners will be influenced by its transaction volume with its trading partners. Previous studies have very rarely examined this factor for technology adoption and the results are not consistent. For example, Archer et al. (2008) reported that for small and medium companies, transaction volume may be too small to justify online supply chain solution adoption. However, others argued that the higher transaction volume with the trading partners, the more likely an organization to adopt the technology in order to maintain or increase the transactions with its trading partners (Iskandar et al. 2000). Higher transaction volume also provides higher incentives for both trading partners to adopt new technology to improve their coordination because of the higher potential benefits. In our study, we propose that high transaction volume leads to reach a positive RFID adoption decision.

HYPOTHESIS 11: *RFID adoption is positively influenced by transaction volume.*

3.3.3.5 Control Variables.

Effects of other possible variables are controlled. In this study, control variables include firm size and industry type. Studies have shown that firm size relates to firms' resources and IT sophistication (Chwelos et al. 2001, Zaheer and Venkatraman 1994). Larger firms may have more experience in information system use, so the benefits to larger firms may be systematically higher than those to smaller firms (Lee et al. 1999). Differences among industries have been found to influence technology adoption.

3.4 Research Methodology

The purpose of the study is to understand what factors are critical for a firm to adopt RFID along supply chain activities. Since the dissertation intends to generalize the findings from this study, Survey method is selected to empirically test the research model.

3.4.1 Instrument Development

Based on a comprehensive literature review and thorough scrutiny of researchers, the study develops a structured questionnaire for the present study. The measures used in this study are listed in Table 2. The instrument is listed in Appendix A.

To test content and face validity, two experts are invited to help us evaluate the instrument (Cronbach 1971). Based on the suggestions from the experts, the instrument is revised. Two pilot tests are conducted. The first pilot test was conducted with several PhD students in one PhD program in a university. Some of the PhD students had conducted surveys for their research and their feedbacks were used to modify the survey in terms of the way of the survey question asked, the number of items on each pages, and the length of the survey in total. The second pilot test was conducted in July 2010. An invitation letter with survey link was sent to 60 email addresses collected from Institute for Supply Management (ISM) websites. In the invitation letter, we asked the respondents to provide comments if they find there were any items which are not clearly understandable about RFID adoption in a supply chain context. We received 2 responses from the second pilot test but no feedbacks are provided related to any unclear issues, so we assume the items are clear. Before sending out the final survey, we further refined the instrument.

Table 2: Measurement of Constructs in RFID Adoption

Dimension	Construct	# of Items	Sources
Technological Dimension	Perceived Benefits	6	Chwelos et al. 2001, Zhu et al. 2006, Developed in this study
	Compatibility	2	Karahanna et al. 2006
	Complexity	4	Zhu et a. 2006
	Technology Maturity	4	Developed in this study
Organizational Dimension	Financial Resources	2	Chwelos et al. 2001, Zhu and Kaemer 2005
	IT Sophistication	4	Chwelos et al. 2001, Ramamuthy and Premkumar 1995
External Dimension	Competitive Pressure	2	Chwelos et al. 2001, Teo et al. 2003
	External Support	3	Szulanski 1996
Interorganizational Dimension	Trading Partner Readiness	3	Chwelos et al. 2001
	Enacted Trading Partner Power	2	Chwelos et al. 2001
	Transaction Volume	2	Sheth and Shah 2003 2003
	RFID Adoption	1	Zhu et al. 2006

3.4. 2 Data Collection

Usually, if the survey focuses on a particular technology not information technology in general, the response rate would be relatively low. This study prepares multiple options to collect data, considering the feature of the research. First, we used the traditional data collection method by sending the online survey to the members of an association of operations professionals. Specifically, we obtained help from The Association for Operation Management (APICS) to collect data from their members. APICS includes more than 43,000 individual and corporate members in more than 10,000 companies worldwide.

The survey was created and hosted on Surveyshare.com, a professional online survey hosting provider. Based on the criteria provided, APICS helped send out the invitation email with the survey link to its members in October, 2010, one week later it sent the first reminder to remind its members about our survey, and two week later it helped send the second reminder. In order to encourage the participation of the survey, we provided an incentive in the invitation message. We specified that those who complete the survey are offered a chance to win a draw from one out of five $50 Amazon gift cards. Among 4050 email addresses successfully sent, 468 members received and opened the email with the survey. Finally, we received 62 responses and the response rate is 13.5 %. While the response rate was in a normal range, the sample size was not large enough to run the analysis at that time and more data needs.

We then decided to take the second approach to collect data by posting multiple messages to retrieve respondents from Linkedin.com. Linkedin.com is the largest online professional network in the world, which has over 80 million members in over 200 countries and many groups such as corporate groups and professional groups. We picked five RFID or SCM related groups: (1) Supply chain Today: Latest News & Trends, Delete Spam, Technology Innovation, Search Executive jobs , (2) Retail Industry Professional Group, (3) Procurement Professionals (#1 supply chain & sourcing group) Business, network, jobs & candidates, (4) RFID professionals, and (5) Auto-ID professionals, to post an invitation message with our survey link. This method did not work well since we only received 9 responses from the postings within two months. So we initiated another attempt to collect data by sending a message with the survey link to individual contact in the groups. We sent the survey to 757 selected supply chain professionals from the groups. We followed the same collection frame: one initial invitation letter and two follow-up messages. The process was very time consuming and the data collection through the second approach extended from November 2010 to July 2011. As an incentive for participating in the survey in Linkedin.com, we also offered the same incentive as an opportunity to win one of two $50 Amazon gift cards. In total, the survey received 108 responses from Linkedin.com. After removing incomplete responses from all of our returned surveys, we had a final sample size of 159 responses. The characteristics of the responded sample are summarized in Table 3.

Table 3: Sample Characteristics

Industry	**Obs.**	**(%)**	**Country**	**Obs.**	**(%)**
Manufacturing	78	49.1%	US	86	54.1%
Logistics/Transportations	23	14.5%	Canada	10	6.3%
Warehousing	6	3.8%	Europe	26	16.4%
Wholesaler/distributor	11	6.9%	South America	4	2.5%
Retailing	8	5.0%	Asia except China	10	6.3%
Others	33	20.8%	China	3	1.9%
			Africa	2	1.3%
			Others	18	11.3%
Total	159	100%	Total	159	100.0%

3.4.3 Operationalization of Variables

We used existing measures to the extent possible and reworded them to meet our specific research context. In the absence of existing items, we developed new scales theoretically. All the antecedent variables are measured with multiple items and most of them are coded on a 5-point Liker scale (1=strongly disagree; 5=strongly agree). While detailed definitions for all measurement items are shown in Appendix A, we briefly highlight the important operationalizations below.

Perceived benefits are measured by six items that reflect the potential benefits of RFID to reduce inventory costs, improve access to information and operational efficiency, increase visibility of supply chain operations, improve coordination with supply chain partners and increase competitiveness. *Compatibility* is assessed using two items that relate to changes needed in supply chain processes and supply chain information system for RFID adoption. *Complexity* was measured in current literature by directly asking if a system or technology is complex or not and the results of the impact of complexity on technology adoption are not unequivocal. Hence, we developed new items for complexity in this study and asked if RFID implementation involves multiple users units, platforms and other systems. Higher values of one or more of these items indicate higher complexity. *Technology maturity* is a new factor not well studied in adoption literature, so we developed specific items for this factor in the present study. Technology maturity is measured through three aspects: cost of RFID components and services, commonly agreed standards, and reliability of RFID readings for supply chain applications. *Trading partner's RFID capability* is measured by four items which are developed in the present study. The four scales relate to trading partner's RFID status, use and benefit experience. For *trading partner power*, the first item used a scale from "No influence" to "Very strong influence" and the second item was captured from "No encouragement or pressure" to "Strong pressure". RFID adoption was measured by a categorical variable: non-adopters (0), potential adopters (1) and adopters (2). Firms are classified as non adopter if they considered RFID and will not adopt RFID in their supply chain activities. Those are classified as potential adopters if they specified that they had considered or were considering RFID and will adopt it. The last category is RFID adopters because they specified they have adopted or pilot-tested RFID in supply chain activities. Otherwise, responses are excluded in the study.

3.4.4 Measurement Validation

Most of constructs and their corresponding measures including items have been validated in previous studies, so we only adapted them in our study. For the new constructs and measures, we systematically validated them in this study. With the help of experts in IS field, content/ face validity of the new constructs and measures are insured.

Several steps were taken to reduce the threat of bias in the data. First, we sent our surveys to only those managers who were directly involved in the supply chain related fields in their firms to ensure that the respondents were qualified to complete the survey and to minimize key informant bias. Second, we explained clearly the total confidentiality of the information provided, to address any motivational barriers. Finally, ANOVA test results indicated that there was no systematic difference in the model constructs between responses from APCIS and those from Linkedin.com. Thus, we merged the responses from the two groups and conducted data analysis.

In this study, factor and reliability analyses were used to test measurement properties (Straub 1989). A principal component analysis with oblique rotation was used to examine the factor structure of the measures in our sample, which followed Hong and Zhu (2006). Eleven factors emerged with Eigenvalue above 1.0, explaining a total of 74.15% of variance in the data. Table 4 is showing the summary of the measurement model from the factor analysis. Reliabilities are reported via Cronbach's alpha, which is the most widely used measure for assessing reliability. All Cronbach's alpha values, except compatibility (0.691) are above the minimum threshold of 0.70 (Nunnally 1967), which indicate adequate reliability of constructs in our study.

Table 4: Summary of Factor Analysis and Reliability

		Component											
		PB	PR CA	CX	ITS	ES	TM	TV	CP	PP	FR	CB	Cronb-ach' α
Perceived Benefits (PB)	PB1	0.71	0.00	0.21	0.07	-0.03	0.09	0.14	0.35	0.07	0.02	0.15	.85
	PB2	0.71	-0.04	0.39	0.22	-0.02	0.08	0.19	0.15	-0.39	0.06	-0.12	
	PB3	0.79	-0.14	0.13	0.02	0.00	0.03	0.21	0.07	-0.19	0.00	0.01	
	PB4	0.79	0.04	0.17	0.14	-0.07	0.30	0.13	0.23	-0.37	-0.16	-0.10	
	PB5	0.76	0.08	0.05	0.22	0.09	0.20	0.08	0.09	0.04	-0.02	0.01	
	PB6	0.79	0.04	0.19	0.29	0.00	0.22	-0.02	0.36	0.01	0.01	-0.19	
Partners' RFID Capability (PRCA)	PRCA1	-0.06	0.82	0.15	-0.01	-0.26	0.10	0.09	0.13	0.28	0.14	-0.03	.90
	PRCA2	0.02	0.90	0.14	0.05	-0.08	0.17	0.01	0.27	0.29	0.14	-0.02	
	PRCA3	-0.03	0.89	0.12	-0.01	-0.05	0.09	-0.07	0.22	0.38	0.23	0.05	
	PRCA4	0.01	0.87	0.11	0.04	-0.16	0.14	0.15	0.24	0.31	0.21	0.05	
Complexity (CX)	CX1	0.24	0.02	0.66	0.07	-0.03	0.11	0.04	0.16	-0.05	-0.03	-0.27	.82
	CX2	0.14	0.17	0.80	0.00	-0.14	-0.25	0.09	-0.12	-0.18	0.04	-0.15	
	CX3	0.10	0.20	0.84	0.12	-0.14	0.05	0.05	-0.03	-0.11	-0.01	-0.24	
	CX4	0.24	0.10	0.89	0.24	-0.17	0.06	0.17	-0.03	-0.02	0.00	-0.25	
IT Sophistication (ITS)	ITS1	0.13	-0.09	0.19	0.80	-0.14	0.12	0.13	0.15	-0.18	0.11	-0.07	.82
	ITS2	0.12	-0.12	0.17	0.81	-0.09	0.05	0.16	-0.03	-0.03	-0.02	-0.19	
	ITS3	0.21	0.08	0.09	0.85	-0.08	0.12	0.12	0.25	-0.06	-0.05	-0.14	
	ITS4	0.20	0.17	-0.01	0.78	0.02	0.05	0.01	0.37	0.01	0.08	-0.16	
External Support (ES)	ES1	-0.01	-0.15	-0.16	-0.11	0.92	0.06	-0.10	-0.04	0.02	-0.10	0.23	.92
	ES2	0.05	-0.11	-0.14	-0.14	0.91	0.08	-0.12	-0.03	0.04	-0.19	0.20	
	ES3	-0.02	-0.18	-0.16	-0.04	0.94	0.03	-0.03	0.03	0.03	-0.09	0.25	
Technology Maturity (TM)	TM1	0.22	0.12	-0.08	0.05	-0.01	0.70	0.13	0.27	0.01	-0.12	0.09	.73
	TM2	0.15	0.16	0.09	0.09	0.17	0.72	0.09	0.24	-0.11	-0.01	-0.08	
	TM3	0.08	0.13	0.10	0.16	-0.03	0.77	0.08	0.17	-0.05	0.09	-0.09	
	TM4	0.16	0.04	-0.09	-0.01	0.07	0.76	0.08	0.05	0.02	0.01	0.01	

Table 4: Summary of Factor Analysis and Reliability (Continued)

Transaction Volume(TV)	TV 1	0.13	0.04	0.13	0.11	-0.05	0.13	0.92	0.08	-0.07	0.02	-0.07	.83
	TV 2	0.18	0.10	0.08	0.17	-0.12	0.13	0.91	0.12	-0.12	0.05	-0.03	
Competitive Pressure(CP)	CP 1	0.19	0.39	0.12	0.30	-0.14	0.29	0.17	0.83	0.07	0.18	0.12	.75
	CP 2	0.22	0.15	-0.10	0.13	0.05	0.15	0.03	0.90	0.05	0.04	0.03	
Partner Power(PP)	PP1	-0.12	0.33	-0.04	-0.03	0.00	-0.03	-0.05	0.14	0.87	0.03	0.05	.74
	PP2	-0.10	0.42	-0.11	-0.10	0.05	0.00	-0.12	-0.03	0.84	0.23	0.12	
Financial Resource(FR)	FR 1	0.02	0.24	0.02	0.03	-0.16	0.10	0.03	0.18	0.10	0.86	-0.11	.72
	FR 2	-0.04	0.14	-0.03	0.03	-0.09	-0.07	0.04	0.01	0.10	0.89	0.16	
Compatibility (CB)	CB 1	-0.06	0.02	-0.19	-0.12	0.25	-0.09	-0.10	-0.03	0.15	0.01	0.88	.69
	CB 2	0.01	-0.01	-0.43	-0.21	0.24	0.10	-0.01	0.23	0.00	0.04	0.81	

Table 5: Summary of Correlations

	Construct	1	2	3	4	5	6	7	8	9	10	11
1	Perceived Benefit	1										
2	Partner's RFID Capability	-.003	1									
3	Complexity	.212**	.137	1								
4	IT Sophistication	.192*	.035	.152	1							
5	External Support	.008	-.145	-.167*	-.094	1						
6	Technology Maturity	.196*	.143	-.012	.113	.053	1					
7	Transaction Volume	.151	.041	.125	.126	-.112	.114	1				
8	Competitive Pressure	.261**	.248**	-.011	.212**	-.011	.255**	.074	1			
9	Partner Power	-.152	.318**	-.124	-.059	.034	-.031	-.117	.04	1		
10	Financial Resources	-.029	.197*	.019	.043	-.126	-.012	.034	.082	.112	1	
11	Compatibility	-.045	.008	-.275**	-.180*	.212**	-.032	-.008	.063	.095	.045	1

**. Correlation is significant at the 0.01 level (2-tailed). Pearson Correlation,. *. Correlation is significant at the 0.05 level (2 tailed).

Convergent and discriminant validities were examined through factor loadings and a correlation matrix (Straub 1989). Convergent validity is demonstrated because all the items have their greatest loadings on their intended construct (loading >0.50). Furthermore, the loadings for all items on their corresponding constructs are much higher than those on other constructs (with no crossing loading greater than 0.36), thus indicating good discriminant validity. There is another evidence for discriminant validity of factors because intercorrelations in Table 5 are generally lower than the reliabilities of the corresponding constructs (Mithas et al. 2011). Overall, our measurement model satisfied the criteria of reliability, convergent validity and discriminant validity.

In order to assess the presence of common method bias in our data, we conducted the Harman's single factor test (Podsakoff and organ 1986). Principal component analysis resulted in eleven factors and no single factor explains a majority of the variance in the data. In fact, the first component accounted for only 14.7% of the variance, thus there was no general factor accounting from more than 50% of the variation. The test results show that common method bias is not a significant threat in our study.

3.5 Data Analysis

Multinomial logistic regression was used to test our hypotheses. This multivariate statistical technique was chosen over other regression analysis because the dependent variable in our model is categorical, with non-adopters, potential adopters, and adopters (Hong and Zhu 2006). Multinomial logistic regression requires fewer assumptions and is considered more robust than discriminant analysis. In our sample of 159 responses, 35 are non-adopters (22.0%), 64 are potential adopters (40.3%), and 60 are adopters (37.7%). The multinomial logistic log functions for our model are defined as follows:

$$f_1(x) = \ln [\frac{P(Y=0|x)}{P(Y=2|x)}$$

$$= \beta_{00} + \beta_1 * PB + \beta_2 * PRCA + \beta_3 * CX + \beta_4 * ITS + \beta_5 * ES + \beta_6 * TM + \beta_7 * TV + \beta_8 * CP + \beta_9 * PP + \beta_{10} * FR + \beta_{11} * CB + \beta_{12} * FIRMS + \beta_{13-18} * IND \quad (1)$$

$$f_2(x) = \ln [\frac{P(Y=1|x)}{P(Y=2|x)}$$

$$= \beta_0 + \beta_{19} * PB + \beta_{20} * PRCA + \beta_{21} * CX + \beta_{22} * ITS + \beta_{23} * ES + \beta_{24} * TM + \beta_{25} * TV + \beta_{26} * CP + \beta_{27} * PP + \beta_{28} * FR + \beta_{29} * CB + \beta_{30} * FIRMS + \beta_{31-36} * IND \quad (2)$$

where $P(Y=0|x)$ is the probability that a firm is non-adopter, $P(Y=1|x)$ is the probability that a firm is potential adopter, and $P(Y=2|x)$ is the probability that a firm is adopter; $f_1(x)$ is comparison between the probability of membership in non-adopter group and the probability of membership in adopter group, ; $f_2(x)$ is comparison between the probability of membership in potential adopter group and the probability of membership in adopter group; βs are the coefficients, and independent variables and control variables are presented as the initials of their names. The conditional probability $P(Y=i|x)$ for i=0, 1, 2 is shown as below.

$$P(Y=i|x) = \frac{1}{1+e^{f_1(x)}+e^{f_2(x)}} \quad for \quad i = 0, 1 \text{ and } 2 \qquad (3)$$

We used the Chi-square test and pseudo R^2 to assess the overall fit of the model. The Chi-square difference is significant at 0.000 level. In logistic regression, Cox and Snell R^2 and Nagelkerke R^2 act similar to the R^2 in multiple regression. Because Nagelkerke R^2 is modified over the Cox and Snell R^2, we used Nagelkerke R^2 to report the explained varation. Nagelkerke R^2 is 0.507 for the overall model, indicating that the model can explain approximately 50.7% of the variance in the dependent variable. Another useful measure to assess the utility of a multinomial logistic regression model is classification accuracy, which compares predicted group memberships based on the logistic models to the actual, known group membership, which is the value for the dependent variable. We compared the overall percentage accuracy rate 63.5%, produced from multinomial logistic regression with a strict criteria, a 25% more than the proportional by chance accuracy $(0.22^2+0.403^2+0.377^2)*1.25 = 0.4412$. We conclude that the regression model has much higher discriminant power than random choice.

In multinomial logistic regression, it is necessary to test multicollinearity among independent variables. Multicollinearity can be detected by examining the standard errors for the beta coefficients from multinomial regression. Following Hong and Zhu (2006), none of the standard errors in our model was greater than 2.0, which indicates that multicolinearity is not a concern for our data.

The results of the multinomial logistic regression are shown in Table 6. We used RFID adopters as the base group to test the predicting power of the independent variables in differentiating the other two groups from the base group. In the overall model, six out of eleven independent variables were significant: compatibility, trading partner power, trading partner's RFID capability, competitive pressure, transaction volume and financial resources. The results of the first regression showed that a subset of significant variables in the overall model could successfully differentiate the non-adopters from the adopters. Lower trading partner RFID capability (negative β), lower competitive pressure, lower trading partner power and lower perceived compatibility differentiated RFID non-adopters from RFID adopters. The second model comparing potential adopters with adopters identified trading partner's RFID capability, competitive pressure and perceived compatibility as significant predictors (as in the first model) and the signs of the coefficients of these variables were consistent across the two models. However, we also found that higher transaction volume and higher financial resources (positive β) separated the potential adopters from RFID adopters.

Based on results, perceived compatibility, trading partner power and trading partner's RFID capability had a positive impact on RFID adoption, supporting H3, H9, and H10. H7 is partially supported because it only appears as a positive factor in differentiating RFID non-adopters from adopters. The other interesting findings were that financial resources and transaction volume were significant predictors, but had a negative effect on RFID adoption. This is contrary to our H5 and H11. The rest of independent variables, as well as firm size (control variable), were not significant in the RFID adoption model.

Table 6: Multinomial Logistic Regression Results

Factor	Overall Model (R^2=50.7%)				Non-adopters vs. Adopters					Potential adopter vs. Adopters				
	-2 LL of Reduced Model	Chi-Square	df	Sig.	β1	Std. Error	Wald	Sig.	Exp (β)	β2	Std. Error	Wald	Sig.	Exp(β)
Perceived Benefit	247.551	2.343	2	0.31	-0.263	0.294	0.803	0.37	0.768	0.185	0.227	0.662	0.416	1.203
Partner's RFID Capability	253.309	8.1	2	0.017**	-0.907	0.317	8.186	0.004***	0.404	-0.568	0.267	4.548	0.033**	0.566
Complexity	247.506	2.298	2	0.317	0.018	0.317	0.003	0.954	1.018	0.356	0.253	1.978	0.16	1.427
IT Sophistication	245.256	0.047	2	0.977	-0.058	0.27	0.047	0.829	0.943	-0.012	0.234	0.003	0.959	0.988
External Support	246.566	1.357	2	0.507	-0.15	0.294	0.261	0.609	0.861	0.157	0.224	0.493	0.482	1.17
Technology Maturity	245.871	0.663	2	0.718	0.176	0.291	0.366	0.545	1.192	-0.05	0.218	0.053	0.818	0.951
Transaction Volume	250.461	5.252	2	0.072*	0.369	0.303	1.486	0.223	1.447	0.535	0.225	5.655	0.017**	1.707
Competitive Pressure	260.19	14.982	2	0.001***	-1.114	0.325	11.766	0.001***	0.328	-0.193	0.266	0.524	0.469	0.825
Partner Power	256.455	11.247	2	0.004***	-0.758	0.31	5.974	0.015**	0.469	-0.811	0.251	10.443	0.001***	0.444
Financial Resources	250.367	5.158	2	0.076*	0.039	0.3	0.017	0.895	1.04	0.48	0.228	4.453	0.035**	1.616
Compatibility	253.218	8.01	2	0.018**	-0.842	0.307	7.527	0.006***	0.431	-0.496	0.233	4.51	0.034**	0.609
Firm Size	Included													
Industry type	Included													

*p<0.1, ***p<0.05, ***p<0.01

3.6 Discussion

RFID can be adopted for many applications, such as tracking animals, roll passing, and library management, so it is important to interpret the findings in our study in the appropriate context of SCM. To capture the context of RFID adoption in supply chain activities, respondents were asked to identify a product line and its corresponding supply chain that currently uses or could potentially adopt and use RFID in its supply chain activities. We also asked respondents to identify the roles of their organization and its trading partner in the supply chain they selected to ensure that they could consider RFID in supply chain activities when they responded the survey. To the best of our knowledge, our study is the first inquiry in IS field to examine RFID adoption in supply chain activities across all major parties of supply chains worldwide and to differentiate non-adopter and potential adopters separately from adopters.

3.6.1 Major Findings

With the purpose of studying RFID adoption, we developed and empirically assessed our theoretical model. All hypotheses were tested and our empirical analysis demonstrated several interesting findings.

FINDING 1. *From the extended TOE framework, perceived compatibility, trading partner power and trading partner's RFID capability are found to be significant factors affecting RFID adoption in supply chain activities.*

Our study found that there are three drivers for RFID adoption in supply chain activities. First, organizations that perceive higher compatibility are more likely to be RFID adopters. This factor was not tested very often in previous IOS studies. Compatibility should be evaluated not only in terms of fitting with existing technologies of the organizations but with existing information systems (Ramamurthy and Premkumar 1995). Incompatibility can lead to significant changes in current processes and supply chain information systems if an organization decides to pursue RFID. Lack of compatibility poses a major difficulty for organizations before they determine to adopt RFID for supply chain activities. Second, trading partner power is a key determinant of RFID adoption. Firms that felt a higher degree of partner power were found to be more likely to be RFID adopters. As noted earlier, powerful trading partners (e.g. Wal-Mart) place strong pressures on their partners on adopting RFID in supply chain activities. Our study provides empirical support to what had often been reported in the industry press as the reason for RFID adoption. Third, our study found a strong relationship between trading partner's RFID capability and focal firm's RFID adoption. Organizations may clearly recognize that RFID should be used by all partners in the supply chain in order to derive network effect and realize its full benefits, so they value RFID adoption status and capability of their supply chain trading partners. Another possible reason may be that an organization whose trading partner has adopted RFID and has greater RFID capability may find that it is easier to learn about RFID and the associated benefits and costs, and it is more likely to behave similar to its trading partner (Burt 1982). Mimetic pressures mentioned in institutional theory also helps explain this finding. Mimetic pressures may cause an organization to change over time to become more like other organizations in its environment (DiMaggio and Powell 1983). When the organization observes its partners have RFID capabilities, the organization will imitate partners' actions as they stand in the same economic network position (Teo et al. 2003).

FINDING 2. *Overall,* c*ompetitive pressure is a significant factor affecting RFID adoption, but it behaves differently in differentiating non-adopters from RFID adopters and in distinguishing potential RFID adopters from RFID adopters.*

Competitive pressure is a statistically significant factor for RFID adoption in the overall model. That means organizations facing higher competitive pressure are more likely to positively decide on RFID adoption. When an organization is facing high competitive pressure, there are strong incentives for it to search new innovations to maintain or enhance its competitive edge (Hannan and McDowell 1984). This finding confirms the impact of economic environment on RFID adopter. However, competitive pressure is a significant factor only for differentiating non-adopters from RFID adopters but not differentiating potential RFID adopters from RFID adopters. This makes sense because the difference in competitive pressure between potential RFID adopters and adopters is smaller than that between non-adopters and RFID adopters. In other words, non-adopter face less competitive pressure than RFID adopters so they may not think it is important to adopt RFID to create competitive advantage; potential adopters who are very sure that they will adopt RFID but just have not adopted it yet, may face similar pressure to that of RFID adopters, and the positive relationship between competitive pressure and RFID adoption turns to insignificant for in the subset of potential adopters and adopters.

FINDING 3. *The direction of two significant factors- financial resources and transaction volume on RFID adoptions are unexpected, thus they are inhibitors for RFID adoption.*

In the research model, we hypothesized that financial resources and transaction volume should be drivers for RFID adoption but they turned out to be inhibitors and only appeared significant in distinguishing potential adopters from RFID adopters. First, financial resources may be a necessary condition to adopt RFID, but may not be a sufficient one. Organizations with more financial resources may have managers who better understand RFID in terms of its benefits, costs and risks. Consequently, they tend to consider more, so when they evaluate RFID project, they may make more cautious adoption decisions, rather than quickly jumping onto the RFID bandwagon. Second, our study found a negative relationship between transaction volume and RFID adoption, specifically differentiating potential adopters and RFID adopters. Previous research argues that the higher transaction volume between supply chain partners, the higher its dependence on the trading partners, and the higher chance the suppliers will install the technology promoted by trading partners. While the process of RFID adoption is significantly influenced by trading partner power, organizations did consider their own conditions on new technology investment. Based on the definition of potential adopters (who have considered and will adopt RFID technology in their supply chain activities) and adopters (who have adopted or piloted RFID) in our study, keeping other factors unchanged, lower transaction volume means lower costs and effort for RFID project, especially considering the variable cost of RFID project, and organizations will more likely to adopt RFID. It may be also because there are still some uncertainties of RFID benefit among RFID believers (potential adopters and adopters). They would like to use RFID but avoid making significant investment before they can really reap benefit. They selected low transaction volume product line to try. This finding suggests that transaction volume and trading partner power in the adoption of RFID or other technology, with relatively high variable costs, is a complex and interesting research topic warranting further examination.

FINDING 4. *Technology maturity is not a statistically significant factor for RFID adoption.*

While there are other factors that were not statistically significant for RFID adoption in our study, technology maturity is worthy to discuss. The relationship between technology maturity and RFID adoption had been ignored in previous technology adoption literature (Wu and Subramaniam 2009) and our study empirically tested the importance of perceived technology maturity in RFID adoption and found it is not a significant factor for RFID adoption. However, there strong sound from industry practitioners to believe that such impact should be significant. One possible reason for the result is that the sample in our study happened to have higher levels of IT sophistication, as reflected in high mean scores for this construct (overall mean=4.14 out of 5), so these organizations may have higher IT capability and perceive RFID maturity is not an issue for their organizations to implement it based on their conditions. Another plausible reason may be that the items for technology maturity may not capture the concept completely although all the items were loaded together and with enough reliability.

3.6.2 Implications

Our results have several implications for research. First, our study explains TOE framework from various theoretical perspectives and provides the evidence to the appropriateness of this framework for RFID study. In our study, TOE framework is enhanced by the support from multiple theories and our research model provides a relatively complete template for undertaking similar studies that bridge theory and practice to investigate IOS adoption. Second, our study further differentiates respondents in three categories: non-adopters, potential adopters and adopters and confirms the differences between potential adopters and adopters. Our study fills the gap in literature for adoption studies, which only captured adoption intention or real adoption decision (yes/no). Third, our study points to the role of trading partner's capability in a specific technology as an enabler of technology adoption among other partners along the supply chain. In the interorganizational dimension, this study indicates transaction volume as an important predictor for RFID adoption and provides evidence that transaction volume turns to a negative factor when variable cost appears for technology adoption project. Our model and results point to the need to expand investigations into other new factors by considering interorganizational issues, which were not part of this study. Finally, while we did not find support to the importance of technology maturity on RFID adoption, we extend literature by validating a set of measures for technology maturity construct.

Our study provides a framework for managers to understand which factors influence RFID adoption in a supply chain context and how such factors impact on RFID adoptions. Our results indicate that compatibility of RFID systems with existing business processes and information systems promotes RFID adoption because compatibility helps to mitigate technological implementation risk and organizational change risk, and to enhance the alignment between the technologies and business processes. This sends a signal to both organizations and RFID vendors. Organizations that search new technology to increase their business efficiency and effectiveness should first leverage the extant information systems and prior knowledge to manage the needs before implementing any new technology and then using their experience and knowledge to minimize the changes when it is necessary to invest in new technology. For RFID vendors or any technology providers, they should learn more about existing business processes related to RFID applications and design RFID with high compatibility for these practices. Furthermore, our study points to the role of trading partner's power and RFID capabilities for RFID adoption and suggests that trading partner's power and RFID capability are effective ways to promote RFID adoption across supply chains.

Second, our results suggest that with the same trading partner power, managers can focus on the partners with relatively less business transaction volume so it can avoid a large amount of investment for RFID project because of high variable cost and then make RFID adoption projects proceed successfully. After gaining successful business case, RFID promoters can apply them as real examples to encourage others to adopt RFID, rather than using simulated cases. For example, Wal-Mart placed mandates to its top 100 and top 200 suppliers for adopting RFID tags on all the pellets and cases shipped to its decks. However, our results would suggest powerful companies, such as Wal-Mart should place pressure on its smaller trading partners for RFID adoption and then display successful business cases to larger suppliers. It will be helpful for overall success of RFID project in Wal-Mart.

Finally, our empirical findings confirm positive network effects—organizations are more likely to adopt RFID when their trading partners have higher RFID capabilities. As trading partners adopt RFID, other organizations in the supply chain have opportunities to conduct more business over RFID mode if they also have RFID capabilities, thus leading to higher levels of benefits from RFID for all players in the supply chain. RFID vendors, therefore, should pay more attention to the potential adopters of RFID whose trading partners already have RFID in place.

3.6.3 Limitations and Future Research

Our study has its limitations. Our dataset was cross-sectional. We were able to test associations but not causalities. We also do not know how these relationships will change over time. Second, we asked respondents to identify the organizations they work for in order to aggregate the results among respondents from the same organizations, however only small percent of respondents provided the information. Given the large geographical span of our sample, we conclude that it is not a serious problem in our study. Third, technology maturity had been tested in our study and it is not a significant factor for RFID adoption; based on the industry press, however practitioners believe technology maturity is one of the major concerns for RFID adoption in supply chain applications. Thus, it may be interesting to retest the role of technology maturity in future RFID and other similar technology research. Fourth, our study only considered RFID adoption decision, however adoption is just the first important stage for technology diffusion. Another interesting direction may be to examine these factors in this study on the other stages of technology diffusion, such as RFID use. Finally, we did not show how RFID are implemented in supply chain activities and it would be worthwhile to investigate RFID implementation process and its impact on supply chain performance, which could provide a deeper and more holistic understanding of the consequences and management of RFID technology.

3.7 Conclusion

An increasing number of organizations seek to improve their supply chain efficiency and effectiveness through the use of RFID which holds great potential to significantly improve SCM. However, facing the challenges of implementing RFID in a supply chain context, organizations need to evaluate not only RFID itself but also internal resources, external environment and trading partner issues in order to successfully adopt this technology. Based on prior literature, our research develops a conceptual model to improve the understanding of RFID adoption in supply chains. The model was empirically tested through data collected from industry professionals worldwide. Survey data also covered different players in supply chains, such as manufacturers, transporters, wholesalers, retailers and others. We find that compatibility, trading partner's RFID capability, trading partner power, competitive pressure, transaction volume and financial resources are significant factors for RFID adoption in a supply chain context. The findings of the research point to the importance of partner issues in RFID adoption. Plus, our study shows that transaction volume behaves in an opposite pattern to other technology adoption studies, confirming the unique characteristics of RFID. The role of financial resources in our study also shows the improvement of decision making in modern companies. Taken together, our study demonstrates the value of tailoring the technology diffusion framework to the adoption of RFID in a supply chain context.

CHAPTER 4: A MODEL OF RFID INFUSION IN SUPPLYCHAINS

4.1 Introduction

Despite the potential of RFID for supply chain transformation, the speed of RFID adoption is lower than many expected. The gap between RFID adoption and infusion may partially explain the situation. IBM and GMA (2006) found that "overall enthusiasm for RFID remains tempered due to the lack of clearly demonstrated business case (pp.2)". A new technology, such as RFID, may be introduced with great enthusiasm and widespread initial acquisition; nevertheless it may still fail to be thoroughly deployed among many acquiring firms (Fichman and Kemerer 1999). One study showed that while 73% of the surveyed firms had adopted Material Requirements Planning (MRP), only 28% of them had integrated MRP into their capacity planning (Cooper and Zmud 1990). The study indicated that there was an obvious gap between MRP adoption and its widespread use. Another study found a similar situation for Computer-aided Software Engineering (CASE) diffusion (Fichman and Kemerer 1999). The study showed that only 7% of the firms studied had achieved "widespread deployment"; while 42% of surveyed firms had reported they adopted the technology. Gallivan (2001) argued that "it is not technology use or user adoption per se that matters as the outcome of interest, but rather how extensively the innovation is used and how deeply the firm's use of technology alters processes, structures, and organizational culture at the organizational level (pp.55)".

In IS literature, innovation diffusion broadly includes two stages: (1) initial decision to adopt or not to adopt an innovation and (2) the actual use of the innovation after the adoption decision has been made. Researchers have argued that post-adoption measures, such as the extent of implementation can better explain the benefits of innovations because it is not all adopted innovations that are completely implemented and the actual use of innovations brings the actual benefits to the adopters (Gallivan 2001).

RFID holds considerable promise to improve an organization's ability to manage its supply chain operationally and strategically. However, the lack of clear evidence in business value has been cited as the most challenging aspect of RFID adoption in supply chain activities (GMA and IBM 2006). Organizations were not able to find a business case for RFID technology suggesting that there is a need to study RFID beyond its adoption.

This chapter integrates understanding from innovation diffusion literature and supply chain literature to investigate RFID infusion in IS and supply chain domains. The specific research questions addressed in the chapter are: (1)*What are the important factors for RFID infusion after adopting it?* (2) *How does RFID infusion impact firm's supply chain process performance?*

Drawing on DOI theory, resource based view (RBV) and TOE framework, this dissertation develops an integrative model for RFID infusion. In this study, RFID infusion is defined as any stage when RFID technology has been piloted or implemented and is being regularly used for business processes. Among adopting organizations, the degree of implementation may vary widely. After implementing a technology, organizations may also use it along different dimensions. This study considers RFID infusion from multiple aspects, including implementation maturity and use. It enables us to capture more variations of RFID use than previous infusion research. This study is among the earliest to develop a fairly comprehensive RFID infusion model.

Another extension to technology diffusion research is that this dissertation explores some variables that have not usually been examined in previous technology diffusion studies, such as technology maturity, absorptive capability and industry collaboration. It richens our understanding of technology infusion, especially for innovative, complex technologies. This chapter also examines the impact of RFID infusion on performance outcomes. It targets a large number of firms to empirically validate the research model, which is different from most of the prior RFID research that have either used very small sample sizes (several firms) or examined a small set of research variables. Our study fills up the gap of a unified theoretical framework to guide RFID empirical research in IS field.

4.2 Theoretical Lens and Literature Review

4.2.1 Theoretical Lens

In this chapter, this dissertation continues investigating RFID diffusion but takes one step further to explore post-adoption stage and its consequences, compared to Chapter 3 which focuses on RFID adoption in supply chain. Therefore, besides TOE framework and DOI theory, the research questions are also examined through the other two theoretical lenses: technology implementation research and RBV of a firm.

According to innovation diffusion literature (Tornatzkey and Fleischer 1990), a theoretical model for any technology diffusion needs to consider different factors from its specific technological, organizational, and environmental contexts, which may have influence on an organization's inclination to use the technology. The TOE framework proposed by Tornatzkey and Fleischer (1990) is hence used in the present study. In prior IS research, TOE framework has been applied to investigate technology diffusion issues for different types of innovations, such as Open Systems, EDI and RFID (Zhu et al. 2006b, Iacovou et al. 1995, Brown and Russell 2007).

DOI theory is a foundation for research on interorganizational systems such as EDI (e.g. Premkumar et al. 1997). This theory focuses on the impact of the characteristics of innovation on its diffusion. Technology implementation research proposed a six stage model: initiation, adoption, adaptation, acceptance, routinization, and infusion (Cooper and Zmud 1990). The diffusion of a new technology starts from initial awareness and evaluation of the innovation to match with organizational needs, such as improving efficiency and keeping competitive advantage. The second stage is adoption in which adoption decision is reached to invest resources in order to accommodate its implementation. Following adoption is the stage of adaptation in which organizational procedures are changed and developed; organizational members are trained for the new procedures and applications. Acceptance is the fourth stage of the diffusion model. Organizational members commit to use the innovation in their activities. The fifth stage is routinization in which the usage of the new technology is perceived as routines in their activities. The last stage is *infusion* in which using the technology in a comprehensive and integrated way supports higher level business of the organization. In their model, infusion stage means that the use has reached its fullest potential (Cooper and Zmud 1990). Broadly speaking, infusion is also viewed as use of technology in literature. In this dissertation, RFID infusion broadly represents any stage after an organization makes a decision to adopt RFID in its supply chain activities.

Prior technology diffusion literature focused more on the issues at adoption stage, however the adoption does not guarantee that there is a widespread usage of the innovation along its value chain to fulfill the full potentials of the innovation. It is time to add more understanding on post-adoption stage by exploring the critical factors for RFID infusion.

As this dissertation also attempts to study the value of RFID in a supply chain context, resource based view (RBV) of a firm is used to investigate RFID value creation for its adopters. According to RBV, information technologies can increase organizational efficiency and effectiveness, enable information and knowledge sharing and effective governance, and create sustained competitiveness through the aggressive pursuit of new opportunities for performance improvement, when the resources of the firm are economically valuable and difficult to imitate (Barney 1991; Wade and Hulland 2004). RBV emphasizes the impact of the heterogeneous resources of a firm on creating and sustaining competitive advantage. The value of IT relies on the extent to which IT is used in the key activities of the firm's value chain (Zhu et al. 2004). In IS literature, this theory has been used to expand and deepen our understanding of IT business value (e.g., Bharadwaj 2000), which provides a theoretical basis to link RFID infusion to firm performance. RFID value depends on the extent to which RFID is implemented and used in the key supply chain activities. The greater the RFID infusion, the more likely a firm is to develop unique capabilities, the more improvement RFID adopter can obtain.

4.2.2 Literature Review

Recently, many publications are related to RFID topics but most of those studies are still case-study based (e.g. Delen et al. 2007; Lee et al. 2008; Wamba et al. 2008). There are very few quantitative empirical studies on RFID diffusion (e.g. Bendoly et al. 2007; Chang et al. 2008; Goswami and Teo 2008; Lee and Shim 2007). However, these studies all focus on RFID adoption stage and did not consider the later stages of technology diffusion. Based on our knowledge, Sharma et al. (2007; 2008) are the only studies which investigated multiple stages of RFID diffusion: evaluation, adoption and early integration. The early integration is defined as the degree to which organization intend to integrate and use RFID after adopting it, so they still did not look at the real usage of RFID.

Based on the literature review, there is an obvious gap in IS literature on RFID diffusion study. While it is important to identify key factors that drive RFID adoption in supply chains, understanding which factors motivate or impede RFID infusion is also desirable. Therefore, this chapter seeks to investigate the antecedents of RFID infusion and its consequences on firm performance. Since there are very limited studies related RFID infusion, this section mainly reviews technology diffusion literature with a focus on post-adoption stage.

As one of first attempts to investigate multiple stages of technology diffusion, Cooper and Zmud (1990) focused on the role of compatibility and complexity in IT implementation, specifically on MRP adoption and infusion. They found that the compatibility and complexity are major factors to explain MRP adoption behavior but they seem not to significantly influence MRP infusion. When investigating the infusion of intranet, Eder and Igbaria (2001) found that earliness of adoption, top management support and IT infrastructure flexibility are positively associated with intranet infusion.

By examining a large group of factors for EDI diffusion, Ramamurthy and Premkumar (1995) found that compatibility, relative advantage, championing, top management support and time since EDI adoption positively impact EDI diffusion. Their study did not show a significant impact of complexity on EDI diffusion, either. Another study from Ramamurthy and Premkumar also investigated EDI diffusion but with different focus. Two interorganizational factors, competitive pressure and trading partner support had significant influence on EDI diffusion; at the same time, four organizational variables: internal support, compatibility, resources intensity and potential benefits show their importance for internal or external diffusion of EDI (Ramamurthy and Premkumar 1999). Ramamurthy et al. (2008) examined important organizational and innovation factors that influence the infusion of data warehouse within organizations and the consequences of extensive infusion of these data warehouses in the organizations. The results showed that compatibility, complexity, organizational support and quality of project management process significantly influence the infusion of data warehouse, which then significantly improve organization performance and stakeholder satisfaction.

There are relatively more studies on Internet use. Mishra et al. (2007) developed an integrative model to examine the antecedents and consequences of Internet use on e-procurement and found that process digitization positively influence Internet use. In their study, the digitization refers to the availability and prior use of an organization's IT infrastructure and solutions to support efficient sales. Drawing upon the TOE framework, Zhu et al. (2006b) identified the specific factors which would influence E-business diffusion and investigated the different effects of these factors on the different diffusion stages. They found that technology readiness, technology integration and regulatory environment have positive impact on use of E-business but firm size, managerial obstacles and competition intensity negatively influence the use of E-business. In a similar study, Zhu et al. (2005) investigated post-adoption stage of E-business in European countries. On the one hand, the findings showed that relative advantages, compatibility, technology competence and partner readiness have positively strong effect on the use of E-business; on the other hand, security concern has relatively strong negative impact on E-business usage but competitive pressure and firm size have negative marginal influence on E-business use.

Most of literatures on technology infusion were investigated under TOE framework which helped indentify important factors for technology infusion. The reviewed literature provides insights on what factors may be important for RFID infusion in the present study. In this chapter, TOE framework helps further indentify more specific factors for RFID infusion in a supply chain context.

4.3. The RFID Infusion Model and Hypotheses

4.3.1 The Conceptual Model

Drawing on DOI theory, RBV theory and the TOE framework, this dissertation develops an integrative model that links technological, organizational, environmental and interorganizational factors to RFID infusion and firms' supply chain process performance as shown in Figure 5. The focus on the post adoption stages is also motivated by the process-oriented view about the use and value creation for IT innovations (Barua et al. 1995; Soh and Markus 1995).

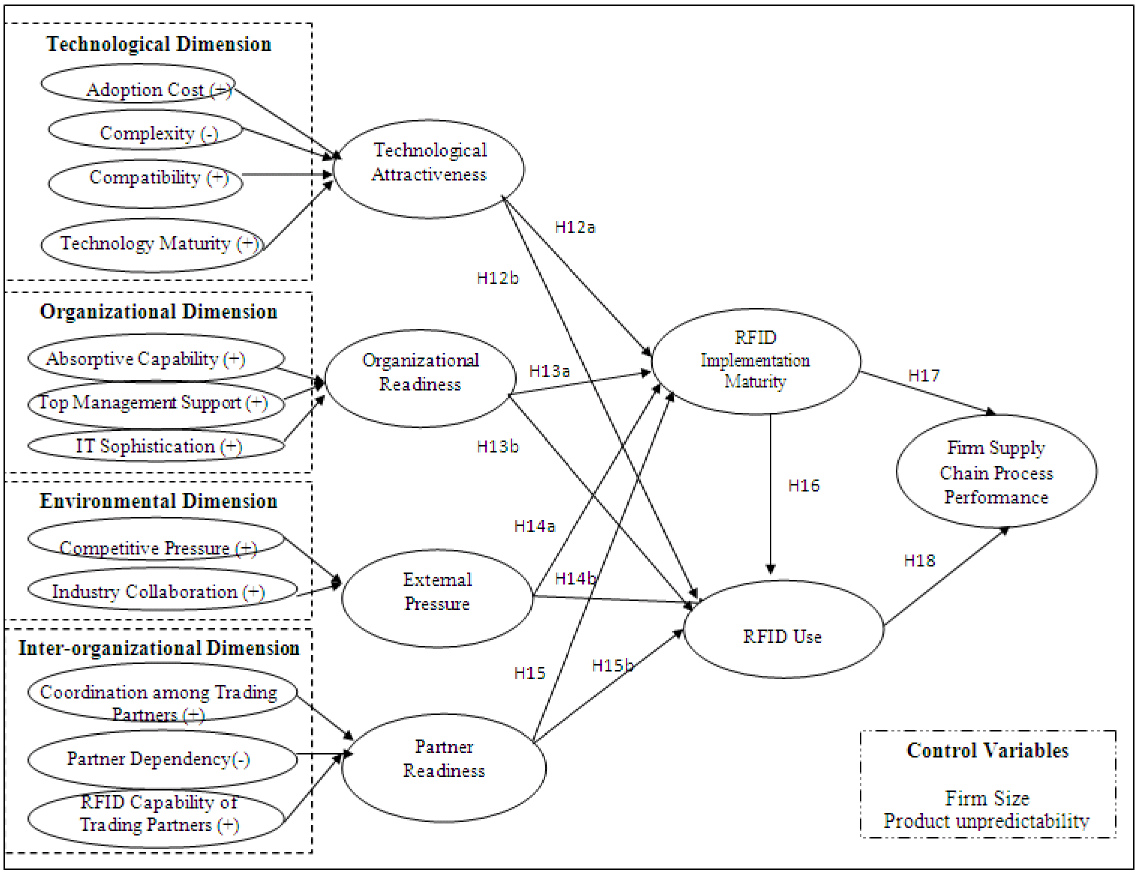

Figure 5: RFID Infusion Research Model

4.3.2 RFID Infusion

In literature, technology infusion occurs when innovation's features are used in a sophisticated manner (Fichman 2000). Even though RFID may be adopted for a supply chain, we need to know the stage of RFID implementation and the extent of RFID implementation in the adopting organization's supply chain activities. On the other hand, IS literature also pointed out that it is important to capture the level of technology infusion through the implementation of its key features and the actual use with related activities (Tornatzky and Klein 1982; Cooper and Zmud 1990). Thus, this study defines RFID infusion as any stage in which RFID technology has been piloted or implemented and has been regularly used for business processes, in order to capture the current status of RFID diffusion. Specifically, this dissertation investigates RFID infusion from two dimensions: implementation maturity and use, which enhance the scope of RFID infusion.

4.3.2.1 RFID Implementation Maturity

While there are many studies investigating IT implementations, few had examined the level of IT implementation. In this study, the level of RFID implementation is explored through three aspects. First of all, organizations may implement different components of RFID technology in their supply chain activities and their implementations may stay at different levels. Some organizations may just implement RFID tags in order to meet the mandates from their trading partners. It is called as “slap and ship”. At this level, RFID implementation only involves putting RFID tags on the entities (e.g. pallets, cases, or items) shipped to the trading partners, so these organizations cannot collect RFID information by themselves. The only way for them to gain RFID data is from their trading partners who share RFID data with their suppliers. This situation affects their RFID use. “Slap and ship” means that RFID may equal to almost 100% expense as the organizations may not attempt to obtain a return from it. Some organizations may implement the tags, readers and software of RFID technology for major customers in order to keep doing business with them. The difference is that the components are implemented to support the supply chain activities.

If organizations actively implement RFID technology in their supply chain activities, it is very likely that they implement all the components of RFID technology (tags, readers, and software) for a better pay off from it. The scope of implementing RFID technology is classified into three levels: for internal supply chain activities, for both internal and external supply chain activities with a single supply chain trading partner, and with multiple supply chain trading partners. In this chapter, we consider all the different levels discussed above as one aspect of RFID implementation maturity in supply chain contexts.

Second, a classification of RFID implementation suggested by Blossom (2005b) is slightly altered and employed in this chapter. This classification indicates the extent to which organizations have integrated RFID into their business process.

Class A: *Pilot studies*. At this level, firms assess RFID readiness, implement a pilot to verify the validity of the goals and objectives of RFID implementation, and explore the new areas of opportunities for improvement.

Class B: *Tagging and Tracking*. At this level, organizations try only to satisfy the mandates from leading trading partners. While these organizations may realize some improvements in some business processes such as inventory, order fulfillment, packing and shipping, RFID is primarily a cost.

Class C: *Application integration*. At this level, organizations integrate RFID data from docks, warehouses and manufacturing facilities into their business activities. The integration can aggregate and route the RFID data into other enterprise applications that perform business tasks such as order management, inventory/warehouse management, accounting, ERP and CRM.

Class D: *Business process improvement*. At this level, RFID data is used for process improvements. An analytical framework helps aggregate RFID data, evaluate business impacts, and convert these insights into certain actions to improve business processes.

Class E: *Collaborative business intelligence.* This is the highest level of RFID implementation. Organizations incorporate RFID knowledge with business intelligence into their operations. The collaborative and predictive business intelligence has been formed and enables organizations immediately to respond, identify and address problems before they really occur.

Third, this dissertation also captures RFID implementation maturity by following traditional implementation models from a process view. According to the innovation diffusion literature (Rogers 1995, Cooper and Zmud 1990), the post-adoption model starts from *adaptation*. In the adaptation stage, RFID application is installed and available to use in the organization's supply chain activities and related work; business processes are changed and developed for the RFID applications; and employees are trained both in new procedures and RFID applications. Following adaptation is the stage of *acceptance*. In the acceptance stage, RFID application is employed in supply chain activities and related work; and employees are induced to commit to RFID use. The third stage of the post-adoption model is defined as *routinization* in which RFID technology is widely used as an integral part in the organizational value chain activities and no longer perceived as something out of the ordinary in the organization.   Figure 6 shows the implementation process.

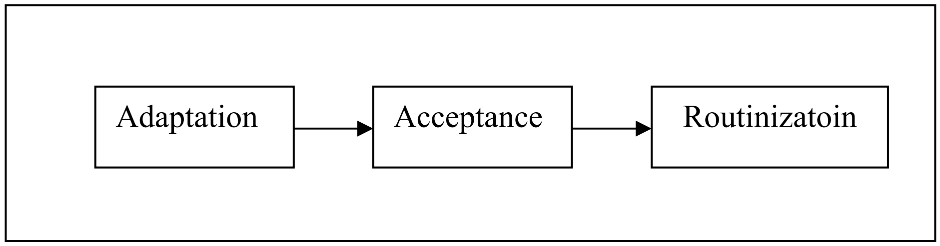

Figure 6: A Process View of Post-Adoption Model
(Adapted from Cooper and Zmud 1990)

The three dimensions of RFID implementation maturity make RFID implementation concept much richer than found in previous IT implementation studies. Organizations implement RFID by choosing different components, e.g. tags, readers, and software and then go through the different levels and classes for RFID implementation.

4.3.2.2 RFID Use

In this chapter, *RFID use* is defined as the extent to which RFID has being used in supply chain activities. Using RFID to purely replace barcode for identifying goods is only viewed as a basic use of RFID. In order to deliver its full potential, RFID technology must be integrated with other internal and external system applications and RFID data gathered from RFID system must be seamlessly transferred into other existing application systems, such as inventory/warehouse management, delivery tracking, production planning, payment systems, etc..

The existing empirical studies found that some firms adopted RFID only for satisfying a powerful trading partner's mandate and they did not have any internal need. In these cases, RFID may not be extensively used within the organization's activities (Pitts 1991). Many predicted that the full potential from RFID will emerge when it is implemented along value chains. Thus, it is also important to establish external links with supply chain partners to exchange and share RFID information, in order to realize the full potential of RFID.

This dissertation conceptualizes RFID use from three interrelated dimensions: breadth, volume, and depth. *Breadth* refers to the number of supply chain activities in which an organization has applied RFID (Zhu et al. 2003, Zhu et al. 2006a). *Volume* refers to the extent to which each of major supply chain activities has been conducted through RFID mode. *Depth* refers to the extent to which RFID technology has integrated with major information systems and databases so RFID information can flow smoothly and be used effectively with backend office systems within the organization, as well as the systems with trading partners. These three dimensions jointly provide a coherent and comprehensive representation of RFID use in the supply chain context.

4.3.3. The Antecedences of RFID Infusion

4.3.3.1 Technological Attractiveness

Technological attractiveness is defined as the extent to which the RFID technology is perceived attractive for the organizations in term of its cost, complexity, compatibility and maturity. In this second order construct, cost, complexity, and compatibility have been investigated in IS literature. However, we have not found any prior literature that applied technology maturity in technology diffusion research, except Wu and Subramaniam (2009). RFID is an emerging and still-maturing technology, so the perception of the development status of RFID among adopters may play a critical role in its infusion. By introducing technology maturity to the technological dimension, this dissertation will better explain the RFID infusion phenomenon.

Adoption costs may include required financial investment and human resources in implementing and using RFID technology (e.g. hardware, software, and training). Costs had been long posited as a barrier for the adoption of technology (Tornatzky and Klein 1982, Iacovou et al. 1995). However, some studies argued that the higher adoption costs could motivate adopters to address the innovation more seriously and use it more actively in order to make it cost-effective (Zaltman et al. 1973, Williams et al. 1998). For example, a firm's IOS investment has an important positive effect on the extent of the firm's IOS use for processing data, connecting with trading partners, and leading to greater benefits (Williams et al. 1998). However, there is a lack of empirical evidence for this proposition because very few studies have investigated technology infusion issues (Cooper and Zmud 1990).

Complexity refers to the degree to which an innovation is perceived as difficult to use (Rogers 1995). RFID does not need line of sight to read entities, and it can make inventory management, tracking management and other related business processes much easier. However, it is difficult to seamlessly integrate RFID technology with existing applications and thoroughly use the large volume of RFID information to make quicker and smarter decisions, because changing existing business processes is even more complex than changing technical infrastructure. Moreover, RFID technology may not only trigger major changes in the supply chain procedures but may also necessitate the change of individual roles in the supply chain. Some personnel positions may not exist anymore.

Furthermore, the external aspect of RFID use makes its implementation and use even more complicated. In order to reach a high level of infusion, the adopters need to share and coordinate RFID data with their trading partners to pursue the full potentials of RFID system. Another complexity of using RFID happens even before the technology is actually used. Allocating RFID cost among supply chain partners is also difficult because manufacturers, distributors, and retailers typically may have different interests from RFID implementation (Alexander et al. 2002). Generally, manufacturers are more interested in tracking cases or pallets through the transportation channels to retailers, while the retailers typically obtain the most benefits from item level tagging. Large-scale changes due to RFID are expected to negatively impact its implementation and use. High complexity may make RFID less attractive. The role of complexity in infusion stage would be more severe than in adoption stage.

Compatibility refers to the degree to which an innovation is consistent with the adopter's current infrastructure, practices and needs (Rogers 1995). It is critical for RFID adopters to use and integrate RFID data with other information systems in order to improve the operational efficiency. For obtaining full benefits, RFID adopters not only need to integrate their RFID systems with other applications within their organizations but also need to cooperate with their partners in its supply chain activities. Compatibility is a technical base to fulfill the integration. However, nowadays RFID incompatibility relating to standards, data modeling, information sharing, and hardware/software platforms may be a major inhibitor for RFID diffusion. In other words, higher compatibility will lead to RFID more attractive for its adopters to use it.

Technology maturity is an important variable but had been ignored in diffusion literature (Wu and Subramaniam 2009). In this chapter, technology maturity is a perception of RFID maturity among RFID adopters, in terms of RFID technology development status. Prior research did not consider the development status of the innovation in its diffusion. They just assumed that innovation technologies were ready to be widespread used. Actually, a particular innovation may not be at its mature stage yet, when organizations start to adopt it, especially for early adopters. For RFID, because of its very attractive benefits proposed by RFID venders, organizations may hold a great enthusiasm to adopt RFID in their supply chain activities but overlook the development status of this technology. While many organizations and venders are working on RFID, this technology is still at developing stage for some supply chain applications. For example, RFID readability is only at 80-90 percentages, which will influence the data quality and information quality for RFID system (Brandel 2004).

RFID standard is another important factor for its infusion (Sharma et al. 2007). It is very possible that RFID tags, readers, and backend systems may be provided by different vendors. However, the current situation is that there is a lack of a commonly agreed global standard for RFID technology. Without the commonly agreed standard, it is difficult for RFID adopters to share information with their supply chain partners and to coordinate and collaborate with them (Markus et al. 2006, Zhu et al. 2006a). Development of RFID standards sets up a foundation for successful implementing RFID and obtaining business value from the technology. In literature findings in RFID standards are mixed. Sharma et al. (2008) found that standard stability could drive RFID adopters to integrate RFID with their existing systems. However, Chang et al. (2008) did not find the support for the importance of mutual standards for Taiwan's logistics companies to determine if they would adopt or not adopt RFID technology. In this chapter, we posits that the higher RFID adopters' perceived maturity of RFID, the higher attractiveness, and the higher implementation and use in their supply chain activities.

Overall, for the second-order construct technological attractiveness, the dissertation hypothesizes that:

HYPOTHESIS 12A: *RFID implementation maturity will be positively associated with RFID technological attractiveness.*

HYPOTHESIS 12B: *RFID use will be positively associated with RFID technological attractiveness.*

4.3.3.2 Organizational Readiness

Organizational readiness refers to the extent to which an organization is ready to implement and use a technology from various aspects such as top management support and knowledge base. Top management support had been consistently indicated as a critical factor for the diffusion of large systems (Brown and Vessey 2003). Absorptive capacity as another feature of an organization may have important impact on RFID infusion. Absorptive capability is a high level of organizational readiness for technology use, especially for new, complex innovations, such as RFID. We also consider IT sophistication as one aspect of organizational readiness because it represents the technological readiness of an organization for technology diffusion.

Top management support refers to the extent to which top management provides a long term strategic vision and necessary resource support to technology implementation (Sharma et al. 2007). Top management can heavily influence other members' behaviors through their engagement and encouragement. Specifically for RFID technology, Lee and Shim (2007) found that a champion at management level is a significant factor for adopting RFID in healthcare industry. For RFID implementation and use, top management support can insure RFID projects a priority in their project list. Their support should be important to encourage employees to actively participate in RFID implementation and use. This dissertation posits that top management support which continuously brings authority and resources to RFID technology can help overcome possible resistance to implementing and use RFID.

Absorptive capacity refers to the ability of an organization to appreciate, value, and adapt to innovations drawn from external sources (Cohen and Levinthal 1990). It is a firm's ability to absorb information and knowledge from outside and then exploit them for its own innovative activities. An organization's absorptive capacity is developed over time through its prior experiences related to the innovation (Cohen and Levinthal 1990). Absorptive capacity has two main aspects: (1) overall ability to access and assess technological opportunities, which depends on human and knowledge capital and (2) learning effects from the previous use of innovative technologies. Acquiring and assimilating external information is an example for the first aspect and absorbing knowledge from new activities to broaden knowledge base is the example for the second aspect. High absorptive capability contributes to organization's readiness to implement advanced, complex technologies. The dissertation posits that an organization with high absorptive capacity can learn more from outside, such as other partners' experience, so it is more likely for it to implement and use RFID in a sophistication way.

IT sophistication is another dimension of organizational readiness to technology infusion. Prior IS literature suggests that the existing technology base of the organization should be considered when discussing technology diffusion (Cooper and Zmud 1990). The study defines IT sophistication as the extent to which IT usage and management is sophisticated in the organization (Iacovou et al. 1995). IT sophisticated organizations more likely use IT in a corporate way, and have access to required technological resources for technology integration. Moreover, the highly integrated, computerized processes in IT sophisticated organizations help reduce incompatibility, enhance responsiveness of information systems (Goodhue et al. 1992), and improve a firm's ability to effectively convert common technologies into capabilities (Mata et al. 1995).

RFID infusion requires streamlined data flows and automatic communication along the supply chain. To reap the full benefits from RFID, organizations must effectively integrate RFID data with existing information systems applications. An organization with a higher level of sophistication for its IT use and management will more easily transmit, combine, and process information with trading partners and it will more easily integrate RFID with existing applications and more likely implement and use RFID.

Overall, for the second order construct organizational readiness, the dissertation hypothesizes that:

HYPOTHESIS 13A: *RFID implementation maturity will be positively associated with the organizational readiness.*

HYPOTHESIS 13B: *RFID use will be positively associated with the organizational readiness.*

4.3.3.3 External Pressure

External pressure refers to the influence arising from outside the organization for its technology implementation and use (Iacovou et al. 1995). Institutional factor has shown its significance for organizational actions (e.g., Burn and Wholey 1993). The speed and level of technology use depends on the communication behavior of adopters in their supply chain networks (Rogers 1995). This second order construct involves two aspects, competitive pressures and collective industry actions.

Competitive pressure refers to the extent of RFID capability of the organization's industry, more importantly the level of its competitors' RFID capabilities (Iacovou et al. 1995). In IS literature, competitive pressure had been investigated as an important antecedent to new technology use (e.g. Premkumar and Ramamurthy 1995). Typically, after adopting a new technology in an organization, it puts pressures on other firms in the same industry or the same supply chain to adopt and use the same technology to improve the coordination and communication along their value chain/supply chains (Iacovou et al. 1995; Premkumar and Ramamurthy 1995). When more competitors have RFID capabilities, RFID adopters should face more pressure to completely and extensively implement and use RFID in order to compete with its competitors.

Industry collaboration refer to the extent to which the industry as a whole has been engaging in addressing critical RFID technology issues, such as RFID standardization and experience sharing. To promote RFID implementation and use, participants in the same industry can work together with standardization organizations and industry consortia to prioritize the development of RFID standards. It will make the required capabilities available quicker to drive expected benefits from RFID technology. The historical experience from barcode also illustrated that it was critical for the industry as a whole to develop and adopt truly global standards for obtaining the benefits from barcode (IBM 2005).

It is found that social, organizational and business network supports adopters with idea, information, and persuasion to use an innovation (Rogers 1995). Since RFID is still an emerging technology for SCM, it will be helpful if leading RFID adopters share their knowledge, experience and findings in some industry forums and conference, in terms of RFID implementation and use in supply chain activities.

Hence, for the second order construct external pressure this dissertation posits the following hypotheses:

HYPOTHESIS 14A: *RFID implementation maturity will be positively associated with external pressure*.

HYPOTHESIS 14B: *RFID use will be positively associated with external pressure*.

4.3.3.4 Partner Readiness

In this chapter, we capture this interorganizational dimension by investigating *partner readiness* which includes the coordination among trading partners, RFID capability of trading partners and supply chain dependency. The partner relationship becomes critical because implementing and using RFID for supply chain activities requires the coordination among supply chain trading partners.

Trading partners' coordination refers to the extent to which an organization and its supply chain partners develop a mutual understanding of each other's capabilities and align their respective goals and activities based on such understanding (Bharadwaj et al 2007). Previous studies found that coordination between trading partners is positively associated with the level of IT use (Son et al. 2005; Bensaou 1997). The full realization of RFID value requires coordination among trading partners to deal with RFID related issues. In supply chain contexts, trading partner coordination can be viewed as having processes in place to ensure that resources and actions are coordinated. RFID implementation is a substantial investment that requires in-depth, joint planning of trading partners. Trading partners need to identify the best path to create an RFID-enabled value chain and work together to determine how they can use RFID technology in an economically viable way. Trading partners' coordinating actions include the negotiation of the ownership of RFID equipment (Curtin et al. 2007), the transmission of information (Au and Kauffman 2005), the post-investment value sharing (Han et al. 2005), and uncertainty related with the technology standards (Kauffman and Li 2005). The greater the trading partner coordination, the more effective the business operations, the more the trust, and the higher the level of implementing and using RFID among the adopters and its trading partners.

RFID capability of trading partners is also required for the sophisticated use of RFID (Iacovou et al. 1995). A complete, successful IOS use depends not only on the adopter's own efforts to incorporate the technology in its operations, but also on the capabilities of its trading partners (downstream or upstream) which conduct businesses with it electronically (Barua et al. 2004). Following Barua et al. 2004, RFID capability of trading partners is defined as the extent to which trading partners along the supply chain have RFID technology in place to conduct transactions with the organization who has implemented RFID.

Fully using RFID technology requires gathering and sharing product information with supply chain trading partners. Trading partners' RFID capability can reduce information uncertainty and enhance coordination among trading partners. Based on network effects (Shapiro and Varian 1990), if trading partners are not ready to conduct business through RFID mode, the RFID adopters cannot achieve a higher level of use.

Supply chain partner dependency is defined as the degree to which an organization relies on its supply chain partners, in terms of resources and services. Previous research has empirically shown that there is a strong positive relationship between the partner dependency and technology adoption (Iacovou et al. 1995). However, supply chain partner dependency may function oppositely on the later stages of technology diffusion, such as infusion. When a supplier heavily depends on a trading partner, the use of RFID technology may be limited only to satisfy the requirement of the powerful trading partner. These early RFID implementation efforts generally do not involve major redesigns of existing business processes in those adopters (Dutta et al. 2007). This may limit suppliers to implement additional RFID functions which would deliver greater benefits to the suppliers (Hart and Saunders 1998). Moreover, because of the higher dependency, organizations may turn to adopt other technologies from other mandates of powerful trading partners. So, there is less chance for such organization to implement and use RFID technology in a sophisticated way to realize its full potentials.

Therefore, for the second order construct trading partner readiness, the dissertation posits the following hypotheses:

HYPOTHESIS 15A: *RFID implementation maturity will be positively associated with trading partner readiness.*

HYPOTHESIS 15B: *RFID use will be positively associated with trading partner readiness*.

While the present study is the first attempt to investigate RFID infusion in supply chains, most of key variables identified in the present could be related to those examined in prior literature on infusion of other information technologies. Table 7 provides commonalities between the variables proposed in the present study and those which had been examined in previous empirical works.

Table 7: Support of Variables from Prior Empirical Work on Technology Use

	Complexity	Compatibility	Technology Maturity	IT Sophistication	Top Management Support	Competitive Pressure	Adoption Cost	Absorptive Capability	Industry Collaboration	Coordination among SC partners	RFID Capability of Trading Partner	SC Partner Dependency
Cooper and Zmud (1990)	√	√										
Edar and Igbaria (2001)				√	√							
Karahanna et al. (1999)	√											
Mishra et al. (2007)				√								
Ramamurthy and Premkumar (1995)	√	√		√	√							
Ramamurthy et al. (2008)	√	√			√							
Ramamurthy et al. (1999)		√			√	√						
Son et al. (2005)										√		
Zhu et al. (2006a)							√				√	
Zhu et al. (2006b)				√		√						√
Zhu et al. (2005)		√		√		√	√					
Zhu et al. (2006c)				√		√						

4.3.4 The Relationship between RFID Implementation Maturity and Use

As discussed early, the study conceptualizes RFID infusion from two perspectives: RFID implementation and RFID use. Given that RFID infusion can be across various units/subunits within the organization and across the boundary of the organization to cooperate with trading partners, RFID implementation would have impact on its use in supply chain activities. When an organization is implementing RFID technology along the post-adoption stage model (adaptation, acceptance and rounitization), it is possible that RFID has being used along different dimensions in different units or across the organization's boundary. It is critical to know which applications of RFID are used, for example what are the tasks in which RFID has being used, and within supply chains which business processes are using RFID. The actual use of RFID technology has to be linked to the day-to-day activities. The overlap between these two phases of RFID diffusion makes us postulate that there is a relationship between RFID implementation maturity and RFID use. An organization that has higher RFID implementation maturity may be in a later stage of post-adoption model or may have implemented RFID in a higher class, as discussed in the previous section. So it is possible for the organization to have a more sophisticated use of RFID, at least along some of the usage dimensions, such as breadth and depth. For example, while an RFID adopter is at the acceptance stage for RFID implementation with only implementing this technology to help external supply chain operation with a single powerful trading partner, it is likely that some of major supply chain activities have been using RFID mode at higher level. It may also integrate RFID data into their other application systems only for those specific products that applied RFID technology.

Therefore, this dissertation posits the following hypothesis about the relationship between RFID use and maturity:

HYPOTHESIS 16: *RFID use is positively associated with RFID implementation maturity.*

4.3.5 The Consequence of RFID Infusion

IS success research suggests that for a deeper and more detailed understanding of technologies, the technologies and their consequences should be examined together (DeLone and McLean 1992). Research also suggests that the impacts of innovations on their adopters needs to be studied explicitly (Rogers 1995), because only when organizations use the innovations to conduct activities to create value, they can improve performance (Zhu and Kraemer 2005). The rationale is that the value of innovations is achieved through its use in specific processes, which in turn, lead to higher-level outcomes such as competitive advantages or other long-term strategic benefits (Mukhopadhyay and Kekre 2002; Porter 1991).

Drawing on the resource-based view, we propose that the greater the extent of RFID infusion, the greater the likelihood that organizations will create RFID capabilities which are rare, inimitable, valuable and sustainable, thereby contributing to improving supply chain process performance of the organizations. Without using RFID in a broad and sophisticated way along value chains, it would be difficult to generate business value from RFID.

RFID is a powerful technology for SCM. Both supply chain and IS literature have suggested specific variables to capture performance improvement from a supply chain process perspective. For example, Rai et al. (2006) analyzed operational excellence and customer relationship in their supply chain process integration study. Mishra et al. (2007) used process efficiencies and cost savings in the procurement process as the measures of procurement process performance. Zhu and Kraemer (2005) measured E-business value along value chains: improving downstream operations by increasing sales and improving customer services, improving internal operations by increasing employee productivity and improving process efficiency, and improving upstream operations by reducing costs and improving coordination with suppliers. Karimi et al. (2007) directly applied process efficiency, process effectiveness and process flexibility to measure process outcome in ERP implementation. Collectively, this dissertation incorporates three level measures of process performance from Zhu and Kraeme (2005), other supply chain literature, and RFID case study literature to form a second-order construct for process performance.

For improved downstream operations, the measures of increased sales by reducing the probability of out of stock (Zhu and Kraemer 2005 and Hardgrave et al. 2005) or gaining more business from the partners (Mukhopadhyay and Kekre 2002) are applied. Internal operation efficiency, staff productivity (Zhu and Kraemer 2005) and operation flexibility by increasing visibility (Karimi et al. 2007) are used to measure improvement in internal operation. As to measuring upstream operation improvement, inventory cost and coordination with trading partners are used (Zhu and Kraemer 2005).

Based on the discussion above, this dissertation hypothesizes the link from RFID infusion to performance improvement:

HYPOTHESIS 17: *RFID implementation maturity is positively associated with firm's supply chain process performance.*

HYPOTHESIS 18: *RFID use is positively associated with firm's supply chain process performance.*

4.3.6 Control Variables

This study controls two variables which may also influence RFID infusion and its consequence: firm size and product predictability. Larger firms may be in a better position in term of achieving high performance, because they have resources and abilities to gain scale efficiencies (Hitt et al. 2002). Product demand predictability can influence firm performance. Product demand predictability is another control variable in this model. According to the product classification from Fisher (1997), while functional products have long product lifecycles and low forecasting errors, innovative products have short product lifecycles and high forecasting errors, thus affecting the performance due to RFID infusion.

4.4. Methodology

4.4.1 Instrument Development

The instrument development procedure has been discussed in Chapter 3 for adoption study. Table 8 summarizes the instrument for the infusion study. All second order constructs are formative measures and all first order constructs are reflective measures. For formative construct, each indicator explains a unique portion of variance in the latent variable and it is not necessary for them to covary and they are not interchangeable (Petter et al. 2007). A reflective construct has indicators caused by the reflective latent variable and they covary and can be interchangeable.

Table 8: Measurement of Constructs in RFID Infusion

Latent Construct	**Type**	**Sub-Construct**	**Type**	**Source**	**# of Items**
Technological Attractiveness (TACHA)	Formative	Adoption Cost (COST)	Reflective	Zhu et al. 2006a	2
		Compatibility (CB)	Reflective	Karahanna et al. 2006	3
		Complexity(CX)	Reflective	Xia and Lee 2003	4
		Technology Maturity(TM)	Reflective	Developed in this study	6
Organizational Readiness (ORRD)	Formative	Absorptive Capability(AC)	Reflective	Lichtenthaler 2009	4
		IT Sophistication(ITS)	Reflective	Chwelos et al. 2001	4
		Top Management Support(TMS)	Reflective	Wang et al. 2006	2
External Pressure (EXPR)	Formative	Competitive Pressure(CP)	Reflective	Chwelos et al. 2001, Teo et al. 2003	3
		Industry Collaboration(IC)	Reflective	Developed in this study	3
Partner Readiness (PRD)	Formative	Coordination among Partner(CRDN)	Reflective	Bharadwaj et al. 2007	4
		RFID Capability of Partner(PRCA)	Reflective	Developed in this study	4
		Supply Chain Dependency(PD)	Reflective	Kumar et al. 1998, Hart and Saunders 1998	4
RFID Implementation Maturity(IMPMT)	Reflective	Items: RFID Use(RU), RFID Stage(RS), RFID Class(RC)		Developed based on Cooper and Zmud 1990	3
RFID Use (USE)	Reflective	Breadth (BRD)	Reflective	Zhu et al. 2006	6
		Depth(DEP)	Reflective	Zhu and Kraemer 2002	2
		Volume(VOL)	Reflective	Hart and Saunders 1998	3
Firm' SC Process Performance (PERF)	Reflective			Makhopadhyaya and Kekre 2002, Karimi et al.2007, Zhu and Kraemer 2002	8

4.4.2 Measures

At the beginning of the web-survey, the respondents were asked to indicate the role of their company and a product line which currently is using or piloting RFID. They also were asked to identify a trading partner in that product line. The respondents were asked to respond the survey with respect to the identified product line and the trading partner. 5 point Likert scale ranging from 1to 5 (1 for "Strongly disagree and 5 for "Strongly agree") was used for most of survey items. Percentage scale was employed to measure use.

As a second-order construct, technology attractiveness was formed with four first-order constructs: compatibility, complexity, technology maturity, adoption cost, each of which was measured using a multi-item scale in this study. Existing measures were adapted for compatibility, complexity and adoption cost. However, we developed new measurements for technology maturity based on a review of industry publications, because of the lack of direct measurement in literature. Technology attractiveness is defined as the extent to which RFID is perceived attractive to organizations to use it after its adoption. Technology maturity is defined to as the extent to which RFID is perceived to be mature based on RFID use in organizations. The first order construct captures stability, availability, standard issue etc. from RFID use perspective. In this study, compatibility and complexity constructs emphasize the implementation process. We asked respondents to state their agreement on if using RFID involves significant changes in supply chain process, supply chain information systems, and IT infrastructure for compatibility construct. Complexity construct is measured by asking respondents if they agree RFID implementation involves multiple user units, platforms, software environments. Adoption cost was reflected by implementing and integrating RFID cost, relative to firm's annual revenue (Zhu et al. 2006).

Organizational readiness is defined as the extent to which an organization is ready to implement and use RFID. The study captures this second order formative construct from three aspects: top management support, absorptive capacity and IT sophistication. Top management support measured the extent of the support from top management to RFID, in terms of promotion and stable funding support. Absorptive capability refers to the ability for an organization to appreciate value and adapt to new technologies from external sources (Cohen and Levinthal 1990). This first order construct is reflected by overall ability to access and assess technology information and opportunities and learning effect from previous use in an organization. IT sophistication reflects the level of IT use and management in an organization.

The extents of external pressure were measured based on the following aspects: competitive pressure in the market and industry collaboration. Respondents were asked to state whether RFID adoption is critical for remain competitive and keep respondent's company at edge. Industry collaboration was measured through items developed in this study because of the innovativeness of this construct. This construct was measured via the activities: actively working together for RFID use, sharing RFID knowledge and collaboratively forming shared focus for RFID use, based on the review from industry papers (e.g. GAM and IBM 2006, IBM 2004).

Trading partner readiness is defined as the extent to which a respondent perceives whether their trading partner in the identified product line is ready to conduct business over RFID mode, in terms of coordination process, RFID capability and dependency.

Indicators of coordination construct were adapted from literature (Bharadwaj et al. 2007) and measured they have processes and understanding to conduct business together. Items of RFID capability was developed for this study. Respondents were asked to state their agreement on: the identified trading partner has RFID ready to conduct business with it, has conducted business with other partners under RFID, and has benefited greatly from RFID use. We ask respondents for their agreement whether their relationship with identified partner is important for each other and it is replaceable for partner dependency.

RFID implementation maturity is defined as the extent which RFID is implemented in the identified product line for the respondent's company. This reflective construct was measured through three items: scale, use and stage of RFID use. As a reflective second order construct, RFID use was measured through breadth, depth, and volume (Zhu et al. 2006). From a SCM perspective, process performance was measured through supply chain related activities: reduced out of stock, increase sales, improve internal efficiency and flexibility, reduce inventory cost, increase inventory accuracy and coordination with partners. As control variables, product unpredictability was measured by product life time and forecast error and annual revenue was used to measure firm size. The survey instrument is presented in Appendix A.

4.4.3 Sample

Empirical data was collected through an online survey over one week period. As discussed in Chapter 3, the survey in this study focuses on a particular technology, RFID and more specifically on RFID use in supply chain activities. The responses to such specific technology uses are usually low. Hence, we used a professional company to collect data through their panel. In their panel, there were 1031 who met the potential criteria of the participants for our study. From their tracking software for survey procedures, they reported that of these 1031 potential participants, 761 started the online survey. Of these 761, 470 potential participants ended the survey because they do not have RFID experience. This left 291 participants with RFID experience and took the survey. So the response rate is 28.2% for the potential 1031 participants and 38.2% of the 761 starters. Of the total responses, 9 participants left with completing ¾ of the survey and 21 had no variance in their answers across items, and hence were removed from dataset. 11 responses from participants who took too long to complete the survey (>2000 seconds or 33.3 minutes) and 77 responses who completed too quickly (<300 seconds or 5 minutes) were also removed. We had a final dataset of 169 usable observations.

Table 9 provides sample characteristics. While the firms are located in different countries and areas, responses were mainly from US. The size of the firms ranges from small to large but the majority are big ones. Industry characteristic shows the firms are mainly manufacturers, logistics companies, warehousing/distributors, and retailers. The data covers the different players of supply chains. The respondents had an average tenure of 5-8 years with senior or C level titles in their current working company, so they can be considered to competent to answer survey questions.

Table 9: Sample Characteristics for RFID Infusion

Country	Frequency	(%) Respondents
US	150	88.8
Canada	7	4.1
Europe	7	4.1
South America	2	1.2
Oceania	1	0.6
Other	2	1.2
Respondent Title	Frequency	(%) Respondents
President, Managing Director, CEO, General Manager	60	35.5
Corporate Officer, CIO, CTO, VPs	41	24.3
IT Director, Manager, Planner, Analyst, etc.	46	27.2
Business Director, Manager, Planner, Analyst, etc.	22	13.0
Years of Work Experience in Current Company	Frequency	(%) Respondents
1 to <3 years	10	5.9
3 to <5 years	41	24.3
5 to <8 years	37	21.9
>= 8 years	81	47.9
Years of Work Experience	Frequency	(%) Respondents
< 5 year	1	0.6
5 to <10 years	44	26.0
10 to <15 years	55	32.5
15 to <20 years	22	13.0
>= 20 years	47	27.8
Industry	Frequency	(%) Respondents
Manufacturing	92	54.4
Logistics/Transportations	29	17.2
Warehousing	16	9.5
Wholesaler/distributor	6	3.6
Retailing	12	7.1
Healthcare	9	5.3
Other	5	3.0

Table 9: Sample Characteristics for RFID Infusion (Continued)

Number of Employee	Frequency	(%) Respondents
<100	16	9.5
100 to < 500	29	17.2
500 to <1,000	45	26.6
1,000 to <3,000	34	20.1
3,000 to <5,000	24	14.2
5,000 to <10,000	9	5.3
>= 10,000	12	7.1
Annual Revenue in Million $	Frequency	(%) Respondents
<$1 million	4	2.4
$1 to <$10 million	21	12.4
$10 to <$50 million	31	18.3
$50 to <$100 million	39	23.1
$100 to <$500 million	36	21.3
$500 to <1000 million	14	8.3
>= $1000 million	24	14.2

4.5 Data Analysis and Results

Partial least squares (PLS)[1] was applied for the data analysis. First, this analytical approach is generally recommended for exploratory research models in which the focus is theory development and the research model is in an early stage of development and has not been tested extensively (Teo et al. 2003). To the best of our knowledge, our study is the first time to apply a large-scale survey to test RFID infusion model. Second, the research model has formative and reflective constructs together and PLS uses components-based algorithms and can estimate formative constructs (Chin 1998). This technique places minimal requirements on measurement scales, sample size and residual distributions (Chin et al. 2003). Third, this approach not only performs a simultaneous evaluation of the quality of measurement and construct interrelationship but also allows small-to-medium size samples. The sample of 169 observations is adequate for PLS

[1] The analysis was done using SmartPLS 2.0.

analysis based on the heuristic that the sample size should be at least 10 times the largest number of structural paths directed at any one construct (Subramani 2004). The largest number of paths to any construct in my research model is eight. The PLS method does not directly provide significance test and confidence intervals to estimate the significance of path coefficients. Hence, a bootstrapping analysis was done with 500 subsamples and path coefficients were re-estimated using each of these samples.

4.5.1 Measurement Validation

The first stage of data analysis focused on measurement properties of constructs. We use confirmatory factor analysis in PLS to validate our data. The correlation pattern indicates that each of the measurement items has highest loading with a significant t-value on its latent construct; however there are some cross loading issues in the correlation table. Following an iterative procedure, refinements to the research model were made by eliminating indicators with high cross loadings (Teo et al. 2003, Gefen and Straub 2005). We eliminated all items for top management support and trading partner dependency because the items show high cross loadings with other constructs. We also removed CX2 and CX4 from complexity construct, TM5 and TM6 from technology maturity, AC2 and AC3 from absorptive capacity construct, ITS1 from IT sophistication, IC2 from industry collaboration, and CRDN1 from coordination among partners construct to minimize cross loading issues. Items of breadth and depth were merged to one dimension based on their construct loadings. The final model comprising of 48 items shows significant improvement in factor loadings as shown in Table 10.

After the refinements, the correlation pattern indicates that an item proposed to reflect a given sub-construct has a stronger correlation with it than with other constructs, providing evidence of discriminant and convergent validity (Gefen and Straub 2005). All items have highest loading on their proposed constructs and all the loadings of the measurement items on their assigned latent variables are an order of magnitude larger than their loadings on other variables (i.e., the lowest difference is > 0.10). In addition, their loadings were all above criterion of 0.707 and significant, except for four items. The errant indicators, VOL1, VOL2, and VOL3 were not significant so they were removed. Thus, RFID use became a first order construct after the refinement. The fourth item, RS which has loading of 0.600 and is significant, does not have cross-loading and convergent validity problems. Hence, it was retained.

Another criterion for assessing discriminant validity is to conduct variance-extracted test. The variance shared by a construct with its indicators should be greater than the variance shared with other constructs in the model. A construct is considered to be distinct from other constructs if the square root of the average variance extracted for it is greater than its correlations with other latent variables (Barclay et al. 1995). Additionally, the correlations between all pairs of constructs are below the threshold value of 0.90 (Bagozzi et a. 1991). The discriminant validity is supported for all the constructs in the study (see Table 11).

Internal consistency was assessed by examining composite reliability and Cronbach's Alpha. All composite reliabilities are all above the suggested threshold of 0.7, indicating reliable measurement. The average variance extracted (AVE) for all latent variables were above 0.50, the recommended threshold (Hair at al. 1998). Thus, internal consistency and convergent validity in our model are demonstrated.

We also attempted to reduce the common method bias. We first allowed response to be anonymous and assured respondents that there is no right or wrong answer. We used different scale, matrix and reversed some of the items in survey questions. These steps help control common method bias. We also added two first order factors with all measures as control variables in the empirical model (Mishar and Agarwal 2010). This addition did not change the variance explained significantly. So we conclude that common method bias is not significant threat in our study.

Table 50: Item-Construct Correlation

Item	Constructs													
	AC	USE	CB	COST	CP	CRDN	CX	IC	ITS	PDP	PERF	PRCA	IMPMT	TM
AC1	0.91	0.62	-0.37	0.39	0.61	0.69	0.66	0.62	0.69	0.41	0.66	0.62	0.48	0.53
AC4	0.90	0.65	-0.34	0.44	0.58	0.67	0.55	0.49	0.61	0.35	0.63	0.61	0.44	0.55
BRD2	0.62	0.85	-0.44	0.45	0.59	0.63	0.56	0.59	0.67	0.45	0.72	0.59	0.45	0.59
BRD4	0.49	0.82	-0.43	0.51	0.56	0.51	0.60	0.64	0.63	0.39	0.62	0.56	0.48	0.60
BRD5	0.59	0.87	-0.37	0.47	0.57	0.55	0.54	0.53	0.66	0.37	0.70	0.65	0.49	0.54
BRD6	0.67	0.86	-0.35	0.46	0.66	0.61	0.60	0.56	0.73	0.38	0.75	0.71	0.50	0.61
DEP2	0.60	0.83	-0.41	0.52	0.58	0.67	0.59	0.62	0.66	0.39	0.67	0.64	0.53	0.61
CB1	-0.40	-0.44	0.95	-0.55	-0.44	-0.31	-0.53	-0.54	-0.43	-0.64	-0.38	-0.46	-0.34	-0.43
CB2	-0.37	-0.47	0.94	-0.50	-0.43	-0.30	-0.48	-0.47	-0.47	-0.55	-0.41	-0.47	-0.28	-0.42
CB3	-0.31	-0.41	0.90	-0.51	-0.38	-0.30	-0.42	-0.46	-0.40	-0.60	-0.42	-0.41	-0.31	-0.38
COST1	0.44	0.54	-0.49	0.93	0.47	0.49	0.55	0.56	0.44	0.55	0.51	0.47	0.38	0.42
COST2	0.41	0.51	-0.55	0.91	0.42	0.42	0.42	0.47	0.38	0.58	0.47	0.44	0.24	0.37
CP1	0.62	0.67	-0.46	0.50	0.94	0.55	0.66	0.71	0.64	0.44	0.62	0.66	0.53	0.72
CP2	0.63	0.64	-0.39	0.42	0.94	0.58	0.65	0.65	0.73	0.40	0.64	0.67	0.46	0.69
CRDN2	0.71	0.67	-0.35	0.48	0.55	0.87	0.58	0.60	0.65	0.40	0.66	0.57	0.41	0.56
CRDN3	0.63	0.62	-0.29	0.44	0.53	0.91	0.46	0.53	0.56	0.37	0.66	0.53	0.47	0.59
CRDN4	0.67	0.59	-0.23	0.41	0.52	0.89	0.44	0.50	0.59	0.32	0.65	0.51	0.42	0.54
CX1	0.67	0.61	-0.47	0.39	0.64	0.52	0.91	0.65	0.67	0.42	0.61	0.62	0.51	0.55
CX3	0.56	0.64	-0.47	0.57	0.63	0.49	0.92	0.66	0.64	0.43	0.55	0.55	0.55	0.57
IC1	0.63	0.66	-0.53	0.54	0.67	0.58	0.68	0.92	0.66	0.58	0.67	0.60	0.54	0.65
IC3	0.51	0.62	-0.45	0.50	0.66	0.54	0.64	0.92	0.59	0.48	0.58	0.60	0.56	0.67

Table 60: Item-Construct Correlation (Continued)

ITS2	0.66	0.69	-0.45	0.43	0.64	0.62	0.66	0.65	0.87	0.40	0.68	0.62	0.40	0.59
ITS3	0.67	0.72	-0.45	0.40	0.65	0.62	0.65	0.59	0.91	0.41	0.71	0.66	0.43	0.67
ITS4	0.59	0.69	-0.35	0.36	0.64	0.56	0.61	0.57	0.89	0.36	0.70	0.62	0.46	0.65
PDP1	0.49	0.42	-0.59	0.54	0.40	0.41	0.45	0.49	0.39	0.90	0.45	0.38	0.39	0.37
PDP2	0.27	0.42	-0.57	0.56	0.40	0.32	0.38	0.54	0.40	0.89	0.43	0.38	0.24	0.40
PERF1	0.63	0.56	-0.27	0.32	0.50	0.55	0.48	0.55	0.62	0.39	0.79	0.55	0.38	0.55
PERF2	0.56	0.73	-0.48	0.53	0.62	0.59	0.53	0.67	0.66	0.52	0.83	0.60	0.48	0.67
PERF3	0.68	0.68	-0.36	0.46	0.56	0.65	0.57	0.55	0.69	0.36	0.81	0.55	0.40	0.52
PERF4	0.56	0.62	-0.34	0.46	0.49	0.55	0.50	0.49	0.61	0.42	0.81	0.54	0.36	0.55
PERF5	0.59	0.72	-0.35	0.41	0.59	0.56	0.52	0.53	0.68	0.36	0.83	0.59	0.38	0.64
PERF6	0.46	0.65	-0.42	0.48	0.59	0.59	0.49	0.59	0.59	0.45	0.80	0.59	0.41	0.67
PERF7	0.60	0.72	-0.37	0.42	0.52	0.66	0.54	0.57	0.65	0.42	0.85	0.58	0.56	0.60
PERF8	0.58	0.61	-0.19	0.37	0.49	0.67	0.49	0.46	0.61	0.25	0.79	0.50	0.41	0.53
PRCA2	0.67	0.69	-0.41	0.39	0.64	0.57	0.65	0.62	0.67	0.37	0.66	0.89	0.54	0.63
PRCA3	0.51	0.57	-0.39	0.45	0.54	0.47	0.48	0.51	0.55	0.37	0.51	0.86	0.35	0.60
PRCA4	0.60	0.71	-0.47	0.48	0.68	0.54	0.56	0.58	0.65	0.38	0.65	0.89	0.43	0.67
RC	0.42	0.48	-0.23	0.29	0.50	0.41	0.46	0.54	0.42	0.24	0.44	0.46	0.84	0.47
RS	0.27	0.29	-0.17	0.14	0.28	0.25	0.29	0.27	0.21	0.13	0.23	0.26	0.60	0.22
RU	0.45	0.51	-0.33	0.31	0.40	0.42	0.53	0.50	0.43	0.39	0.48	0.40	0.82	0.42
TM1	0.48	0.58	-0.38	0.35	0.56	0.53	0.44	0.52	0.57	0.32	0.59	0.56	0.49	0.76
TM2	0.42	0.50	-0.29	0.35	0.61	0.46	0.50	0.58	0.50	0.33	0.50	0.54	0.36	0.82
TM3	0.53	0.58	-0.32	0.30	0.61	0.53	0.49	0.54	0.63	0.35	0.63	0.62	0.41	0.85
TM4	0.51	0.60	-0.44	0.39	0.66	0.53	0.56	0.67	0.60	0.39	0.64	0.61	0.37	0.82

Table 71: Establishing Discriminant Validity

Construct	AVE	Composite Reliability	AC	CB	COS T	CP	CRD N	CX	IC	IMPMT	ITS	PDP	PERF	PRCA	TM	USE
AC	0.81	0.90	0.90													
CB	0.86	0.95	-0.39	0.93												
COST	0.85	0.92	0.46	-0.56	0.92											
CP	0.88	0.94	0.66	-0.45	0.49	0.94										
CRDN	0.79	0.92	0.75	-0.32	0.50	0.60	0.89									
CX	0.83	0.91	0.67	-0.51	0.53	0.69	0.56	0.91								
IC	0.85	0.92	0.62	-0.53	0.56	0.72	0.61	0.72	0.92							
IMPMT	0.58	0.80	0.51	-0.33	0.34	0.53	0.48	0.58	0.60	0.76						
ITS	0.79	0.92	0.72	-0.47	0.45	0.73	0.68	0.72	0.68	0.48	0.89					
PDP	0.80	0.89	0.43	-0.64	0.61	0.45	0.41	0.46	0.57	0.35	0.44	0.90				
PERF	0.66	0.94	0.71	-0.44	0.53	0.67	0.74	0.63	0.68	0.53	0.78	0.49	0.81			
PRCA	0.77	0.91	0.68	-0.48	0.50	0.71	0.60	0.64	0.65	0.50	0.71	0.43	0.69	0.88		
TM	0.66	0.89	0.60	-0.44	0.43	0.75	0.63	0.61	0.71	0.51	0.71	0.43	0.73	0.72	0.81	
USE	0.72	0.93	0.70	-0.47	0.57	0.70	0.71	0.68	0.69	0.58	0.79	0.47	0.82	0.75	0.70	0.85

4.5.2 The Structural Model

The structural model was tested in SmartPLS 2.0. A bootstrapping procedure was used to generate significance and confidence interval. The size, the sign and the significance of path coefficients and the weights of dimensions of constructs were examined, respectively. Predictive validity of the model was assessed though the R^2 and structural path. R^2 values indicate the amount of variance in the construct that is explained by the path model (Barclay et al. 1995).

We followed existing literature and organized the constructs across the dimensions of an extend TOE framework and proposed each dimension as a second order construct. When we analyzed the data, we found that the technology attractiveness dimension was not significant. One of the reasons could be due to the relative newness of the RFID technology and its use for supply chain. Hence we decided to test an alternative model in which we replaced the second-order technology construct with its first-order constructs. We retained the other second-order constructs due to their extensive use in other technology infusion literature. We found that complexity and adoption cost are important for RFID infusion and overall, the model can explain more variance of RFID infusion (R^2 is higher for both RFID use and RFID implementation maturity in the revised model). The results and findings presented in this chapter relate to this revised model.

The results of the analysis for the structural model are presented in Table 12, 13 and Figure 7. In Figure 7, the results indicate that the research model explained 69 percent of the variance in performance from a SCM perspective. Similarly, 42 percent of variance in RFID implementation maturity and 75 percent of RFID use were explained in the model.

In the technological dimension, the results indicate that adoption cost is important for RFID infusion, specifically for RFID use and it is positively associated with RFID use. The study also finds that complexity is a significant facilitator for RFID infusion, specifically for RFID implementation maturity. Technology maturity and compatibility are not significant for RFID infusion.

H13A and H13B predicted the impact of organizational readiness on the extent of RFID implementation maturity and RFID use. The results support H13B, but not H13A, demonstrating the significance of organizational readiness on RFID infusion. H14A and H14B posited that influence of external pressure on the extent of RFID infusion. The results indicate that external pressure positively influences RFID implementation maturity but not RFID use. We hypothesized that trading partner readiness has impact on both RFID implementation and use, however the results only support the relationship between trading partner readiness and RFID use. Thus, H15B is supported, but H15A is rejected. Since we do not have H12A and H12B in the alternative model, we skip them.

As hypothesized in H16, the extent of RFID implementation maturity is significantly related to the extent of RFID use, so H9 is supported. However, we do not find that RFID implementation maturity has influence on firm's supply chain process performance. Thus, H17 is rejected. H18 predicted the impact of RFID use on firm's supply chain process performance and our results indicate that the impact is significant and strong. This finding is consistent with literature for technology use. As control variables, while find firm size has no impact on performance, product unpredictability has significant impact on the supply chain process performance.

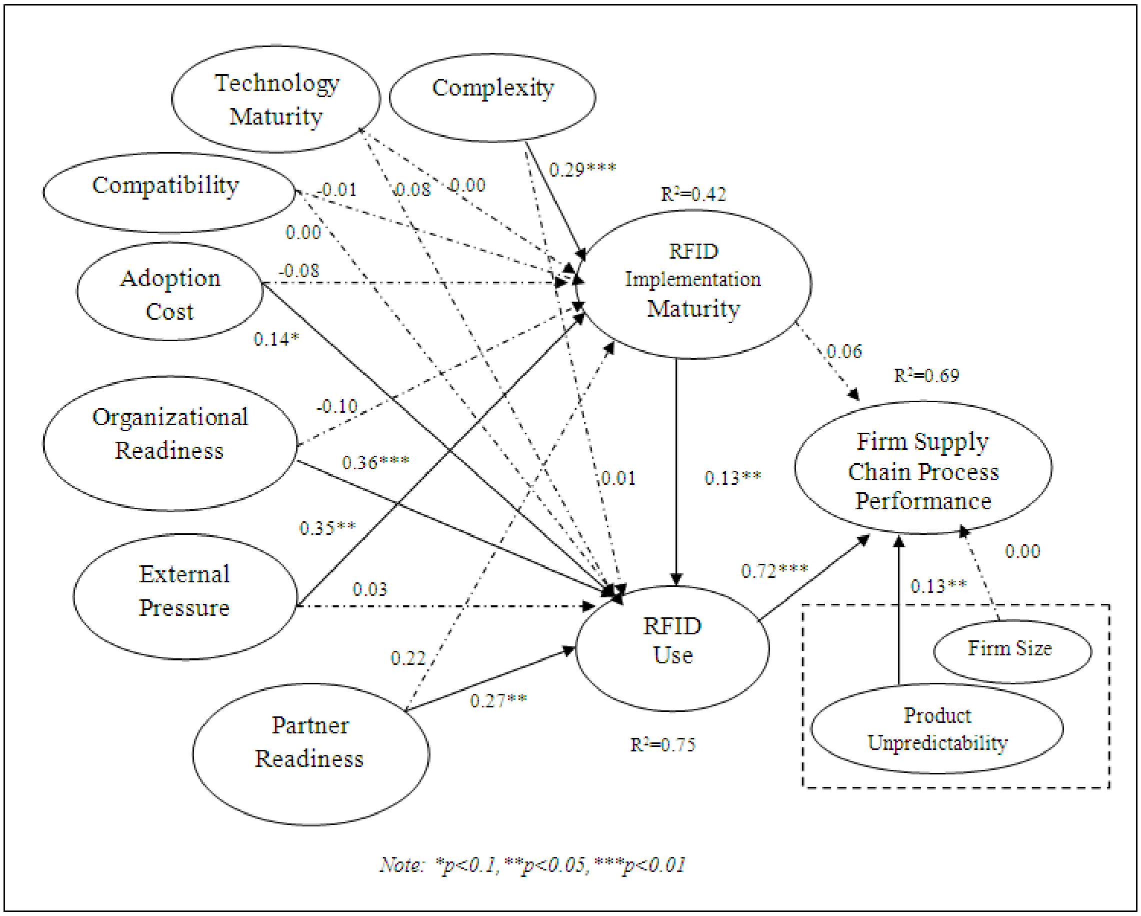

Figure 7: Results of Path Analysis

Table 12: Second-Order Constructs Conceptualization

	Weights	T Statistics	Significance
AC -> ORRD	0.43	4.87	***
ITS -> ORRD	0.64	7.55	***
CP -> EXPR	0.47	4.88	***
IC -> EXPR	0.61	6.81	***
CRDN -> PRD	0.50	4.86	***
PRCA -> PRD	0.61	6.18	***

****$p<0.01$

Table 13: Results of PLS Analysis-Path Coefficients

Path	Path Coefficients	T Statistics	Significance
CB -> IMPMT	-0.01	0.13	n.s.
CB -> USE	0.00	0.07	n.s.
COST -> IMPMT	-0.08	0.93	n.s.
COST -> USE	0.14	1.92	*
CX -> IMPMT	0.29	2.66	***
CX -> USE	0.01	0.09	n.s.
TM -> IMPMT	0.00	0.01	n.s.
TM -> USE	0.08	0.66	n.s.
EXPR -> IMPMT	0.35	2.36	**
EXPR -> USE	0.03	0.25	n.s.
ORRD -> IMPMT	-0.10	0.73	n.s.
ORRD -> USE	0.36	3.61	***
PRD -> IMPMT	0.22	1.61	n.s.
PRD -> USE	0.27	2.25	**
IMPMT -> PERF	0.06	1.34	n.s.
IMPMT -> USE	0.13	2.15	**
USE -> PERF	0.72	9.73	***
PDP -> PERF	0.13	2.60	***
AR ->PERF	0.00	0.09	n.s.

*Note: *p<0.1,**p<0.05,***p<0.01, n.s:nonsignificant*

Sub-dimensions underlying three second-order formative constructs were also examined and presented in Table 12. First, both of two dimensions: absorptive capability and IT sophistication for organizational readiness are found to be significant. Companies can make them ready to use innovative technologies by establishing high IT and information management capability. The weights on the subconstructs reveal their relative importance in determining the organizational readiness. IT sophistication (β=0.64, $p<0.001$) is more important than absorptive capability (β=0.43, $p<0.001$). Second, it is similar to external pressure, both of subconstructs: competitive pressure and industry collaboration are positive and significantly contribute to RFID implementation maturity, rather than RFID use, though industry collaboration (β=0.61, $p<0.001$) is more critical than competitive pressure (β=0.47, p<0.001). Third, as the subconstructs of trading partner readiness, both of coordination and RFID capability in trading partner are important for RFID use.

. Since PLS models are estimated through a series of multiple regression (Chin 1998), the power of PLS path models can be assessed by following a procedure similar to calculating power in linear regression (Chin and Newsted 1999). The construct with maximum number of predictors in this study has 9 variables. A post hoc power analysis was run in G*Power which offers a wide variety of calculations along with graphics and protocol statement outputs. Medium effect size of R^2 13% and F-test with alpha 0.05 were specified. With the sample size 169, the power of the test was 95%. We also tested the power of the multi-group comparison test through a two-tail t-test with alpha 0.05 and medium effect size, 0.5. When the two sample sizes were 100 and 69, the power was 88%. The results of post hoc power analysis indicate that the path analysis had an acceptable level of power to detect the effects that existed when medium effect sizes were assumed.

4.6 Discussion

IT use in firms and its business value are enduring questions in IS research. Despite a significant body of research, insights regarding the antecedents of IT use in different stages, the interrelationship between such use and the performance implications of use are lacking in the literature (Mishra et al. 2007). The purpose of this study is to understand RFID infusion in supply chains from two aspects and the antecedents and implications of such infusion in an integrative framework. The empirical results of the study lead to several significant findings and implications to research and practice.

4.6.1 Major Findings

Overall, the study finds support to examine RFID infusion and its consequence using factors addressing four dimensions. The study also confirms the two aspects of RFID infusion: implementation maturity and use.

FINDING 1. *The positive effect of adoption cost on RFID use suggests that high cost is not necessarily detrimental to technology diffusion because it drives firms with high cost of adopted applications to infuse the technology.*

First, in literature, adoption cost has been examined as a factor to influence adoption and argued that the less expensive the technology, the more likely it will be adopted. However, its link to technology diffusion is not clear. Our results show that once RFID is adopted, its relative high cost actually motivates organizations to more actively use it in order to make it cost-effective. The active use of RFID likely drives supply chain partners to implement and use RFID to maximize the benefits. The positive relationship between adoption cost and RFID use seems to suggest that at early stage of its diffusion, a new technology such as RFID can stay at a relatively higher costs if the benefits realized are greater down the line.

Although RFID has high costs, its benefits relative to the costs may be also high. Firms that find themselves having made higher investments in RFID than other firms may use the technology to a greater extent in order to derive benefits. Since the investment is already made, the focus could be on maximizing the utilization. The higher costs could also motivate these firms to push for RFID's integration with their trading partners in the supply chain. With extensive use along the supply chain, RFID technology can bring a huge amount of benefits which in turn influence RFID diffusion behavior within or across the supply chain. In short, when RFID is perceived to be more cost-effective for supply chain management, the high cost can drive organizations to use and integrate it with other IS applications, link with greater proportion of their trading partners and business transactions, thereby maximize RFID benefits.

FINDING 2. *Complexity shapes technology implementation because implementing a technology needs to overcome its complexity to successfully deploy it.*

Although prior studies observed that complexity discourages technology adoption and may lead to greater difficulty in its implementation and further diffusion, our study suggests that complexity can lead organizations to implement RFID in a higher level. In order to deploy an innovation, organizations must address and overcome its complexity. When organizations have high IT capabilities, technical and managerial, high complexity of an innovation will not stop them to successfully implement it; on the other hand, it may motivate the users to implement the technology quickly and completely. This scenario is supported in our dataset: the respondents' companies have high IT sophistication scores (average 4.1 out of 5 with STDEV 0.8). That means they have high IT use and management skills and will help them to reach a high level of RFID implementation.

In addition, we measure complexity in relation to the need for multiple platforms and user units. Higher levels of RFID implementation maturity means RFID is implemented in multiple functions and applied not just internally but also with multiple trading partners. So when a respondent perceives RFID complexity in the way we measured, their RFID implementation may have reached internal and external usage and involved multiple trading partners. That means their RFID implementation maturity is high.

FINDING 3. *Organizational readiness is important for RFID infusion, specifically for RFID use, suggesting that an organization's capabilities associated with IT and knowledge management facilitate RFID use.*

Organizational readiness has a positive and significant relationship with RFID infusion, specifically RFID use. This result aligns with the findings of previous research on technology adoption (Chwelos et al. 2001). Our research extends this finding to infusion stage of technology diffusion. The strength of the path coefficient on organizational readiness and its subconstructs (absorptive capability and IT sophistication) indicates that there are a number of necessary conditions that contribute to RFID use. That means even for motivated companies for RFID, they must have necessary technical and information ability and management skills to enable them to use RFID, after they have adopted RFID in their organizations activities. This may explains why there is the gap between substantial firm spending on IT and the really use of these technologies in practice. The gap is due to the lack of such necessary conditions before the technology is really used and is used in appropriate ways. Our study suggests that organizations should enhance their capabilities to use and manage IT and knowledge in order to reap from implementing new technologies.

FINDING 4. *External pressure is critical to RFID infusion, specifically for RFID implementation maturity, suggesting that RFID diffusion does need help from industry environments.*

It seems that external pressure is the only explanatory second order construct influencing firms to implement RFID and reach high maturity for its implementation. For external pressure, two dimensions are competitive pressure and industry collaboration which are found significant. Iacovou et al. (1995) also found similar results for EDI adoption in EDI initiators. In literature, competitive pressure was consistently found as a key factor to determine the overall level of external pressure with the absence of industry collaboration. Porter and Millar (1985) suggested that using an innovation can enable companies to alter the rules of competition, affect the industry structure, and leverage new ways to outperform rivals. In our sample, majority of companies are big ones so they have necessary resources and may more likely adopt RFID to create competitiveness.

Based on the unique features and status of RFID in SCM applications, we introduce industry collaboration into external pressure construct and it is surprising to find that industry collaboration has a higher weight than competitive pressure for external pressure construct. Our study is the first one to introduce industry collaboration in IT use research. When a technology is perceived to have quite potential to improve fundamental operation practice, such as barcode for retailing industry in the past, industry collaboration turns to more critical for its widespread use. Industry collaboration can encourage establishing a shared focus to drive RFID adoption and use. It can also put supply chain trading partners in the same industry together to address key issues, such as common agreed standard to promote RFID use. In this situation, these companies are not pure traditional competitors anymore, and there is a complex relationship between these companies: co-opetition in which companies compete and cooperate at the same time.

FINDING 5. *Partner readiness is a key determinant of RFID infusion, specifically for RFID use, suggesting that supply chain partner issues are critical for supply chain technology diffusion.*

Trading partner readiness is an important determinant of RFID infusion, specifically RFID use. In our study, trading partner coordination and RFID capability are two sub-constructs of the partner readiness for RFID infusion. Both of them are significant. Trading partner RFID capability implies the importance of network effect for RFID infusion. The result confirms that the value of a network technology is positively related to the size of the network (Katz and Shapiro 1986). When a supply chain trading partner also has RFID capability, firms will have stronger incentives to use RFID with this supply chain trading partner because of network effect. Our finding supports literature on network effect for Internet adoption study (Zhu et al. 2006).

In recent years, many manufacturing companies have changed their practices to not only promote internal coordination but also facilitate external coordination with supply chain partners (Bharadwaj et al. 2007). In a supply chain context, coordination among trading partners can means that they have processes in place to ensure that resources and actions are coordinated based on the partner inputs, capabilities, economies and needs. For example, a retailer and a manufacture share joint responsibility to implement the initiative of quick customer response. Coordination between trading partners also facilitate problem solving. For RFID use, there are many issues (e.g. cost allocation, information sharing) need to address between trading partners if they apply RFID along their supply chains. With coordination, these issues should be solved appropriately and engender trust and reciprocity between partners, and in turn lead to excelling in productivity and efficiency for RFID use.

FINDING 6. *RFID implementation maturity is positively associated with RFID use, suggesting that advanced RFID implementations provide value by encouraging greater RFID use.*

As two aspects of RFID infusion, RFID implementation maturity is positively associated with RFID use. On the one hand, when a firm implements RFID in a product line or multiple product lines through its supply chains, its RFID implementation maturity is high and it is likely for the firm to use RFID in multiple supply chain activities, such as inventory management, forecasting and ordering. To maximize benefits, it is important to implement RFID along supply chains. That means RFID system needs to integrate not only with internal information systems and databases but also with the information systems and databases in supply chain trading partners. To do so, cooperation and collaboration between supply chain trading partners turn to critical. On the other hand, it is not necessary that high level implementation maturity can lead to high level RFID use. We measure RFID use from breadth, depth and volume. Organization may use RFID extensively along one product line but only uses it in a small proportion of the entire product. In this situation, breadth and depth should be high but the volume may be low. In another scenario, a company may implement only RFID tags but through the whole product line or multiple product lines to meet the mandate from trading partner, such as Wal-Mart, so the use of RFID may be high in terms of volume, but its RFID implementation maturity is still low.

In addition, while the study does not find a direct significant link between external pressure and RFID use, the results indicate that RFID implementation maturity mediates the relationship between external pressure and RFID use. Compared with organizational readiness and trading partner readiness, it is easy to understand that external pressure contribute RFID use through RFID implementation maturity, which is an intermediate aspect of RFID infusion. As to organizational readiness and trading partner readiness, they are either internal capability or show direct connections with the organizations, so impact RFID use directly. However, external pressure (i.e. competitive pressure and industry collaboration) involves issues out of the control of organizations. For competitive pressure and industry collaboration, they only have indirect impact on RFID use. External pressure can only promote technology implementation, which in turn leads high level of technology usage.

FINDING 7. *The linkage between RFID use and RFID value is positive and RFID use is mediating the relationship between RFID implementation maturity and firm's supply chain process performance. This shows that actual usage is an important link to IT value.*

We confirm the linkage between RFID use and RFID value. The greater the extent of RFID use, the greater the likelihood that RFID adopters will create RFID capability, thereby contributing to create value. Through deeper usage RFID can create asset specificity to provide competitive advantage for its adopters. Both academic literature and industry reports have noted that business competitions are no longer purely between individual firms but rather between supply chains (Lambert and Cooper 2000, Straub et al. 2004). When RFID is used along supply chains, it creates competitive advantage for the entire supply chain. The significant link between RFD use and supply chain process performance also support our research design, in which use and value are assessed together in one model.

Our study also indicates only high degree of RFID usage is associated with improvement performance, but high RFID implementation maturity does not guarantee to improve performance. So, implementing RFID is not enough to significantly improve performance. Only when organizations are actually using RFID to conduct related supply chain activities can RFID have an impact on process performance from a SCM perspective.

4.6.2 Implications

This study results in several key insights for researchers and practitioners and will help better understand the factors and conditions that impact RFID infusion in a supply chain context.

From an academic perspective, this study is one of the first that empirically examine RFID infusion in supply chains. We define RFID infusion from multiple aspects: implementation maturity and use, which richens the understanding of RFID infusion in supply chain contexts. Because of the great potential of RFID for SCM and current diffusion status of RFID in this context, it is important for us to understand the drivers for RFID infusion and its consequence in practice. This study presents the first attempt to empirically examine RFID infusion in supply chains with a large dataset, compared to previous RFID studies.

Further, this study complements TOE framework with a new set of factors, technology maturity, absorptive capability, industry collaboration, partner coordination and RFID capability of trading partner for interorganizational technologies, such as RFID. Although there may be other traditional factors for technology infusion, our results suggest that it is critical to examine technology infusion based on the unique characteristics of technology use in practice. This study confirms the necessity of investigating RFID infusion in supply chain contexts. The data suggest that most of these new factors play important roles in explaining RFID infusion phenomenon in supply chain context. In this context, RFID is viewed as IOS-enable technology sharing some of features of IOS technology and can also be used with a single organization.

Furthermore, the study confirms that the linkage between implementation maturity and technology use. The idea of using RFID is very easy, as what we discussed in early chapter. However, implementing RFID in a supply chain context is not a simple task, for example selecting appropriate RFID tags, arranging appropriate locations of RFID readers, and addressing a huge amount of RFID information. Implementing RFID also means setting up the usage of RFID data for related activities. Plus, our results show that usage is shown as an important link to RFID value, which seems to be understudied in the IS literature (Zhu and Kraemer 2005). Our research model could be used by other researchers to investigate other supply chain technology use.

Finally, we have developed several constructs, including RFID implementation maturity, technology maturity, industry collaboration, trading partner RFID capability. After refining the instruments for data analysis and performing various reliability and validity tests, we believe that these constructs can be used in future RFID studies.

From a managerial perspective, these results have generated several significant implications. First, this study shows RFID use can significantly improve performance from a SCM perspective. More importantly, the study sheds light on ways to realize RFID value: not only simply implementing RFID but also using broadly and deeply. Although lack of business case is cited as one of major challenges for RFID diffusion, our study implies that if an organization can use it appropriately, its supply chain process performance can be significantly improved. This is especially important for retailing industry in which companies have been using multiple IT platforms over the years. It may be challenging for them to implement RFID, however retailing industry is one of the industries which can benefit most from RFID. Thus, retailers must develop successful RFID implementation plan by incorporating the important factors reported in our study and execute it appropriately for extensive use of RFID in order to reap great benefits from this technology.

Second, firms with less financial resources need to ensure that they conduct a comprehensive cost-benefit analysis for RFID applications. As shown in our study, organizations, unlike other adoption studies, adoption cost is positively associated with RFID use which significantly improves supply chain process performance. It indicates that RFID is high risk and high return technology. If organizations with less resource quickly reject RFID because of the high costs, they may lose an opportunity to significantly improvement their performance.

Third, potential value of RFID could be affected by organizational readiness, so managers need to assess new organizational characteristics (e.g. absorptive capability), as suggested by our empirical study, for RFID infusion. Effective RFID use depends on necessary business process reengineering which needs organizations to have capabilities to understand the needs of RFID application, design an appropriate plan to execute RFID implementation, and finally use RFID in their activities. It is important for organizations to have absorptive capability to access and assess technological opportunities and effectively learn from previous use of innovative technologies, in order to successfully implement and use RFID.

Fourth, our study reinforces the importance of trading partner issues for RFID diffusion, for example, trading partner selection for RFID use. Firms keen on enhancing RFID use are very likely to conduct business with its trading partner through RFID mode. If a large majority of a firm's trading partners lack RFID capability, the firm must anticipate problems in using RFID in its supply chain activities. In other words, an organization needs to be careful to select trading partner to implement and use RFID. In addition, it is critical to coordinate with supply chain trading partners for RFID use. The research findings suggest that supply chain trading partners should establish processes to ensure coordination and understand each other's capabilities.

Fifth, our study has highlighted the important link between RFID implementation maturity, RFID use and performance improvement. Like other technologies, implementing RFID just makes the technology ready to use and contribute to performance; organizations must extensively use the technology in order to reap the benefits. It is not uncommon that organizations may be detracted from learning and how to use existing applications effectively and chase the latest technologies to compete with other players in their industry. A new technology such as RFID becomes effectively only through gradual, careful and sustained implementation that provides organizations with tacit knowledge and the managerial skills necessary to use this technology efficiently and thus improve performance.

Finally, the results suggest RFID vendors and providers to actively engage in industry collaboration for RFID diffusion. They can encourage their customers to share their knowledge of RFID use with other players in order to reach a critical mass for full potential from RFID. They need to work closely with RFID adopters for overcoming related issues such as common standards.

4.6.3 Limitation and Future Research

First, some factors that potentially affect RFID infusion may have been omitted in our current study, even though it was based on current literature on technology infusion and RFID. If additional factors are identified, it may be interesting to test a more comprehensive model. We did not find any significant impact of technology attractiveness on RFID infusion; however, this dimension may turn to be significant if new factors are incorporated. Second, our sample may represent advanced RFID firm users, because the majority of sample companies are big ones. Third, our study presents a cross-sectional analysis of RFID infusion. So we cannot establish the causality of arguments. It would be interesting to collect longitudinal data to examine RFID infusion and its impact over a long period of time. Finally, this study focuses on the infusion of RFID but it might be useful to take a process-oriented view to examine the whole process of RFID diffusion in one study.

4. 7. Conclusion

Though RFID technology is attracting increased attention among researchers and practitioners, the critical factors that enable or inhibit its infusion are not very well understood in the IS and supply chain literature. Drawing upon DOI, RBV and the TOE framework and grounding our research in practice through expensive review of industry papers, we develop an integrative research model, which examines both antecedents and the relationship between RFID infusion and its consequence, firm supply chain process performance. To our best of our knowledge, this study is the first RFID infusion study which is theoretically and empirically rigorous and has accomplished such an investigation with a relatively larger dataset support in IS and SCM literature. Our research model and results suggest that organizational readiness, external pressure and trading partner readiness significantly influence RFID infusion. We also find that the impact of complexity and adoption cost on RFID infusion is positive. The results show that RFID implementation maturity is positively associated with RFID use which finally improves performance. These results contribute to an emerging stream of research to examine the phenomena of IT use and its performance impacts holistically.

CHAPTER 5: THE IMPACT OF RFID ON SUPPLY CHAIN PERFORMANCE: A SIMULATION MODEL

5.1 Introduction

RFID technology has been cited as “the best thing since bar-code” in managing retail chains (e.g. Economist 2003). Some industry reports claim that the potential benefits of RFID in supply chains will come in many forms, such as improved forecasts, improved product availability, better supply chain coordination, reduced inventory, reduced out of stock, and increased revenues. Accenture estimated that 100% of the labor cost in physical counting could be eliminated and the savings in receipt could be 6.5% (Lacy 2005); IBM’s estimate on inventory reduction was 5% to 25% (Economist 2003); and SAP (2003) estimated theft loss would be reduced by 40% to 50%. However, these reports were published by RFID consultants and system integration providers. It is common to find that these claims, such as reduced inventory and improved customer service level, were reported without describing the details of how these benefits are realized. Lee and Ozer (2007) argued that there is a credibility gap in how the proclaimed values of RFID are arrived and encouraged to close the gap by using more systematic research methods.

Recently, academic empirical research has studied the benefits of RFID in terms of out of stock reduction (e.g.,Hardgrave et al. 2005) and provides relatively more detail on how RFID can create value. However, these studies focused on specific retail chains, such as Wal-Mart, and may not be readily generalizable to other retail settings which are very different from Wal-Mart or METRO, a big retail chain in Germany.

In order to quantify RFID benefits, more accurate and reliable methods are desirable and will help practitioners to better estimate the true value of RFID. However, measuring the value of RFID is not an easy task (Dutta et al. 2007). Generally, there are three ways to evaluate the value of a new technology (Lee and Ozer 2007): (1) asking experts to subjectively provide their best estimates based on their knowledge and experience; (2) conducting in-depth case studies among some early adoptions and drawing inferences on the value of the new technology based on observations; and (3) starting with understanding how the new technology can affect the fundamental operations of a system, and modeling how the changes in the operating characteristics from technology implementation can improve planning and operational decisions, and what effects these improvements have on performance, thereby estimating the value of the technology. Industry reports and white papers have mainly applied the first two approaches to evaluate the value of RFID. However, it is more appropriate to use the third approach to study advanced technologies (e.g. RFID) with revolutionary in nature.

More importantly, the unique features of current RFID technology make studying its value more challenging than those of other innovation technologies such as EDI or bar code. Like bar code, RFID tag needs to be placed on the entities (e.g., individual products, boxes, cases or pallet, even trucks), however, the read rate of RFID tags vary on different types of products, such as metal or liquids. Some RFID tags can overcome the issue but the choice of appropriate tags also depends on the objectives of each business application for RFID adopters. The adoption cost of EDI can be seen as one time investment because the variable costs for using EDI can be ignored. RFID adopters need not only consider the initial investment (e.g. readers, software and training) but also continuously count variable cost for the use of RFID. Actually, the variable cost is important than initial investment. All these challenges offer opportunities for researchers to specifically investigate how RFID creates value with its unique features in SCM.

Majority of existing studies on RFID in supply chains are case studies or apply analytical approach (e.g. Delen et al 2007, Wamba et al. 2008, Tzeng et al. 2008, Rekik et al. 2009). Case studies provide insights of RFID applications in specific cases and analytical models offer more generalizable results. However, case studies are too specific to particular organizations and analytical studies need to be kept simple in order to find closed-form solutions. While simulation-based research on RFID in supply chains has increased, it is still very rare. Simulation model could represent the physical operational flows and one can then simulate the performance of a business system with or without RFID. This approach is in line with Lee and Ozer's (2007) call to investigate the value of RFID from a ground-up approach. In other words, simulation offers an appropriate tool to model the detailed operating characteristics and dynamics of a system and help better understand RFID effects.

In this dissertation, Chapter 4 has empirically investigated RFID use and its impact on firm performance with data collected from supply chain professionals. Now, Chapter 5 develops an analytical model that links the underlying operating characteristics of a supply chain with the re-order decisions, firm performance, and supply chain performance, from inventory management perspective. The detailed operational models describe where and how RFID can address inventory inaccuracy problem in inventory system, so the quantification of RFID impact is performed accurately. Since the analytical model is too complicated for closed-form solutions, the study applies a simulation approach to solve the models.

Specifically, the objectives of this study are to address the following issues: (1) *How does RFID eliminate or reduce the inventory inaccuracy, and consequently improve firm performance and supply chain performance?* (2) *To what extent does product type impact RFID value creation, based on (1)? and* (3) *To what extent does RFID read rate that represents RFID perfection status impact the performance and what is the relationship between them?*

This study extends current RFID value research in several ways. First, the study considers detailed operating characteristics of an RFID-enabled supply chain and captures RFID value at a more granular level. Second, the study investigates RFID value in a multi-echelon supply chain with different types of products in multiple time periods. All these features differentiate our study from existing literature, most of which examines single item, single manufacturer and single retailer in supply chains. Third, this research takes into account the technology development status of RFID and this consideration will position our study in a more realistic setting, compared to existing literature where RFID was treated as a perfect technology providing 100% supply chain visibility. Fourth, the study considers RFID's cost in a complex supply chain setting and measures RFID value from total gross profits (henceforth, profits) at both firm and supply chain levels. Overall, we believe that our study is a step toward concretely measuring the value of RFID in supply chains and can be used with other research on supply chain technologies to better understand the management of inventory inaccuracy problem.

For practitioners, our study provides important implications for RFID implementation and value creation. First, our research offers a model to evaluate RFID value from an inventory management perspective. Further, companies must recognize that product type is a critical issue to evaluate when they consider RFID. RFID advocates, such as Wal-Mart have started a segmented approach to implement RFID, thereby not forcing hundreds of suppliers to simultaneously implement RFID. Next, managers should consider RFID from operation strategy level. For instance, if a company's business strategy is to reduce cost, probably RFID can help more. But, if its strategy is to satisfy its customers at whatever costs it will take, RFID may not be helpful at least from inventory inaccuracy perspective. The company can just keep high levels of inventory to satisfy customers. Furthermore, as a supply chain, all trading partners should consider if it really is necessary to install RFID across the supply chain or is a partial RFID implementation sufficient for all parties to benefit? Our study shows there are differences between partial and full RFID implementation cases and partial case is better than full implementation for some products, at least from an inventory accuracy perspective. Finally, RFID read rate does matter for its value creation. So companies need to seriously select appropriate RFID tags and readers in order to meet their objective from RFID use.

5.2 Literature Review

Since RFID applications in supply chains are relatively new, the related literature is still limited. This chapter reviews the existing literature from two aspects: industries reports and academic research. Since chapter 2 has broadly discussed RFID benefits in supply chains, this chapter focuses on the impact of RFID on inventory management.

5.2.1 RFID in Inventory Management

From an inventory management perspective, inventory inaccuracy, which is the difference between inventory record and physical inventory, is a critical issue. DeHoratius and Raman (2008) reported that 65% of the inventory records in retail stores were not accurate in their case study in which 370,000 inventory records were examined from 37 stores of an important retailer. Raman et al. (2001) found that such inaccuracies could reduce 10% of profit because of higher inventory cost and lost sales.

RFID holds a promise to bring significant benefits to organizations from inventory management perspective. Among the benefits, labor cost savings, less shrinkage, and higher visibility are the most visible ones. While many organizations have automated their inventory management by using information systems, inventory level in information systems are not matched with physical inventory level (Fleisch and Tellkamp 2005), and not all the physical inventory are available to sell. In the stores of a global retailer, the best performing store has with only 70-75% of its inventory records match with its actual inventory and on average, the inventory accuracy in the stores of the retailer is only 51% (Kang and Gershwin 2005). After relaxing the requirements by allowing the inventory record within ±5 units, the average accuracy of the stores only increases to 76%.

Among different sources for inventory inaccuracy in supply chains, inventory shrinkage (i.e. stock loss) is always a major issue, especially for retailers. National Retail Security Survey (2010) reported that average shrinkage accounts for 1.8% of annual sales in 2010, and the number for supermarket/grocery store is even higher at 3.12%. The main causes of shrinkage are internal and external theft, accounting for about 80% of shrinkage (NRSS 2002; 2005). In an RFID-enabled system, accurate inventory record can reduce the opportunity for these mistakes and prevent or discourage theft. Alexander et al. (2002) estimated that RFID can help reduce two third of shrinkage at manufacturers and by 47% at retailers. While these studies provide some evidence of RFID value, they are either based on subjective judgment of experts or a survey result, so they are considered speculative (Dutta et al. 2007).

Misplacement is another main source for inventory inaccuracy. Misplaced items are those that are put in a location where paying customer or employees cannot find them, and hence they are actually not available for sales (Fleisch and Tellkamp 2005). For example, a customer takes a skirt to a fitting room to try it on, but he/she eventually leaves the item in the fitting room and walks away. The next coming customer who looks for the same skirt will not be able to find it. Raman and Ton (2004) found that 3.4% of the SKUs had been misplaced in a specialty retailer, which led to stock-out occurring just because inventory was not accessible for sales. Misplacement also affects salable inventory in two ways (Atali et al. 2006): it reduces salable inventory during periods between inventory counts and increases the salable inventory when misplaced items are returned to stock after inventory count. It changes salable inventory but keeps physical inventory without and change. There is still holding cost for those misplaced items. Misplacement is viewed as the most challenging part for inventory inaccuracy.

RFID can identify where the misplaced items are in real time and lead to returning the misplaced items to their correct locations. Thus, RFID can help reduce forecast errors, make better decision on orders, and reduce inventory. For inventory management at retailers, AT Kearney (2004) estimated a 5% inventory reduction, while SAP (2003) estimated a reduction of 8%-12% by reducing inventory errors due to misplacement. Booth-Thomas (2003) cited an Accenture study showing 10%-30% inventory reduction in the supply chain. Neimeyer et al. (2003) mentioned that McKinsey's estimates on inventory reduction ranged from 20%-40% from a RFID enabled vendor-managed inventory (VMI).

Other sources for inventory inaccuracy include transaction errors, which typically occur at inbound and outbound sides of the facility (Kang and Gershwin 2005). There may be a difference between shipment record and actual shipment for inbound side and scanning error at sales (outbound side). Transaction errors only affect inventory record but leave physical inventory unchanged. Incorrect product identification, such as wrong labels, is another source of inventory inaccuracy. Among these error sources of inventory inaccuracy, shrinkage (i.e. theft) and misplacements are most severe and thus are studied in the dissertation.

For inventory management, it is important to determine replenishment policy to maximize profits along with achieving high customer satisfaction. In inventory control systems, the most critical decisions are (1) review time for the inventory stock, (2) reorder point and (3) quantity to order. In literature, there are several replenishment policies under periodic review (R, S) or continuous review (s, S). Inventory managers or automated inventory management systems make replenishment decisions based on inventory position in information systems (Sarac et al. 2010). RFID can improve the inventory accuracy in information systems in real time and make companies rethink their order policies, in terms of review time, order point and order quantities.

5.2.2 Academic Literature on RFID Value

After reviewing extant literature that addresses inventory inaccuracy problem by using RFID, I identified three streams for RFID value research, shown in Table 14.

Table 14: Literature Review on RFID Value Research

<table>
<tr><th>Research Focus</th><th>Research Methods</th><th>References</th><th>Summary and Main Limitations</th></tr>
<tr><td>Understand difficulties and efficiency of RFID integration and evaluate associated costs and benefits for RFID applications in supply chains.</td><td>Empirical, especially case-studies</td><td>Delen et al. (2007), Ngai et al. (2007), Wamba et al. (2008)</td><td rowspan="3">Single case or a few cases

One or two levels of supply chain in a single period

One or two sources of errors
Cost is the main measure

One type of product

RFID is viewed as perfect

Naïve system as benchmark</td></tr>
<tr><td>Model operating characteristics of a business system to investigate how RFID could impact basic business control policies.</td><td>Analytical, operation research</td><td>Atali et al. (2006), Kok and Shang (2007), Gaukler et al. (2007), Rekik et al. (2009)</td></tr>
<tr><td>Model detailed operating characteristics and dynamics of a system to help better understand RFID effects in more complicated settings.</td><td>Simulation approach</td><td>Lee et al. (2005), Kang and Gershwin (2005), Fleisch and Tellkamp (2005), Wang et al. (2008)</td></tr>
</table>

First, empirical studies use the data observed in experiments with RFID technology to explore the impact of RFID in different industry settings. A majority of existing literatures are case studies, which provide understanding of the difficulties and efficiency of RFID integration and associated costs/benefits of RFID applications in supply chains. Delen et al. (2007) conducted a case study in which actual RFID data collected from the cases shipped from one supplier to a retailer was used to assess the value of RFID. They identified performance metrics that can be computed from RFID readings and discussed how these measures can help improve logistical performance at a supply chain operation level. Ngai et al. (2007) studied RFID integration in a mobile commerce system. By developing an RFID prototype system on a local depot to analyze the impacts of RFID system on locating, tracking, and managing the containers, they found that RFID helps improve visibility, decrease errors and accelerate operational processes. Wamba et al. (2008) investigated RFID impact on B2B e-commerce and found that RFID can cancel, automate or trigger some business processes and foster a higher level of information sharing between supply chain partners. By examining nearly 370,000 inventory records from 37 stores of one global retailer, DeHoratius and Raman (2008) found that 65% inventory records are inaccurate and suggested RFID can help improve the issue.

The second stream of RFID application research uses analytical, operation research models to represent operating characteristics of a business system and investigates how RFID could impact basic business control policies. Kang and Gershwin (2005) developed an analytical and simulation model of a single item inventory system. They found that even a small rate of stock loss undetected by the information systems can lead to inventory inaccuracy that disrupts the replenishment process and creates severe out-of-stocks. However, their study is limited because it considers only stock loss for a single item for a single retailer. Atali et al. (2006) also studied a single item periodic review inventory problem for a retailer but they use shrinkage, misplacement and transaction errors as the sources of inventory inaccuracy in their model. Kok and Shang (2007) studied joint inventory replenishment and counting policy problem and found that there exists a threshold inventory level for the counting decision.

Gaukler et al. (2007) analyzed the costs and benefits of an item-level RFID application in a supply chain including one manufacturer and one retailer. They examined two different scenarios: a centralized case with and without RFID at item level and a decentralized wholesale prices contract case with item level tagging. In the centralized case, they derived the break-even tag price for any given set of model parameters and in the decentralized case they investigated how tag cost should be shared between the supply chain partners. They found that cost sharing of RFID tag does not matter if the manufacturer is dominant in the supply chain. However sharing RFID tag cost is important when the retailer is the leader in the supply chain. This study is limited to only considering a two level supply chain at a single period. Dehoratius et al. (2008) also analyzed a two-level, multi-period inventory system and demonstrated that a Bayesian inventory record is an efficient method to provide good replenishment policies.

Zhou (2009) modeled the value of RFID information visibility at item-level in a manufacturing setting. The study showed that the benefits of RFID item-level information visibility is a function of the scale of the information system, the distribution of the sample spaces, the revenue functions and the control function. Rekik et al. (2009) analyzed only the role of theft in retail stores for information inaccuracy problem. They provided the optimal inventory policy for three approaches examined in their study and proposed a critical tag cost which makes RFID implementation cost-effective. Most of these analytical studies above consider simplified supply chains that contain a single product, a single period at a single or two levels (e.g. retailer). They also assumed RFID is a perfect technology that can eliminate all inaccuracy problems.

The third research stream makes use of simulation models to assess RFID value (e.g. Lee et al. 2003; Kang and Gershwin 2005; Fleisch and Tellkamp 2005). Lee et al. (2003) explored potential benefits of RFID in inventory reduction and service level improvement. In their more recent study, Lee et al. (2005) conducted a quantitative analysis and found that RFID can reduce the distribution center inventory by 23% and completely remove backorders. They also showed that RFID can help reduce order quantity and lead to reducing inventory level of distribution center up to 47%. This study is limited since the benchmark case is where the inaccuracy problem is ignored by managers and it assumes that the RFID read rate is 100%. RFID read rate is a “term usually used to describe the proportion of tags that can be read accurately within a given period” (RFID Journal).

In Kang and Gershwin (2005), they examined the effect of the shrinkage as a source of inventory error on lost-sales, through a simulation model. They found that even a small rate of stock loss undetected by inventory information system can lead to severe out of stock problems, and consequently loses sales. The limitations of their study are that it only examined the impact of the shrinkage as inventory error and investigated their research question within a single firm. They ignored other errors sources such as misplacement that also has important impact on inventory inaccuracy problem. However, they did provide some good methods to compensate for inventory inaccuracy.

Fleisch and Tellkamp (2005) is the first attempt that evaluated the impact of multiple inventory error sources in a three level supply chain and claimed that RFID as a new technology can improve inventory accuracy. Three main sources of inventory inaccuracy are modeled: theft, unsaleable items, and process quality. While it is a good first attempt, it has its limitations. First, they did not explicitly model the role of RFID in their systems and did not consider cost of new technology such as RFID in their study so these drawbacks make their results weak, in terms of the performance measure (i.e. total operating cost of the supply chain used in their study). Second, they applied a naïve system (i.e. without RFID and totally ignored discrepancies in inventory) as the benchmark to evaluate RFID value. Third, they considered inventory inaccuracy problem can be 100% solved with new technology. With this benchmark and assumption, the value of RFID could be over-estimated (Lee and Ozer 2007).

Based on a case of a well-known LCD monitor manufacturer in Taiwan, China, Wang et al. (2008) simulated the impact of an RFID system on the inventory replenishment and examined its global operations and logistics operation. They found that the RFID-enabled pull-based supply chain can effectively achieve a 6.19% decrease in the total inventory cost and a 7.60% increase in inventory turnover rate.

Lee and Ozer (2007) provided an excellent review for ongoing research on RFID value studies and concluded that credibility gap of the value of RFID exists and solid model analyses are needed to fill the gap. From an inventory management perspective, RFID has two distinct values: visibility and prevention. However the prevention function is rarely studied in existing literature (Lee and Ozer 2007).

Based on the literature review, investigating RFID value through modeling more errors sources of inventory inaccuracy in supply chain wide is desired (Kang and Gershwin 2004, Fleish and Tellkamp 2005). Modeling and studying the profit can bring additional benefits to RFID study for inventory inaccuracy problems (Atali et al 2005). Setting up an appropriate benchmark is important when assessing the value of RFID (Lee and Ozer 2007). The chapter takes all these suggestions into account when investigating the impact of RFID in supply chains and contributes to literature with the more complete and realistic scenarios for the value of RFID in supply chains.

5.3 Problem Description

To investigate the value of RFID in supply chains, this study considers a three level supply chain including a manufacturer, a distributor and a retailer in T periods, with different products. This research setting differentiates the present study from most of existing literature which analyzed single-level supply chains and/or in a single time period and/ or for a single product type. Figure 8 shows the configuration of the supply chain in this study. The retailer places orders and receives products from a distributor, which obtains the products from the manufacturer in order to fulfill the retailer's demands. Theft and misplacement occur and cause inventory accuracy problem at each player of the supply chain. The supply chain system is focused on RFID application in inventory tracking and replenishment function of inventory management process, specifically in the distribution of finished goods.

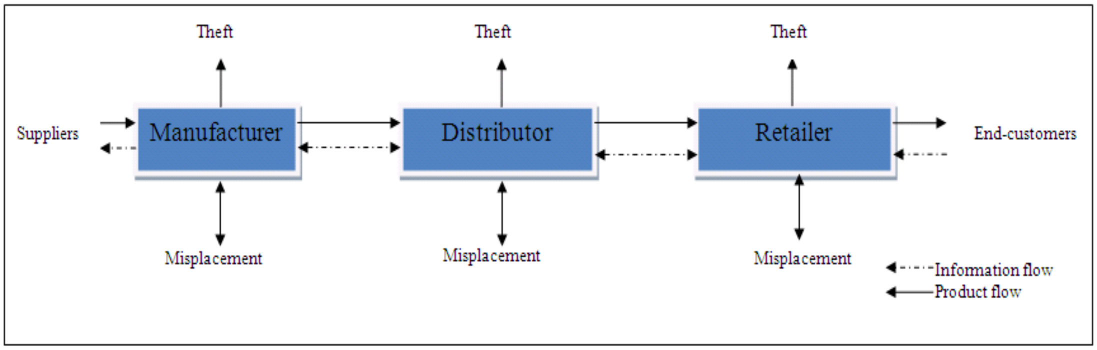

Figure 8: A Supply Chain in the RFID Impact Study

In this study, the selected products have different average demand, demand variability and shrinkage/misplacement problem. This study intentionally examines the impact of product type on the value of RFID and helps understand which type of product is more suitable to implement RFID in a supply chain setting. Practitioners also think that RFID may not be valuable for all product categories (IBM and A.T. Kearney 2004). Intuitively, one may think that a product with a high demand will benefit more from implementation of RFID. However, there is no study systematically investigating the relationship between product demand and RFID value. Therefore, the question in this chapter is how different products influence the benefits from RFID, in terms of average demand, demand variability and inventory inaccuracy problem.

In this research, the retailer faces a certain end-customer demand in each period t. The demand from end-customer is a paying demand because customers will pay money for the product. The retailer can fulfill customer demand as long as enough products are in stock (i.e. there is no difference between shelf inventory and backroom inventory). The study assumes that end-customers will walk away without purchasing if their demands could not be fulfilled immediately. That means these are lost sales for the retailer. Since this study considers a retail supply chain environment, the lost sale penalty is more realistic, compared to taking backorder assumption for unsatisfied demand in existing literature (e.g. Lee at all 2004). In each period, the retailer places an order based on inventory and outstanding orders under a replenishment policy (s, S) if necessary. The focus of the study is to examine the difference between supply chain systems with RFID and without RFID, in terms of supply chain performance. The retailer shares end-customer demand with the distributor and the manufacturer.

For the distributor, it tries to fulfill incoming orders from the retailer. If the order could not be fulfilled, the distributor will enter the order backlog and will fulfill it in a future period. The assumption of considering backorder for the distributor also makes our model closer to real world case. In each period, the distributor places its order to the manufacturer, based on its replenishment policy (s, S), as well as its inventory, backorders and outstanding orders placed in previous periods.

The manufacturer tries to fulfill the order from the distributor, if possible. Orders that could not be satisfied immediately will be entered in order backlog for production and will be delivered in a future period with a lead time. The manufacturer produces the product according to its current inventory and backorder, as well as the productions in previous periods under its production policy.

During all the processes discussed above, inventory errors, such as theft and misplacement occur and lead to inventory inaccuracy problems along the supply chain. Every party of the supply chain faces the inventory inaccuracy problem and consequently suffers inefficient inventory management, higher inventory levels and poor customer service. Overall, supply chain performance is curtailed.

Because of the unique features of RFID, this technology can be used to eliminate or at least reduce inventory inaccuracy problems. Among the inventory error sources discussed in the early section, this study focuses on theft and misplacement for inventory discrepancy problem in the given supply chain.

The present study is exploratory in nature. The purpose of the present study is not to provide conclusive evidence of the impact of inventory inaccuracy, but to understand the mechanism by which RFID can impact supply chain performance. Specifically, we are interested in investigating how RFID affects different sources of inventory errors and thereby improves performance of each party in the supply chain and the entire supply chain. It is important to understand that when one of the parties in the supply chain installs RFID tags to the product, only the downstream parties benefit directly from the RFID information. Any benefit to upstream parties is due to the indirect effects of more efficient ordering from the downstream parties.

Hence, to gain maximum insights from the simulation, we pick 5 scenarios that represent two benchmark scenarios and three configurations of RFID implementation scenarios, based on the extent of RFID implementation and its technology perfection. Table 15 presents the scenarios and detailed information are provided in later section.

Table 15: Five Scenarios in RFID Impact Study

Scenario	Model	Description
Scenario 1	Base case[2] without RFID	Barcode or the similar identification technology is used, inventory inaccuracy problem exists, and the inventory inaccuracy is ignored by managers and inventory control system.
Scenario 2	Full RFID[3] implementation	RFID tags are installed on products by the manufacturer and used by all the downstream parties of the supply chain.
Scenario 3	Partial RFID[4] implementation	RFID is installed by the distributor; only the distributor and the retailer use RFID technology but the manufacturer may also benefit from more accurate order information.
Scenario 4	Informed[5] system without RFID	Inventory manager is aware of inventory discrepancy and uses the historical data to adjust inventory record for ordering in each period.
Scenario 5	Perfect RFID[6] Implementation	RFID tags are installed on products by the manufacturer and used by all the downstream parties of the supply chain. RFID is perfect technology and no cost of using it.

Scenario 1: Base case. In this case, barcode or the similar identification technology is used, inventory inaccuracy problem exists, and the inventory inaccuracy is ignored by managers or inventory control system. This model helps understand the dynamic and stochastic behaviors of the supply chain and establish the baseline for examining RFID value in a supply chain. Based on empirical and survey analyses, most inventory management systems in practice apply ignorant replenishment policies (Atali et al. 2006).

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[2] This chapter uses “o” to represent the base case in the notation.
[3] This chapter uses “*” to represent full implementation of RFID in the notation
[4] This chapter uses “#” to represent the partial implementation of RFID in the supply chain.
[5] This chapter uses “’” to represent the informed case.
[6] This chapter uses “&” to represent the perfect RFID case in the supply chain.

Scenario 2: Full implementation with RFID. In this case, full RFID implementation means that RFID tags are installed on products in the most upstream stage of the supply chain, the manufacturer and are used by all the downstream parties of the supply chain. Any developing technology is perfected over time. This scenario models this current status of RFID development and views RFID as an imperfect technology for supply chain application. That means RFID read rate cannot reach 100% so RFID data is then not 100 % correct. In this case, theft can be detected and corrected at the end of each period of the system. However, not all the misplaced items can be detected by RFID technology because of its imperfect situation and only the detected misplaced items are returned to correct locations at the end of each period. Generally, inventory record is not perfectly aligned with salable inventory at the end of every period.

In this study, shrinkage is mainly represented by theft because 80% shrinkage is from customer or employee theft, based on NRSS in 2005. The study also assumes that each product needs only one RFID tag throughout the entire supply chain, so the costs of the tags can be shared by all the parties in the supply chain.

Scenario 3: Partial RFID implementation. In this scenario, RFID is considered to be installed by the distributor, rather than the most upstream party, the manufacturer; so only the distributor and the retailer use RFID technology to reduce inventory errors for their inventory management but the manufacturer may also benefit from more accurate orders in the system. The partial implementation scenario helps understand how increased inventory accuracy in one party or two parties of the supply chain impacts the performance of the other party in the same supply chain. It is also interesting to compare partial implementation with RFID to full implementation in order to examine supply chain benefits of each party in the supply chain with different RFID implementation. As to RFID itself, the scenario still assumes it is an imperfect technology.

Scenario 4: Without RFID, there are still other methods which can be used to compensate inventory inaccuracy problem. In Scenario 4, the dissertation assumes that inventory manager is aware of inventory discrepancies and would like to use the historical data to update inventory record at end of each period (Atali et al. 2006). The results are compared to those from other scenarios. This scenario enables us to get a real incremental value of RFID and not confound it with a smarter system which applies an adjustment without using RFID. Lee and Ozer (2007) stated it will be a long time for many systems to have RFID for their SCM, this study also provides a way to improve the performance of such systems.

Scenario 5: In this case, the supply chain is the exact same to the one is Full RFID implementation scenario, except that RFID is set as a perfect technology with 100% read rate without costs. In this scenario, RFID can provide the complete visibility of inventory inaccuracy problem in the supply chain. It means that all theft can be detected and all misplaced items can be detected and returned to the right place at end of each period. This scenario is used as an extreme case to show the maximum benefit from RFID and also helps verify our findings with prior research.

5.4. Simulation Models

To explore how RFID affects supply chain performance through improving inventory accuracy at each player of the supply chain, this dissertation models a three level supply chain with different products in T simulation periods. The research problem is modeled by using discrete event simulation which generally provides more information about the system.

5.4.1 Notation and Assumption

The following notation scheme is used in the chapter to develop simulation models. For the set of notations specified for retailers, there are corresponding sets for the distributor and the manufacturer.

T: Total number of periods

t: Time period

L: Lead time for every party in the supply chain, constant number of periods, can be customized at each party

$D_{r,t}^{(.)}$: Demand at period *t* for retailer r and (.)$\in (o,\ *,\ \#,\ ')$ represents the demand in base case, full RFID case, partial RFID case, and informed case, respectively

$A_{r,t}^{(.)}$: Paying customer demand at period t, (.)$\in (o,\ *,\ \#,\ ')$

$G_{\eta,t}^{(.)}$: Shrinkage (i.e. theft) demand at period *t*, for party $\eta \in (r, d, m)$, *r* for retailer, *d* for distributor, and *m* for manufacturer, (.)$\in (o,\ *,\ \#,\ ')$

$K_{\eta,t}^{(.)}$: Misplacement demand at period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$\hat{I}_{\eta,t}^{(.)}$: Inventory record in information systems at the beginning of period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$I_{\eta,t}^{(.)}$: Salable inventory at the beginning of period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$B_{\eta,t}^{(.)}$: Cumulative misplacement error since last counting at the beginning of period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$Q_{\eta,t}^{(.)}$: Cumulative shrinkage error since last counting at the beginning of period t, $\eta \in (r, d, m)$, $(.) \in (o,\ *,\ \#,\ ')$

$k_{\eta,t}^{(.)}$:Actual misplacement during period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$g_{\eta,t}^{(.)}$:Actual shrinkage during period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$N^{(.)}$: Counting cycle length in different scenarios, (.)$\in (o,\ *,\ \#,\ ')$

$O_{\eta,t}^{(.)}$:Order placed at the beginning of period t, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

($s_{\eta}^{(.)}, S_{\eta}^{(.)}$): Replenishment policy for each party, $\eta \in (r, d, m)$, (.)$\in (o,\ *,\ \#,\ ')$

$a_{r,t}^{(.)}$: Realized sales for the retailer in period t, (.)$\in (o,\ *,\ \#,\ ')$

$p_{\eta}^{(.)}$: Paid price for product per unit, $\eta \in (r, d, m)\ and\ (.) \in (o,\ *,\ \#,\ ')$

c_{η}: Order cost per unit per period, $\eta \in (r, d, m)$

h_{η}: Holding cost per unit per period, $\eta \in (r, d, m)$

z_{η}: Penalty for lost sales/backorder per unit per period, $\eta \in (r, d, m)$

$c_{\eta,c}$: Physical counting cost per time, $\eta \in (r, d, m)$

$c_{\eta,q}$: One time cost per unit for shrinkage items after each physical counting, $\eta \in (r, d, m)$

c_g: RFID tag cost per unit

α: The proportion of RFID tag cost shared by the retailer in the full RFID implementation scenarios

β: The proportion of RFID tag cost shared by the distributor in the full RFID implementation scenarios

$\alpha^{\#}$: The proportion of RFID tag cost shared by the retailer in the partial RFID implementation scenario.

ω: RFID tag read rate

$DL_{d,t}^{(.)}$: Delivery from the distributor to the retailer at the beginning of period t, $(.)\in(o,\ *,\ \#,\ ')$

$DL_{m,t}^{(.)}$: Delivery from to the manufacturer the distributor at the beginning of period t, $(.)\in(o,\ *,\ \#,\ ')$

$R_{r,t}^{(.)}$: Received products at the retailer at the beginning of period t, $(.)\in(o,\ *,\ \#,\ ')$

$R_{d,t}^{(.)}$: Received products at the distributor at the beginning of period t, $(.)\in(o,\ *,\ \#,\ ')$

$BL_{d,t}^{(.)}$: Backorder taken by the distributor at the beginning of period t, $(.)\in(o,\ *,\ \#,\ ')$

$BL_{m,t}^{(.)}$: Backorder taken by the manufacturer at the beginning of period t, $(.)\in(o,\ *,\ \#,\ ')$

$M_{m,t}^{(.)}$: Production amount for the manufacturer in period t, $(.)\in(o,\ *,\ \#,\ ')$

Assumptions:

1. Demand during zero salable inventory will result in lost sales at the retailer.
2. End-customer will not ask help from employee if he/she cannot find product.

3. In case of insufficient inventory, demand/order will be backordered at the distributor and the manufacturer.
4. Lead time is stable and constant, but configurable to each party of the supply chain.
5. Manufacturer's supplier has infinite capacity.
6. Expediting backlog amounts is not included in the model. In other words, when a party may have the inventory available to ship, backlog remain unfulfilled until the next order comes.
7. No discount for future cash flow.

5.4.2 Supply Chain Scenarios

In this section, each scenario is modeled and explained, respectively. Every party of the supply chain starts from satisfying demand to gain profits.

5.4.2.1 Base Case^{o}

After an end-customer arrives at the retailer, he/she finds a product and can act in three different ways: he/she can go to a cashier and buy the product; he/she may change his/her mind and just put the product in a wrong shelf and walk away, and he/she can also steal the product. If the customer cannot find the product he/she is looking for, he/she will not ask employees for shelf replenishment. So demand for the product is grouped under third classes: paying customer, theft and misplacement. First, let $D^{o}_{r,t}$ be the random end-customer demand for the retailer during period t. $A^{o}_{r,t}$, $G^{o}_{r,t}$ and $K^{o}_{r,t}$ denote demand from purchase, shrinkage and misplacement for the retailer during period t in the base case, respectively. Among the three demands, only purchasing demand incurs a penalty cost if it cannot be satisfied. That means lost sales.

There are still holding cost for theft and misplaced items. When an inventory counting is conducted at the end of a certain period, the misplaced items are discovered and returned to salable inventory. Inventory counting may be done to increase inventory accuracy or just comply with legal requirements.[7] Unlike misplacements, theft changes physical and salable inventory but leaves inventory record unchanged. Theft can be detected during physical counting but cannot be returned to inventory after physical counting. These accumulated errors due to misplacements and shrinkage since last inventory counting period are denoted by $B_{r,t}^{o}$ and $Q_{r,t}^{o}$. Physical counting is conducted every N periods, $T \in \{N, 2N, 3N, \dots\}$. In the model, $\hat{I}_{r,t}^{o}$ is defined as on-hand inventory record for the retailer and $I_{r,t}^{o}$ is defined as salable on hand inventory at the beginning of period *t* before a replenishment order is placed.

The sequence of events in the retailer is as follows.

(1) At the beginning of period *t*, inventory manager/automatic inventory control system in the retailer reviews the inventory position and places an order $O_{r,t}^{o}$ to the distributor by following a replenishment policy (s_r^o, S_r^o), if necessary. The delivery arrives for the order placed at period t-L. L is the lead time, a number of periods. The order cost per unit is denoted as c_r.

(2) During period *t*, sales $a_{r,t}^{o}$ and inventory errors (theft $g_{r,t}^{o}$ and misplacement $k_{r,t}^{o}$) take place.

(3) At the end of period *t* or says the beginning of period *t+1*, holding cost occurs based on on-hand inventory record including misplaced items and theft and h_r denotes the holding cost per unit per period. Cost from lost sales also occurs if there are

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[7]A taxpayer without a perpetual inventory system must take a physical count at year-end to determine costs of goods sold.

unsatisfied end-customers and z_r denotes lost sales cost per unit per period. However, there is no cost for unmet demand from non-paying customers.

(4) If period *t* is a counting period, a physical audit is conducted at the end of the period. So in this period, the inventory record is reconciled: inventory errors are corrected and all misplaced items are found and returned to salable inventory. Otherwise, inventory errors are accumulated continuously.

Based on Atali et al. (2006), the formulation for the retailer in the base scenario is as below.

At the beginning of period *t*, the retailer reviews the inventory position under the replenishment policy (s_r^o, S_r^o) and places an order if necessary. The retailer makes the order decision based on inventory position under (s_r^o, S_r^o). Otherwise, no order will be placed. After that, the retailer receives products $R_{r,t}^o$ at the beginning of period *t*, which was shipped from the detailer to the retailer in period *t-L*.

$$O_{r,t}^o = \begin{cases} S_r^o - (\hat{I}_{r,t}^o + \sum_{j=1}^{L} O_{r,t-j}^o) & if\ \hat{I}_{r,t}^o + \sum_{j=1}^{L} O_{r,t-j}^o < s_r^o \\ 0 & Otherwise \end{cases},$$

During the period, three types of demand, paying customer, theft and misplacement occur at the retailer. The total demand for the retailer in period *t* is:

$$D_{r,t}^o = A_{r,t}^o + G_{r,t}^o + K_{r,t}^o$$

where $A_{r,t}^o, G_{r,t}^o$ and $K_{r,t}^o$ follow certain distributions.

When formulating realized sales, theft and misplacement in the period, we referred Kang and Gershwin (2005).

$$a_{r,t}^o = \begin{cases} A_{r,t}^o & if\ D_{r,t}^o \le I_{r,t}^o + R_{r,t}^o \\ \left(I_{r,t}^o + R_{r,t}^o\right)\left(\frac{A_{r,t}^o}{D_{r,t}^o}\right), & Otherwise \end{cases},$$

$$g_{r,t}^{o} = \begin{cases} G_{r,t}^{o} & if\ D_{r,t}^{o} \le I_{r,t}^{o} + R_{r,t}^{o} \\ \left(I_{r,t}^{o} + R_{r,t}^{o}\right)\left(\frac{G_{r,t}^{o}}{D_{r,t}^{o}}\right), & Otherwise' \end{cases}$$

$$k_{r,t}^{o} = \begin{cases} K_{r,t}^{o} & if\ D_{r,t}^{o} \le I_{r,t}^{o} + R_{r,t}^{o} \\ \left(I_{r,t}^{o} + R_{r,t}^{o}\right)\left(\frac{K_{r,t}^{o}}{D_{r,t}^{o}}\right), & Otherwise' \end{cases}$$

where $R_{r,t}^{o} = DL_{d,t-L}^{o}$ and $DL_{d,t-L}^{o}$ was shipped from the distributor to the retailer in period *t-L*.

At the end of period *t*, the inventory state of the retailer evolves, according to the following equations:

$$i_t^o \equiv Mod(t, N^o).$$

The inventory errors are accumulated if there is no physical counting at the end of period t.

$$Q_{r,t+1}^{o} = \begin{cases} 0 & if\ i_t^o = 0 \\ Q_{r,t}^{o} + g_{r,t}^{o} & Otherwise' \end{cases}$$

$$B_{r,t+1}^{o} = \begin{cases} 0 & if\ i_t^o = 0 \\ B_{r,t}^{o} + k_{r,t}^{o} & Otherwise' \end{cases}$$

If period *t* is a counting period, with the physical inventory counting at the end of the period, accumulated theft is detected and removed from inventory record. Misplaced items are also detected and returned to correct locations, so they help increase salable inventory. However, this action does not change inventory record. With the physical counting, inventory record is aligned with salable inventory. If period *t* is not a counting period, inventory record in information system only updates with reached delivery and sales happened in the period. The inventory record and salable inventory are calculated at the end of period *t* as followings.

$$\hat{I}^{o}_{r,t+1} = \begin{cases} I^{o}_{r,t+1} = \hat{I}^{o}_{r,t} + R^{o}_{r,t} - a^{o}_{r,t} - Q^{o}_{r,t} - g^{o}_{r,t}, & if\ i^{o}_{t} = 0 \\ \hat{I}^{o}_{r,t} + R^{o}_{r,t} - a^{o}_{r,t} & Otherwise \end{cases},$$

Without physical counting, theft and misplacement reduce salable inventory.

$$I^{o}_{r,t+1} = \begin{cases} \hat{I}^{o}_{r,t+1} = I^{o}_{r,t} + R^{o}_{r,t} - a^{o}_{r,t} - g^{o}_{r,t} + B^{o}_{r,t} & if\ i^{o}_{t} = 0 \\ I^{o}_{r,t} + R^{o}_{r,t} - a^{o}_{r,t} - g^{o}_{r,t} - k^{o}_{r,t} & Otherwise \end{cases},$$

To simplify the formulation, the study simply lets salable inventory equal to inventory record when period *t* is a counting period. For the retailer, the single period profit incurred in period *t* is:

$$\pi^{o}_{r,t} = \begin{cases} p^{o}_{r} a^{o}_{r,t} - c_{r} O^{o}_{r,t} - h_{r} \hat{I}^{o}_{r,t+1} - z_{r}\left(A^{o}_{r,t} - a^{o}_{r,t}\right) - c_{r,c} - c_{r,q} \sum_{j=0}^{N^{o}-1} g^{o}_{r,t-j} & if\ i^{o}_{t} = 0 \\ p^{o}_{r} a^{o}_{r,t} - c_{r} O^{o}_{r,t} - h_{r} \hat{I}^{o}_{r,t+1} - z_{r}\left(A^{o}_{r,t} - a^{o}_{r,t}\right) & Otherwise \end{cases},$$

where p^{o}_{r} is the product price per unit per period for end-customer in the Base case $and\ z_{r}$ is the penalty cost per unit per period for unsatisfied customers to the retailer, $c_{r,c}$ is the cost of conducting a physical counting at the retailer, and $c_{r,q}$ is the cost per unit per period for detected theft.

In T simulation periods, the profit for the retailer is:

$\pi^{o}_{r} = \sum_{t=1}^{T} \pi^{o}_{r,t}$.

While the distributor's formulation is similar to the retailer, there are still some differences worthy to mention. The study assumes that there are less demand for shrinkage and misplacement at the distributor because only employees are responsible for these two types of inventory errors, compared to the retailer in which both end-customers and employees can take products away without paying for them. Therefore, the study models the distributions of demands for shrinkage and misplacement in the distributor smaller than those in the retailer. For backorder, the study does not consider backorder for the retailer; however it allows the distributor to take backorder when an order from the retailer cannot be met. This assumption makes our model more realistic.

At the beginning of period *t*, following the similar procedure to the retailer, the distributor reviews its inventory position under the replenishment policy (s_d^o, S_d^o) and places an order, if necessary. The distributor also receives delivery $DL_{m,t-L}^o$ shipped in period t-L from the manufacturer to the distributor, if applicable.

$$O_{d,t}^o = \begin{cases} S_d^o - (\hat{I}_{d,t}^o + \sum_{j=1}^{L} O_{d,t-j}^o - BL_{d,t-1}^o) & if\ \hat{I}_{d,t}^o + \sum_{j=1}^{L} O_{d,t-j}^o - BL_{d,t-1}^o < s_d^o \\ 0 & Otherwise \end{cases},$$

The distributor tries to satisfy the retailer's order and backorder after placing an order but still at the beginning of period t.

$$DL_{d,t}^o = \begin{cases} O_{r,t}^o + BL_{d,t-1}^o & if\ O_{r,t}^o + BL_{d,t-1}^o \le I_{d,t}^o + R_{d,t}^o \\ I_{d,t}^o + R_{d,t}^o & Otherwise \end{cases},$$

$$BL_{d,t}^o = O_{r,t}^o + BL_{d,t-1}^o - DL_{d,t}^o,$$

where $R_{d,t}^o = DL_{m,t-L}^o$ and $R_{d,t}^o$ is received products at the distributor at the beginning of period t, which was shipped in period *t-L,* from the manufacturer to the distributor.

After attempting to satisfy the order and backorder, theft and misplacement occur in the distributor during period t. $G_{d,t}^o$ and $K_{d,t}^o$ follow certain distributions.

$$g_{d,t}^o = \begin{cases} G_{d,t}^o & if\ G_{d,t}^o + K_{d,t}^o \le I_{d,t}^o + R_{d,t}^o - DL_{d,t}^o \\ (I_{d,t}^o + R_{d,t}^o - DL_{d,t}^o)\left(\frac{G_{d,t}^o}{G_{d,t}^o + K_{d,t}^o}\right), & Otherwise \end{cases},$$

$$k_{d,t}^o = \begin{cases} K_{d,t}^o & if\ G_{d,t}^o + K_{d,t}^o \le I_{d,t}^o + R_{d,t}^o - DL_{d,t}^o \\ (I_{d,t}^o + R_{d,t}^o - DL_{d,t}^o)\left(\frac{K_{r,t}^o}{G_{d,t}^o + K_{d,t}^o}\right), & Otherwise \end{cases}.$$

At the end of period *t* or the beginning of period, t+1, the inventory state of the distributor evolves according to the following equations:

$$i_t^o \equiv Mod(t, N^o),$$

$$Q^o_{d,t+1} = \begin{cases} 0 & if\ i^o_t = 0 \\ Q^o_{d,t} + g^o_{d,t} & Otherwise \end{cases},$$

$$B^o_{d,t+1} = \begin{cases} 0 & if\ i^o_t = 0 \\ B^o_{d,t} + k^o_{d,t} & Otherwise \end{cases},$$

$$\hat{I}^o_{d,t+1} = \begin{cases} I^o_{d,t+1} = \hat{I}^o_{d,t} + R^o_{d,t} - DL^o_{d,t} - Q^o_{d,t} - g^o_{d,t}, & if\ i^o_t = 0 \\ \hat{I}^o_{d,t} + R^o_{d,t} - DL^o_{d,t} & Otherwise \end{cases},$$

$$I^o_{d,t+1} = \begin{cases} \hat{I}^o_{d,t+1} = I^o_{d,t} + R^o_{d,t} - DL^o_{d,t} - g^o_{d,t} + B^o_{d,t} & if\ i^o_t = 0 \\ I^o_{d,t} + R^o_{d,t} - DL^o_{d,t} - g^o_{d,t} - k^o_{d,t} & Otherwise \end{cases}.$$

For the distributor, the single period profit incurred in period *t* is:

$$\pi^o_{d,t} = \begin{cases} p^o_d O^o_{r,t} - c_d O^o_{d,t} - h_d \hat{I}^o_{d,t+1} - z_d BL^o_{d,t} - c_{d,c} - c_{d,q} \sum_{j=0}^{N^o-1} g^o_{d,t-j} & if\ i^o_t = 0 \\ p^o_d O^o_{r,t} - c_d O^o_{d,t} - h_d \hat{I}^o_{d,t+1} - z_d BL^o_{d,t} & Otherwise \end{cases},$$

where, $p^o_d = c_r$, z_d is the penalty cost per unit per period for unsatisfied order to the distributor, $c_{d,c}$ is the cost of conducting a physical counting at the distributor, and $c_{d,q}$ is the cost per unit per period for detected theft at the distributor.

In T simulations periods, the profit for the distributor is:

$$\pi^o_d = \sum_{t=1}^{T} \pi^o_{d,t}.$$

For the manufacturer, the study assumes that there is even less demand for shrinkage and misplacement than those for the distributor. The manufacturer also takes backorder when it cannot satisfy the distributor's order and will deliver the backorder in the future period by adding lead time *L*.

At the beginning of the period, the manufacturer reviews the inventory position and sets up production under the replenishment policy (s^o_m, S^o_m), if necessary. And, the manufacturer places completed production to inventory.

$$M^o_t = \begin{cases} S^o_m - (\hat{I}^o_{m,t} + \sum_{j=1}^{L} M^o_{t-j} - BL^o_{m,t-1}) & if\ \hat{I}^o_{m,t} + \sum_{j=1}^{L} M^o_{t-j} - BL^o_{m,t-1} < s^o_m \\ 0 & Otherwise \end{cases}.$$

The manufacturer then tries to satisfy the order from the distributor at the beginning of period *t*. It also takes backorder if the order and backorder from previous period *t-1* cannot be satisfied.

$$DL^{o}_{m,t} = \begin{cases} O^{o}_{d,t} + BL^{o}_{m,t-1} & if\ O^{o}_{d,t} + BL^{o}_{m,t-1} \le I^{o}_{m,t} + M^{o}_{t-L} \\ I^{o}_{m,t} + M^{o}_{t-L} & Otherwise \end{cases},$$

$$BL^{o}_{m,t} = O^{o}_{d,t} + BL^{o}_{m,t-1} - DL^{o}_{m,t},$$

where M^{o}_{t-L} is the production amount of the manufacturer at period *t-L* and available at period *t*. Because the manufacturer does not have capability constricts, it can obtain all the materials it needs to produce the products. The only issue is the lead time L.

After shipping products for meeting order and backorder, theft and misplacement occur at the manufacturer during the period. $G^{o}_{m,t}$ and $K^{o}_{m,t}$ follow certain distributions.

$$g^{o}_{m,t} = \begin{cases} G^{o}_{m,t} & if\ G^{o}_{m,t} + K^{o}_{m,t} \le I^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t} \\ \left(I^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t}\right)\left(\frac{G^{o}_{m,t}}{G^{o}_{m,t}+K^{o}_{m,t}}\right), & Otherwise \end{cases},$$

$$k^{o}_{m,t} = \begin{cases} K^{o}_{m,t} & if\ G^{o}_{m,t} + K^{o}_{m,t} \le I^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t} \\ \left(I^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t}\right)\left(\frac{K^{o}_{m,t}}{G^{o}_{m,t}+K^{o}_{m,t}}\right), & Otherwise \end{cases},$$

At the end of period *t*, the inventory state of the manufacturer evolves according to the following equations:

$$i^{o}_{t} \equiv Mod(t, N^{o}),$$

$$Q^{o}_{m,t+1} = \begin{cases} 0 & if\ i^{o}_{t} = 0 \\ Q^{o}_{m,t} + g^{o}_{m,t} & Otherwise \end{cases},$$

$$B^{o}_{m,t+1} = \begin{cases} 0 & if\ i^{o}_{t} = 0 \\ B^{o}_{m,t} + k^{o}_{m,t} & Otherwise \end{cases},$$

$$\hat{I}^{o}_{m,t+1} = \begin{cases} I^{o}_{m,t+1} = \hat{I}^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t} - Q^{o}_{m,t} - g^{o}_{m,t}, & if\ i^{o}_{t} = 0 \\ \hat{I}^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t} & Otherwise \end{cases},$$

$$I^{o}_{m,t+1} = \begin{cases} \hat{I}^{o}_{m,t+1} & if\ i^{o}_{t} = 0 \\ I^{o}_{m,t} + M^{o}_{t-L} - DL^{o}_{m,t} - g^{o}_{m,t} - k^{o}_{m,t} & Otherwise \end{cases},$$

For the retailer, the single period profit incurred in period *t* is:

$$\pi^{o}_{m,t} = \begin{cases} p^{o}_{m} O^{o}_{d,t} - c_{m} M^{o}_{t} - h_{m} \hat{I}^{o}_{m,t+1} - z_{m} BL^{o}_{m,t} - c_{m,c} - c_{m,q} \sum_{j=0}^{N^{o}-1} g^{o}_{m,t-j} & if\ i^{o}_{t} = 0 \\ p^{o}_{m} O^{o}_{d,t} - c_{m} M^{o}_{t} - h_{m} \hat{I}^{o}_{m,t+1} - z_{m} BL^{o}_{m,t} & Otherwise \end{cases}$$

where $p^{o}_{m} = c_{d}$.

Overall, the total profit of the entire supply chain in T simulation periods in the base case is:

$$\Pi^{o} = \sum_{\eta=\{r,d,m\}} \sum_{t=1}^{T} \pi^{o}_{\eta,t}.$$

5.4.2.2 Full RFID implementation*

In scenario 2, the supply chain is designed with full RFID implementation. With RFID, inventory manager can detect theft and misplaced inventory and return the misplaced items back to the right place at the end of each period. However, RFID may not reach 100% read rate based on the reality. In this scenario, RFID is thus modeled as imperfect, in terms of RFID read rate. That means some of RFID tags cannot be read correctly, so only part of misplaced items can be detected and returned. Undetected misplaced items are accumulated but the accumulated misplaced items are much smaller than those in Base Case. Moreover, RFID can also prevent theft from occurrence (Patton and Hardgrave 2009). Theft and misplacement are smaller in this case than the one in Base Case. Because of the current development status of RFID technology for supply chain applications, the system still needs to conduct physical inventory counting but can be at a less frequency.

The formulation of demand and order placed in this case is similar to those in Base Case, so we skip them and only discuss the different part.

At the end of period *t*, the inventory state of the retailer evolves according to the following equations:

$i_t^* \equiv Mod(t, N^*)$,

RFID's perfection is set up rang from (0.85, 1.00) based on industry reports (Walfram 2007), so the retailer still needs to conduct physical counting but it may do it less frequently. N^*should be greater than N^o.Because RFID can help detect all theft at the end of each period, all the theft will be subtracted from inventory record; however for misplaced items, only proportion of them can be detected and returned to salable inventory because of imperfect status of RFID. ω represents the perfect level. For example, if the read rate is 95%, that means 5% misplaced items cannot be detected and are accumulated in the system. It is treated as theft and deducted from inventory record.

The cumulated misplacement is as follow:

$$B_{r,t+1}^* = \begin{cases} 0 & if\ i_t^* = 0 \\ B_{r,t}^* + (1-\omega)k_{r,t}^* & Otherwise \end{cases},$$

The inventory record is as below:

$$\hat{I}_{r,t+1}^* = I_{r,t+1}^* \begin{cases} I_{r,t}^* + R_{r,t}^* - a_{r,t}^* - g_{r,t}^* + B_{r,t}^* & if\ i_t^* = 0 \\ I_{r,t}^* + R_{r,t}^* - a_{r,t}^* - g_{r,t}^* - (1-\omega)k_{r,t}^* & Otherwise \end{cases}.$$

For the retailer, the single period profit incurred in period *t* is:

$$\pi_{r,t}^* = \begin{cases} p_r^* a_{r,t}^* - (c_r + \alpha c_g)O_{r,t}^* - h_r \hat{I}_{r,t+1}^* - z_r\left(A_{r,t}^* - a_{r,t}^*\right) - c_{r,q}(g_{r,t}^* - B_{r,t}^*) - c_{r,c} & if\ i_t^* = 0 \\ p_r^* a_{r,t}^* - (c_r + \alpha c_g)O_{r,t}^* - h_r \hat{I}_{r,t+1}^* - z_r\left(A_{r,t}^* - a_{r,t}^*\right) - c_{r,q}[g_{r,t}^* + (1-\omega)k_{r,t}^*] & Otherwise \end{cases}.$$

In this scenario, the system treats undetected misplaced items $(1-\omega)k_{r,t}^*$ as theft at each period when calculating the profit for the retailer. $p_r^* = p_r^o$, z_r is the penalty cost per unit per period for unsatisfied customers to the retailer, and α is the proportion of RFID tag cost, c_g shared by the retailer.

In T simulation periods, the profit for the retailer is:

$\pi_r^* = \sum_{t=1}^{T} \pi_{r,t}^*$.

In this scenario, the demand of shrinkage and misplacement at the distributor are smaller than those at the retailer. The distributor first reviews the inventory position and places the order $O_{d,t}^*$ if necessary under the replenishment policy (s_d^*, S_d^*). And, the distributor receives products which the manufacturer shipped in period *t-L*. The distributor then tries to satisfy the order and make delivery $DL_{d,t}^*$ first at the beginning of period *t*. Any order cannot be satisfied immediately from inventory on hand, will be backordered, as $BL_{d,t}^*$.

$$DL_{d,t}^* = \begin{cases} O_{r,t}^* + BL_{d,t-1}^* & if\ O_{r,t}^* + BL_{d,t-1}^* \le I_{d,t}^* + R_{d,t}^* \\ I_{d,t}^* + R_{d,t}^* & Otherwise \end{cases},$$

$$BL_{d,t}^* = O_{r,t}^* + BL_{d,t-1}^* - DL_{d,t}^* ,$$

where $R_{d,t}^* = DL_{m,t-L}^*$; $R_{d,t}^*$ is received products at the distributor at period *t*, which was shipped from the manufacturer to the distributor at period *t-L*.

During the period, theft and misplacement occur at the distributor. At the end of period *t*, the inventory state of the distributor evolves according to the following equations:

$$i_t^* \equiv Mod(t, N^*),$$

$$B_{d,t+1}^* = \begin{cases} 0 & if\ i_t^* = 0 \\ B_{d,t}^* + (1-\omega)k_{d,t}^* & Otherwise \end{cases},$$

$$\hat{I}_{d,t+1}^* = I_{d,t+1}^* = \begin{cases} I_{d,t}^* + R_{d,t}^* - DL_{d,t}^* - g_{d,t}^* + B_{d,t}^* & i_t^* = 0 \\ I_{d,t}^* + R_{d,t}^* - DL_{d,t}^* - g_{d,t}^* - (1-\omega)k_{d,t}^* & Otherwise \end{cases}.$$

For the distributor, the single period profit incurred in period *t* is:

$$\pi^*_{d,t} = \begin{cases} p^*_d O^*_{r,t} - [c_d + (\alpha+\beta)c_g]O^*_{d,t} - h_d \hat{I}^*_{d,t+1} - z_d BL^*_{d,t} - c_{d,q}(g^*_{d,t} - B^*_{d,t}) - c_{d,c} & if\ i^*_t = 0 \\ p^*_d O^*_{r,t} - [c_d + (\alpha+\beta)c_g]O^*_{d,t} - h_d \hat{I}^*_{d,t+1} - z_d BL^*_{d,t} - c_{d,q}[g^*_{d,t} + (1-\omega)k^*_{d,t}] & Otherwise \end{cases}.$$

where $p^*_d = (c_r + \alpha c_g)$, z_d is the penalty cost per unit per period for unsatisfied order to the distributor, and β is the proportion of RFID tag cost c_g shared by the distributor.

In T simulation periods, the profit for the distributor is:

$\pi^*_d = \sum_{t=1}^{T} \pi^*_{d,t}$.

For the manufacturer, the study assumes that there is even less demand for shrinkage and misplacement for the manufacturer than those for the distributor. This setting is the same as in Base case. The manufacturer also places an order first based on inventory position, if necessary, takes backorder when it cannot satisfy the distributor's order and will deliver the backorder in a future period when inventory is available.

At the beginning of the period, the manufacturer reviews its inventory position and places its production order M^*_t, if necessary, under the replenishment policy (s^*_m, S^*_m). And, it receives what the manufacturer shipped at *t-L*. The manufacturer then tries to satisfy the order placed by the distributor and ship the available products. It may take backorder if it cannot satisfy the order. During the period, theft $g^*_{m,t}$ and misplacement $k^*_{m,t}$ occur at the manufacturer. At the end of period *t*, the inventory state of the manufacturer evolves.

$$DL^*_{m,t} = \begin{cases} O^*_{d,t} + BL^*_{m,t-1} & if\ O^*_{d,t} + BL^*_{m,t-1} \le I^*_{m,t} + M^*_{t-L} \\ I^*_{m,t} + M^*_{t-L} & Otherwise \end{cases},$$

$$BL^*_{m,t} = O^*_{d,t} + BL^*_{m,t-1} - DL^*_{m,t} ,$$

where M^*_{t-L} is the production amount at the manufacturer at period *t-L* and available at period *t*. Because the manufacturer does not have capability constricts and can obtain all materials it needs, the only issue is lead time *L*.

At the end of period *t*, the inventory state of the manufacturer evolves according to the following equations:

$$i^*_t \equiv Mod(t, N^*) ,$$

$$B^*_{m,t+1} = \begin{cases} 0 & if\ i^*_t = 0 \\ B^*_{m,t} + (1-\omega)k^*_{m,t} & Otherwise \end{cases} ,$$

$$\hat{I}^*_{m,t+1} = I^*_{m,t+1} \begin{cases} I^*_{m,t} + M^*_{t-L} - DL^*_{m,t} - g^*_{m,t} + B^*_{m,t} & if\ i^*_t = 0 \\ I^*_{m,t} + M^*_{t-L} - DL^*_{m,t} - g^*_{m,t} - (1-\omega)k^*_{m,t} & Otherwise \end{cases} ,$$

For the manufacturer, the single period profit incurred in period *t* is:

$$\pi^*_{m,t} = \begin{cases} p^*_m O^*_{d,t} - (c_m + c_g)M^*_t - h_m \hat{I}^*_{m,t+1} - z_m BL^*_{m,t} - c_{m,q}(g^*_{m,t} - B^*_{m,t}) - c_{m,c} & if\ \ i^*_t = 0 \\ p^*_m O^*_{d,t} - (c_m + c_g)M^*_t - h_m \hat{I}^*_{m,t+1} - z_m BL^*_{m,t} - c_{m,q}[g^*_{m,t} + (1-\omega)k^*_{m,t}] & Otherwise \end{cases}$$

where $p^*_m = c_d + (\alpha + \beta)c_g$.

In T simulation periods, the profit for the manufacturer is:

$$\pi^*_m = \sum_{t=1}^{T} \pi^*_{m,t}.$$

For the overall supply chain, the total profit in T simulation periods is:

$$\Pi^* = \sum_{\eta=\{r,d,m\}} \sum_{t=1}^{T} \pi^*_{\eta,t}.$$

5.4.2.3 Partial RFID Implementation[#]

In this scenario, RFID is installed in the distributor, rather than in the manufacture. This scenario combines Base case and Full RFID implementation case. The formulation is very similar to those in the two scenarios and attached in Appendix B.

5.4.2.4 Informed System'

Without implementing RFID, this scenario lacks inventory visibility. However, inventory manager is aware of inventory inaccuracy problem and has some historical data available about unobservable error sources (Kang and Gershwin 2005). He/she then uses these historical data to compensate inventory discrepancy problem by deducting an estimated total error demand for example for retailer, e_r at the end of each period.

Although this method was applied at only retailer in Kang and Gershwin (2005), it is reasonable to apply this informed policy in each party of a given supply chain and examine the impact on the whole supply chain performance. This scenario also serves as a more reasonable benchmark for RFID value in supply chains, compared to the Base model. It overcomes the weakness of using naïve system (i.e. Base case) as the benchmark in existing literature.

The formulation of this scenario is very similar to Base Case and the different part is when we calculate inventory record $\hat{I}'_{r,t+1}$ at end of each period, we also calculate another inventory record, $\hat{I}'_{r,p,t+1}$ only for calculating inventory position for ordering purpose.

At the end of period *t*, the inventory state of the retailer evolves according to the following equations:

$$i'_t \equiv Mod(t, N'),$$

$$Q'_{r,t+1} = \begin{cases} 0 & if\ i'_t = 0 \\ Q'_{r,t} + g'_{r,t} & Otherwise \end{cases},$$

$$B'_{r,t+1} = \begin{cases} 0 & if\ i'_t = 0 \\ B'_{r,t} + k'_{r,t} & Otherwise \end{cases},$$

$$\hat{I}'_{r,p,t+1} = \begin{cases} I'_{r,t+1} & if\ i'_t = 0 \\ \hat{I}'_{r,t} + R'_{r,t} - a'_{r,t} - e_r & Otherwise \end{cases},$$

where e_r is an adjustment placed by inventory manager at the end of period t, to reduce the inventory inaccuracy error based on historical data. $\hat{I}'_{r,p,t+1}$ is used to calculate inventory position for period *t+1*. This setup makes the inventory position closer to the real one. However, in order to avoid miscalculating inventory and holding cost, inventory record keeps the same formula we used in Base case.

$$\hat{I}'_{r,t+1} = \begin{cases} I'_{r,t+1} & if\ i'_t = 0 \\ \hat{I}'_{r,t} + R'_{r,t} - a'_{r,t} & Otherwise \end{cases},$$

$$I'_{r,t+1} = \begin{cases} \hat{I}'_{r,t+1} = I'_{r,t} + R'_{r,t} - a'_{r,t} - g'_{r,t} + B'_{r,t} & if\ i^o_t = 0 \\ I'_{r,t} + R'_{r,t} - a'_{r,t} - g'_{r,t} - k'_{r,t} & Otherwise \end{cases}.$$

When the period is a physical counting period, all the theft and misplaced items are detected and corrected in the system, inventory record, salable inventory and inventory for inventory position calculation are aligned.

For the retailer, the single period profit incurred in period *t* is:

$$\pi'_{r,t} = \begin{cases} p'_r a'_{r,t} - c_r O'_{r,t} - h_r \hat{I}'_{r,t+1} - z_r\left(A'_{r,t} - a'_{r,t}\right) - c_{r,c} - c_{r,q} \sum_{j=0}^{L-1} g'_{r,t-j} & if\ i'_t = 0 \\ p'_r a'_{r,t} - c_r O'_{r,t} - h_r \hat{I}'_{r,t+1} - z_r\left(A'_{r,t} - a'_{r,t}\right) & Otherwise \end{cases},$$

where $p'_r = p^o_r$, z_r is the penalty cost per unit for unsatisfied customers to the retailer.

In T simulation periods, the profit for the retailer is:

$$\pi'_r = \sum_{t=1}^{T} \pi'_{r,t}.$$

For the distributor and the manufacturer, the study keeps the same setting as the one in Base case. Only is the adjustment different in inventory position calculation.

For the overall supply chain, the total profit in T simulation periods is:

$$\Pi' = \sum_{\eta=\{r,d,m\}} \sum_{t=1}^{T} \pi'_{e,t}.$$

5.4.2.5 Perfect RFID Scenario

In this scenario, RFID is viewed as a perfect technology for inventory management, so it can provide 100% visibility of inventory. We also assume there is no cost for RFID, so we can compare our results with those in existing literature. For the formulation of this scenario, it is the same as full RFID implementation scenario except RFID read rate and cost. In this perfect RFID scenario, RFID read rate is set as 100% and cost is zero.

5.5 Experimental Design

In previous IS studies, simulation method is used to provide insights of complex phenomena in real world (e.g. Jones et al. 2006, Kumar et al. 2008). The complexity of our analytical models requires using simulation to model the operation of the supply chain in the dissertation. The purpose of the study is primarily to provide understanding of the mechanism on how RFID impacts supply chain performance and to what extent RFID improves overall supply chain performance. Further, the study is also interested in the impact of RFID perfection status on the results. This section describes the design of simulation experiments including performance measures, factors investigated and key parameters.

Each simulation includes 200 periods with one week as an interval and was run 500 times, as similar to other studies (Brown 2001, Fleisch and Tellkamp 2005, and Kang and Gershwin 2005). The average values of system performance measures were calculated. This approach is consistent with prior IS research (e,g. Kang and Gershwin 2005, Jones et al. 2006, Kumar et al. 2008). The inventories for all players of the supply chain are set up to the order-up-to levels in a synchronized state at the beginning of the simulation by following Basinger (2006).

5.5.1 Performance Measures

Prior studies mainly apply non-monetary measures (e.g. inventory accuracy) or costs as performance measures when investigating the value of RFID. However, researchers suggested that profit can provide additional benefits of RFID that reduce the inventory discrepancy problem (Atali et al. 2006). In the dissertation, two monetary measures (total supply chain profit and each party's profit) are selected to capture performance changes of a supply chain, with or without RFID. Total supply chain profit includes the profits from the three players (retailer, distributor and manufacturer) in a supply chain. The total supply chain performance demonstrates the value of RFID, based on the comparison among the five scenarios discussed in the model descriptions section. Profit at each player in the supply chain is used to examine which player of the supply chain gains the largest improvement when RFID is introduced.

5.5.2 Factors in Simulation Models

We first examine the five scenarios of the supply chain modeled, with or without RFID and evaluate the value of RFID for the supply chain. We also examine the impact of product type on RFID value creation. Finally, RFID read rate is tested for the relationship between RFID read rate and total supply chain performance. Details for each factor are described as follows.

5.5.2.1 Scenarios

In the model description section, five scenarios: base case, full RFID implementation, partial RFID implementation, informed case and perfect RFID case are discussed. In different scenarios, product information is kept unchanged across scenarios, so the difference in results is purely from the difference of each scenario setting. While both of Base case and informed case are without RFID and used as benchmarks to assess RFID value, informed case gives us more accurate evaluation on RFID value. Perfect RFID case is another extreme case to show the maximum value that RFID can create for the supply chain, from inventory management perspective. These scenarios not only demonstrate the value of RFID but also show any difference among scenarios, especially the difference between full RFID implementation and partial RFID implementation for the supply chain.

5.5.2.2 Products

When examining RFID impact across scenarios, we use only a single product. It would be interesting to test the impact of RFID on product category. Many consumer package goods (CPG) companies did and continue to believe that there is a great ROI in some product categories (SupplyChainDigest 2011). In the past, RFID programs, such as Wal-Mart's, were not designed or executed well. For example, Wal-Mart had a mass mandate across hundreds of suppliers, when there are products which may be more profitable from RFID. Now, Wal-Mart starts correcting its program and takes apparel as new start point for its RFID program (NewAmerican 2011).

With the support from Wal-Mart, Hardgrave et al. (2010) found that the influence of RFID on inventory record inaccuracy varied by product category through experimental field study. Their study suggested that RFID is most effective for product categories characterized by known determinants of inventory record inaccuracy (Dehoratius and Raman 2008): item cost, quantity, sales volume (item cost × quantity sold), audit frequency (frequency of physical inventory audit), inventory density (the total number of units found in a retailer‘s selling area), product variety (the number of different merchandise categories within a store), and the distribution structure (whether or not it was shipped from a retailer-owned DC). In our study, however, we focus on simple, but not yet studied characteristics of a product to examine RFID impact: average demand, demand variability and shrinkage/misplacement rate.

Since we are interested in improving supply chain performance by addressing inventory inaccuracy problem, we first consider the main sources of inventory inaccuracy. As discussed in literature review section, shrinkage and misplacement are the most important reasons for inventory inaccuracy, so they become the first characteristic to examine for possible product features in our study. We expect that products with high shrinkage and misplacement benefit more from RFID than those with low values on shrinkage and misplacement.

Prior study has mentioned the impact of average demand on RFID value in inventory management (Hardgrave et al. 2010). However, variability of demand may be even more important than average demand for RFID to bring values. Demand variability refers to the range of values for average demand, which is variable based on effort in marketing or promotions, special events, seasonality, holidays and other extrinsic factors. We use relative measure, coefficient of variance (CV) to represent the demand variability. Small variance in customer demand can result in large variations in orders placed to upstream partners. Demand variability is increasing for most companies, with impact on inventory levels and customer service. Hence, this study investigates different types of products with 2(high vs. low average demand, μ) ×2 (high vs. low demand variance) × 2 (high vs. low shrinkage/misplacement rate) full factorial. Table 16 shows the 2×2×2 product categories. Eight types of products represent different categories of products and are all finished goods in the supply chains.

Table 16: Product Categories

	Customer Demand		**Shrinkage & Misplacement Rate**
	μ	**CV**	
Product A	High	High	High
Product B	High	High	Low
Product C	High	Low	High
Product D	High	Low	Low
Product E	Low	High	High
Product F	Low	High	Low
Product G	Low	Low	High
Product H	Low	Low	Low

5.5.2.3 RFID Read Rate

As a new technology, RFID is not going to be perfect on day one (Lee and Ozer 2007). Hence, some RFID tags may be not stable or there are some misreads from RFID data. Researchers suggest that we need to model the impact of RFID that is not 100% reliable, in order to more accurately assess the value of RFID (Lee and Ozer 2007).. Hence, our study sets up the read rate as imperfect, for example read rate as 85% and this setting is closer to the current RFID development status in reality. We use the read rate of RFID tag to indicate the extent of RFID perfection. While a uniform distribution (0.85, 1.00) is used to represent RFID read rate in simulations for scenario comparison (Walform 2007), different read rates are set to run the simulations for the full implementation cases, in order to investigate the relationship between RFID read rate and total supply chain performance.

Although RFID tags are installed at one party of the supply chain, the costs of RFID can be shared among all parties of the supply chain. When comparing the performance of each party of the supply chain and overall supply chain, sharing policy is set up as the manufacturer, the distributor and the retailer equally bearing RFID cost. The study ignores the fixed cost of RFID system and only considers variable cost, the cost of RFID tag in the simulation model.

5.5.3. Parameters

Table 17 describes the numerical values and justification for parameters used in our simulation experiments. Whenever possible, we attempt to apply the values that have been used in practitioner literature or prior research.

While prior studies use Normal distribution to represent end-customer demand, we use Gamma distribution because negative demand number should be avoided when we have high demand variability. The demand variability, CV is set up as 50% vs. 10% for high and low variability. High product demand is set as 1400 units per period and low demand is 640 units per period. NRSS (2010) reported shrinkage rate for supermarket and grocery store was 3.12% and majority of shrinkage was theft. Plus, Raman at el. (2001) found average misplacement was 3.5% of annual sales for a group of SKUs. Since the average shrinkage and misplacement rate is 6.62%, we set high shrinkage/misplacement rate as 10% and low rate as 3%. These shrinkage and misplacement are equally weighted in our simulation model. Table 18 shows the parameter values for each product and also includes k and θ for Gamma distribution.

Table 17: Key Simulation Parameters

Parameters	Description
$A_{r,t}$	End-customer demand for each product, Gamma distribution, shared among three parties.
$G_{\eta,t}$	Theft, uniform distribution , $\eta \in (r, d, m)$ (Fleisch and Tellkam 2005); based on the shrinkage rate 3.12% for supermarket/Grocery in NRSS (2010)
$K_{\eta,t}$	Misplacement, uniform distribution, $\eta \in (r, d, m)$ (Fleisch and Tellkam 2005); misplacement is 3.5% (Raman et al. 2001)
N	Counting cycle length, twice every year (Hardgrave et al. 2010)
(s_η, S_η)	Replenishment policies, $\eta \in (r, d, m)$, installation stock policy, we do not consider ordering cost so it is s=S
p_η	Paid price for product per unit, $\eta \in (r, d, m)$. We select four types of products based on the example product from Wal-Mart website (Hardgrave et al. 2010) and use their prices based on real market prices.
c_η	Order cost per unit, $\eta \in (r, d, m)$. We determine the cost per unit based on gross margin from annual report of example company.
h_η	Holding cost per unit per period, $\eta \in (r, d, m)$, 1/52*20% of cost per unit (Fleisch 2005, Pawer 2006).
z_η	Penalty for lost sales/backorder per unit, $\eta \in (r, d, m)$; for retailer, the lost sales represents loss of goodwill from customer, for distributor and manufacturer, backorder is calculated 5% of cost per unit (Fleisch 2005, Pawer 2006).
$c_{\eta,c}$	Physical counting cost per time, $\eta \in (r, d, m)$, for high product, \$2000(retailer), \$1500(distributor) and \$1200 (manufacturer); for low demand product C(\$1000, \$800, \$600).
c_g	RFID tag per unit, \$0.1 (Thiesse et al. 2007).
α	The proportion of RFID tag cost shared by the retailer, 1/3 in full case and ½ in partial
β	The proportion of RFID tag cost shared by the retailer1/3 in Full case, ½ in partial case
ω	RFID tag read rate, (0.85,1.00) (Walform 2007)

Table 18: The Product 2×2×2 Factorial Design

	Customer Demand				Shrinkage & Misplacement
	μ	CV	K	θ	
Product A	1400	50%	4	350	10%
Product B	1400	50%	4	350	3%
Product C	1400	10%	100	14	10%
Product D	1400	10%	100	14	3%
Product E	640	50%	4	160	10%
Product F	640	50%	4	180	3%
Product G	640	10%	100	6.4	10%
Product H	640	10%	100	6.4	3%

Usually, a company conducts physical counting once a year or every half year (Hardgrave et. al. 2010). Based on the value of average demand, we set physical counting cost per time for high demand as $2000 in the retailer, $1500 in the distributor and $1200 for the manufacturer; for low demand product, the values are $1000, $800, and $600 respectively. In our study, physical counting frequency is set up every 25 periods for all three players in all scenarios in order to compare the performance difference among them. We use periodic review order policy as replenishment policy for each player of the supply chain and do not consider ordering cost, so we set its order-up-to S level equal to reorder point s. For product price, we set high demand product has low price $10 per unit at the retailer and low demand product has high price $20 per unit. For the cost of each product, we determine it based on gross margin from the annual report of an example company for each player in the modeled supply chain. For example, Wal-Mart's gross margin is used as the retailer's margin to calculate the cost per unit for each product. Holding cost is set as annually 20% of product cost by following general guide in many textbooks and previous studies (Fleisch et al. 2005, Pawer 2006). Penalty cost of lost sale at the retailer can be viewed as loss of goodwill from customer and is set as 5% of product cost per unit. The distributor and the manufacturer incur backorder cost when they cannot satisfy downstream orders and is also set as 5% of product cost.

When comparing the performance among scenarios, there are two ways to set up RFID read rate, which describes the number of tags that can be read within a given period. One is to assume the read rate is 100% which means all RFID tags can be read. The second is to set up the read rate as imperfect, for example read rate as 90% and this setting is closer to the current RFID development status in reality. Hence, our study selects the second approach and uses a uniform distribution (0.85, 1.00) to represent it in simulations for scenario comparison (Walform 2007). In this study, RFID cost is $0.1 per unit and shared equally among its direct users in the supply chain (Thiesse et al. 2007).

With the values of the parameters for each product, example products of each product category can be found from typical consumer goods. For example, Product A can be general batteries which were reported with high shrinkage rate and misplacement (Diane 2010) and demand variability may be also high. Product E can be razor blades and it also has high theft rate and its demand should be smaller than batteries.

5.6 Analysis and Results

This section presents important results from our simulation experiments. These results demonstrate the value of RFID, in terms of performance measures in a supply chain setting: total supply chain profit (monetary measure), profit at each party of the supply chain (monetary measure), and satisfied customer orders (non-monetary measure).

In order to check the robustness of the findings, we also run the simulation by using different product demand distributions (e.g. Gamma and Uniform) and find that the general trend of performance changes is held. Hence, the results regarding the impact of RFID on total supply chain performance is robust.

5.6. 1 Performance Comparison of Scenarios

To compare the performance, we use base scenario as a basis to examine how well each scenario performs, including full RFID implementation and partial implementation cases, in terms of total supply chain profit, profit at each party. By using the same set of assumptions and parameters, we examine how much improvement is made from the base case to the other scenarios. We also apply informed case as a new benchmark to gauge RFID incremental value.

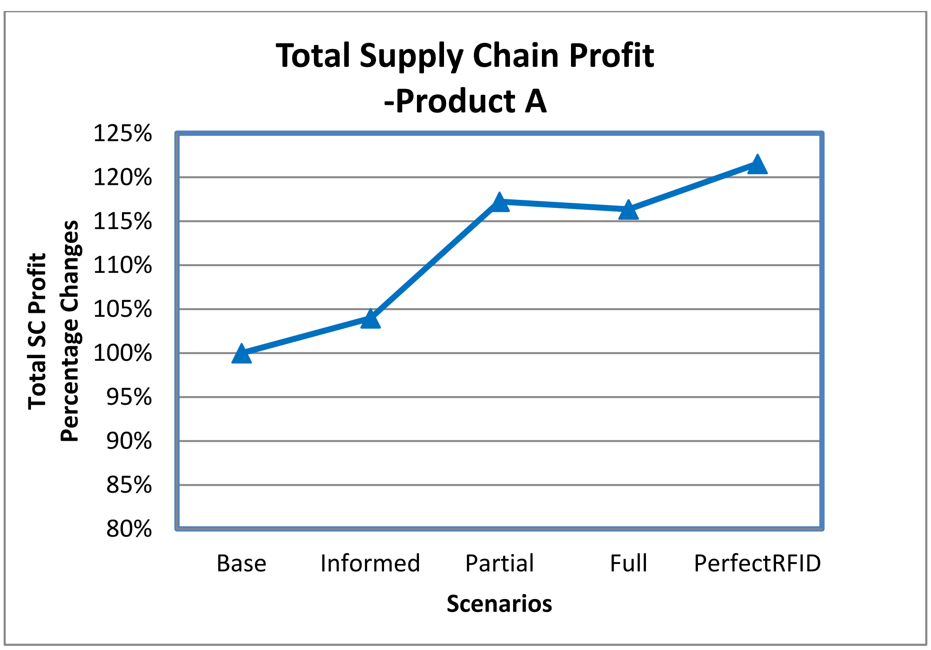

Figure 9: Total Supply Chain Profit on Product A

Figure 9 shows how the supply chain performance changes with product A when the five scenarios are implemented. In order to observe the impact of RFID on the supply chain operation, we use total supply chain profit in the base case as 100%, and compare the other scenarios as a percentage of the profit in the base case. It is quite intuitive that products with shrinkage and misplacement in inventory management could gain great benefit from RFID. However, this valuation is based only on survey estimates from practitioners and experts, and the assessment method can only be categorized as wild guesses (Dutta et al. 2007). Through a ground-up approach suggested by senior researchers (Lee and Ozer 2007), this study finds solid support to the statement that the benefit of implementing RFID is clear for product A and RFID can improve total supply chain performance of product A through solving shrinkage and misplacement problem. Figure 10 presents lost sales at retailer in different scenarios and shows that in RFID cases, lost sales are significantly reduced.

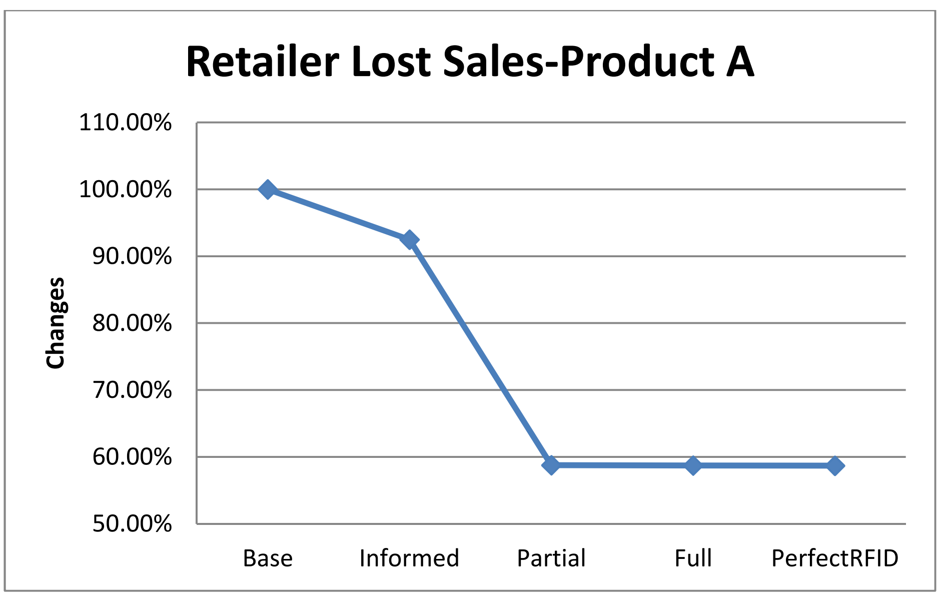

Figure 10: Lost Sales at Retailer for Product A

As originally expected, without RFID informed case improves the performance. The finding is consistent with prior literature (Kang et al. 2004). Prior studies commonly used non-monetary measure such as average inventory to capture the changes only for retailer's performance. However, our study applies total supply chain profit as the performance measure and offers practitioners more desirable insights of RFID value. Informed case brings another method for companies and supply chains which will not have or may not have RFID for a long time to improve their supply chain operations almost without costs. However, it is worthy to emphasize that the degree of improvement through informed method is much less than those gained in RFID cases. In our study, informed case provides a more realistic benchmark to evaluate RFID value and we do not overestimate the value of RFID value.

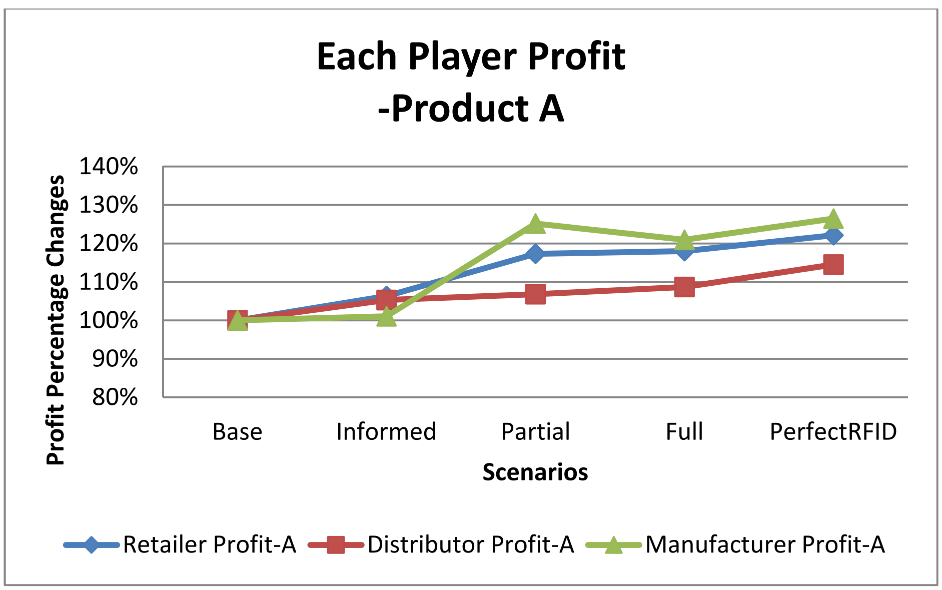

Figure 11: Each Player's Profit for Product A

For product A, interestingly, the supply chain was more able to improve performance with partial RFID implementation case than full RFID implementation case. The total supply chain profit in partial RFID case is over about 1 % than the one in full RFID case and the difference is statistically significant. This finding does not align with our initial hopes. The profit at each party in the supply chain may help explain.

In Figure 11, total supply chain profit change is broken into different parties in the supply chain. Usually, people think retailers should benefit most from implementing RFID for inventory management and that is one of the reasons why big retailers, such as Wal-Mart and Target pushed their suppliers very hard to implement RFID, and it was not suppliers to encourage its supply chain downstream partners to use RFID. Surprisingly, our finding indicates that the manufacturer gains the largest improvement and the retailer better performs than the distributor when the entire supply chain is implemented with RFID. Even in the partial RFID implementation scenario, the manufacturer does not implement RFID in its inventory system; its profit improvement is still large and actually is still the largest among the three players in the supply chain. The results show that the manufacturer gains significant indirect benefit from its trading partners' RFID implementation.

The bullwhip effect is also clear in our study: with RFID, small improvement in inventory management system at downstream partners can significantly increase the performance of upstream partners of the supply chain. Plus, we assume the manufacturer does not have capacity limitation, so it can supply whatever the distributor orders after certain lead time. Once getting into the distributor, however, the effect is not as clear. The distributor still shows improved performance, but the magnitude of the improvement is smaller. Possible reason may be the distributor has more backorder with RFID than in base and informed case and there is cost for these backorder occurred.

When moving from partial RFID implementation to full RFID implementation, both the retailer and the distributor improve their performance. The two parties not only gain direct benefits from implementing RFID in their organization through solving shrinkage and misplacement problem but also obtain indirect benefits from other trading partners' RFID implementation. For example, it may be through more accurate orders from downstream partner. In other words, RFID reduces the mismatch between order placed and product needs.

However, the manufacturer gains much more profit in partial RFID scenario than in full RFID scenario. A possible reason is that the source of profit improvement at manufacturer is mainly from indirect benefit, such as more orders placed by the distributor and the retailer in supply chain system, rather than from solving shrinkage and misplacement problems in its own organization. In the model, the manufacturer does not have production capacity, so it can supply what the distributor orders and just take a constant lead time to produce and deliver. Plus, the manufacturer does not bear RFID cost in partial RFID implementation but it does in full RFID implementation case. This helps explain why the manufacturer's profit in full RFID is lower case than the one in partial RFID case.

In informed case, inventory system simply adjusts inventory record at the end of each period to make the inventory record closer to salable inventory overtime and then reduces mismatch between order placed and product needs. The results show that all three players of the supply chain improve their performance. Among three players, this method is more beneficial to the retailer and the distributor. It may be because their shrinkage and misplacement problems are more severe, compared with the manufacturer. Prior research showed that informed case can provide a new benchmark for evaluating RFID impact for retailer, in term of non-monetary measure such as average inventory (Kang and Gershwin 2005). We apply this strategy across a supply chain and find that the finding is held for each party in the supply chain when comparing to base case.

Perfect RFID implementation case sets up an upper level for RFID value and our finding is consistent with those in literature. When RFID is reliable and provides 100% read rate, RFID-enabled inventory systems can detect all the theft and misplacement and make corresponding adjustment in inventory record. Plus, the gain of performance at each player without considering RFID cost in the perfect RFID implementation case can help decide how to allocate RFID cost to make every party in the supply chain profitable. In Figure 11, the manufacturer gets largest improvement, so it seems reasonable to allocate more RFID cost to the manufacturer.

5.6.2 The Impact of Product Category

In the scenario comparison section, our study finds that different scenarios perform differently, but overall Product A can get benefit from RFID across scenarios. In this section, we investigate whether RFID impact is held on different product categories; if not, how product type impacts RFID value creation. Figure 12 presents the results on total supply chain performance for eight products across the five scenarios. The results indicate that some products benefited more from RFID, and for some products the improvement from RFID are only marginal.

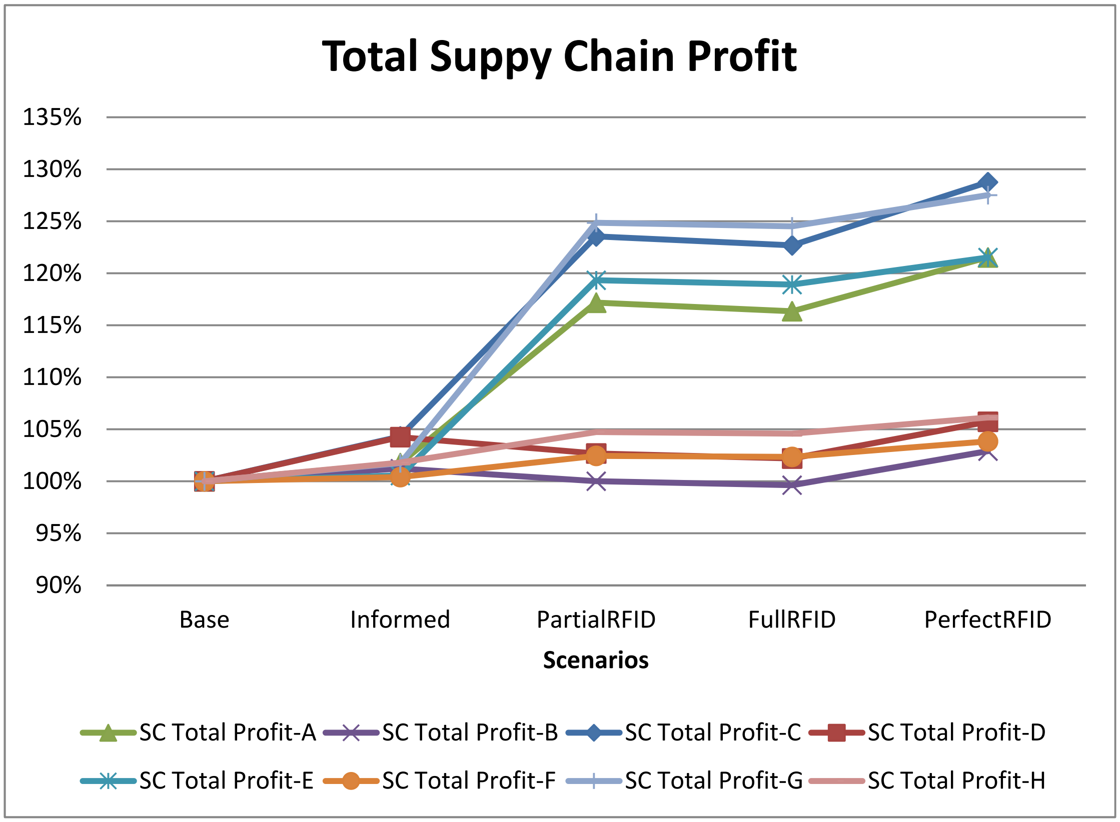

Figure 12: Total Supply Chain Profit for Different Products

In Figure 12, these products are clearly grouped into two groups: one group with high shrinkage and misplacement gains much larger improvement from RFID implementation than the other; and RFID benefits for the second group with low shrinkage and misplacement are relatively limited. The result is intuitive. In our research, we model RFID as a technology to address inventory inaccuracy problems caused by theft and misplacement. In RFID-enabled inventory systems, this technology helps observe theft in each period and inventory system or manager then removes these thefts from inventory record and makes inventory record close to salable inventory overtime. Please remember that RFID is not 100% perfect, so it can only help detect part of misplaced items and return them to right locations.

In addition, more accurate inventory information leads to more accurate orders placed to the upstream partners in the supply chain. This increases the probability to meet customer demand. With RFID, returned misplaced items become salable inventory again and makes profit for the retailer, the distributor and the manufacturer. Overall, our study suggests that RFID is more suitable for products with high shrinkage and misplacement.

While the inventory inaccuracy characteristic of a product is relatively intuitive for RFID impact, average demand and demand variability are not very clear. Figure 13-21 indicate whether these two product characteristics matter for RFID impact. Recall product categories discussed in the factor section, both of product A and product C have high demand and high shrinkage/misplacement, they are different in demand variability. With low demand variability, Figure 13 shows that product A gains greater improvement from RFID than product C does. Figure 14 indicates that when products with high shrinkage and low average demand, low demand variability makes product gain more benefit from RFID, from inventory management perspective. Smaller profit difference between product A and E in Figure 15 and the difference between product C and G in Figure 16 indicates that with high shrinkage/misplacement and high demand variability, product with low demand is more beneficial from RFID implementation. We observe the same results in low shrinkage and misplacement group in Figure 17 to 21. Variable cost of RFID may help explain the results. High average demand means the system will sell more products. With RFID, each product has a variable RFID cost. When the average demand is high, the total costs of products are high and it may be higher than the benefit RFID can bring in. Our result suggests managers need consider product average demand when evaluating RFID for their products. Another possible reason may be that keeping the other characteristics same, it may be more efficient for RFID to solve inventory inaccuracy problems in low demand products, so low demand products can benefit more from RFID.

Overall, in our study shrinkage and misplacement is most important to ensure products more beneficial from RFID; demand variability is more critical than average demand. Profit improvement is positively associated with shrinkage/misplacement rate, in RFID cases. RFID can directly address misplacement and reflect theft in inventory information, so the importance of shrinkage and misplacement is quite understandable for RFID to contribute to profit.

Once demand variability is introduced, however, its influence on RFID impact is not that intuitive. Usually, it is difficult for managers to manage products with high demand variability which have a huge bearing on the quality of forecast and customer service level. For example, an average weekly forecast error of 45% at the distribution center level is estimated in a CPG supply chain, measured as mean absolute percentage error of forecast with respect to actual sales (Infosys 2009). To compensate high demand variability and avoid stockouts, managers need carry substantially higher level safety stock when a corrective action is not taken as opposed to a system that works to eliminate inaccuracy in inventory record and salable inventory. When a company (e.g. retailer, distributor or manufacturer) applies this method and carries high level of safety stock, the large amount of inventory can cover up stockout problem caused by theft and misplacement. RFID can address theft and misplacement. However, if the company keeps high safety stock to address demand variability, RFID may not be very helpful because at some degree, high inventory compensates the influence of shrinkage and misplacement on inventory replenishment. In other words, shrinkage and misplacement are not such a severe problem anymore if there are enough inventories in stock, in terms of meeting customer demand. Thus, profit is negatively associated with demand variability with common inventory policies.

Our study also indicates that the influence of average demand of product is not as important as demand variability (see Figure 17-22). We measure RFID impact from profit perspective and there is variable cast for RFID implementation. When a product as high demand and RFID variable cost is high, the benefit from RFID may not be able to cover RFID cost though this technology can correct the error in inventory record.

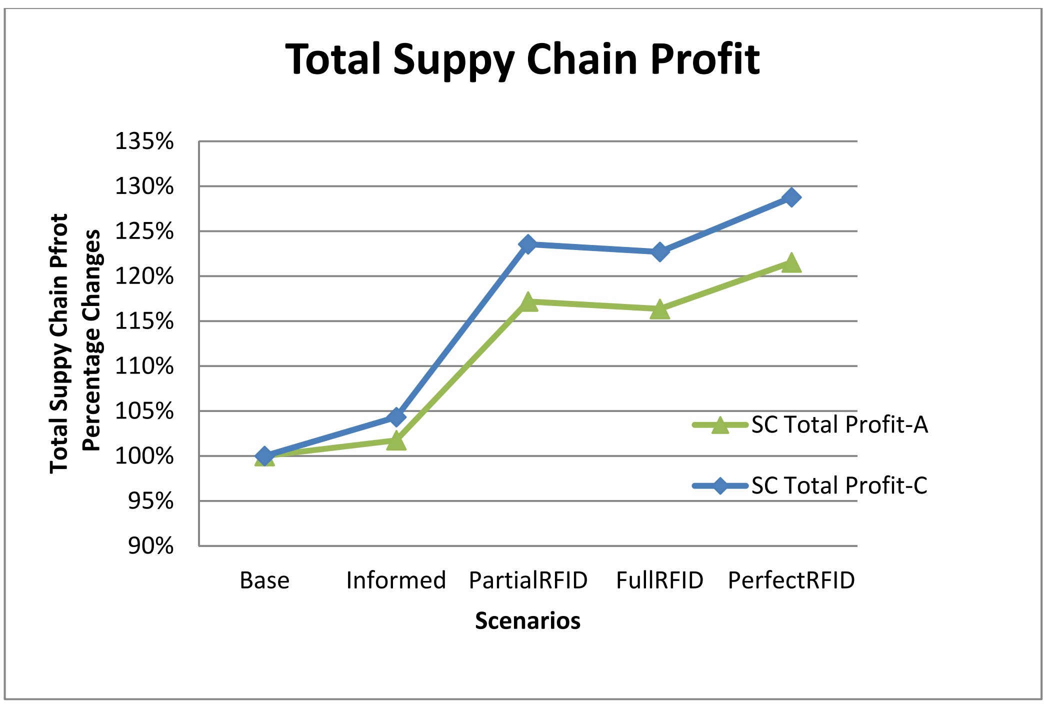

Figure 13: Demand Variability- High Demand-High Shrinkage/misplacement

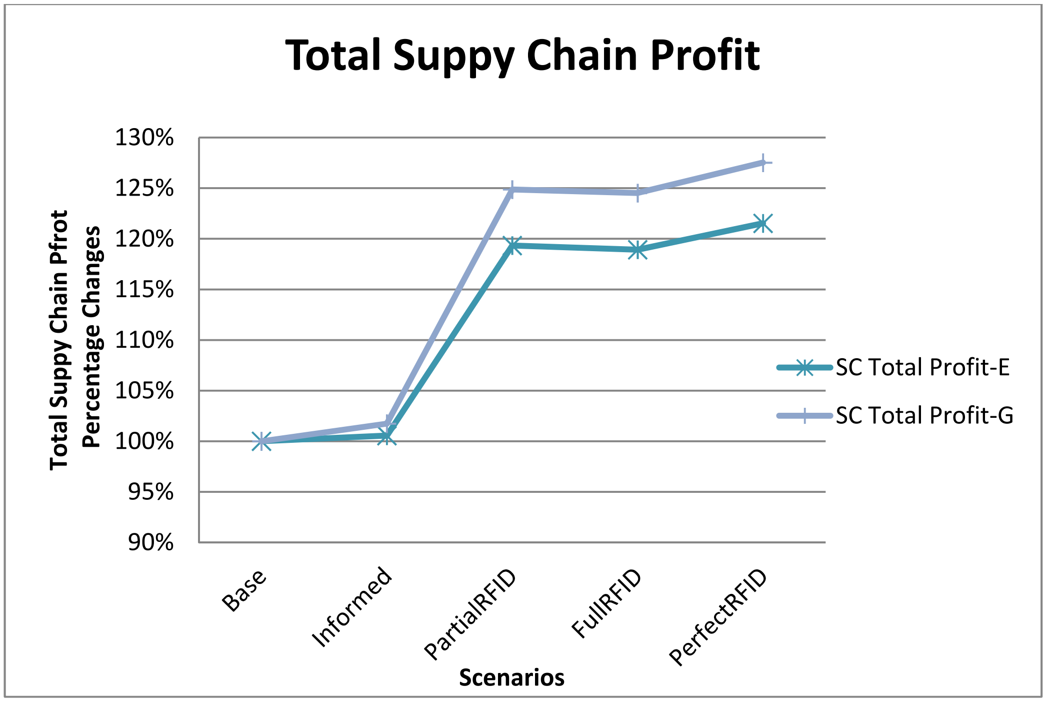

Figure 14: Demand Variability- Low Demand-High Shrinkage/misplacement

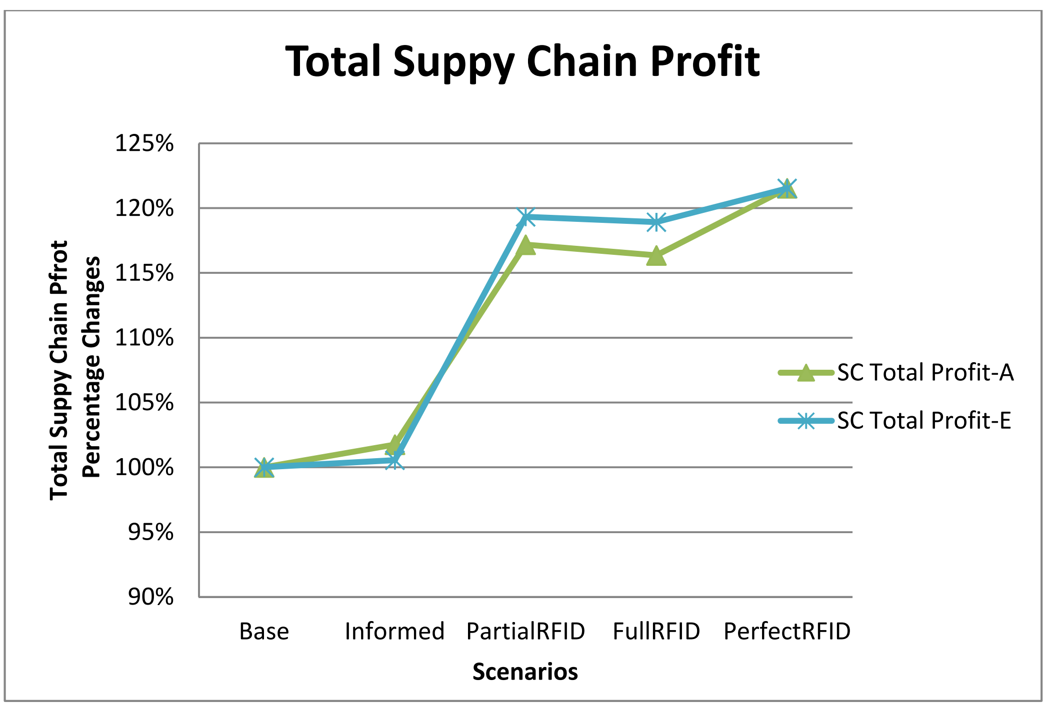

Figure 15: Demand - High Demand Variability-High Shrinkage/misplacement

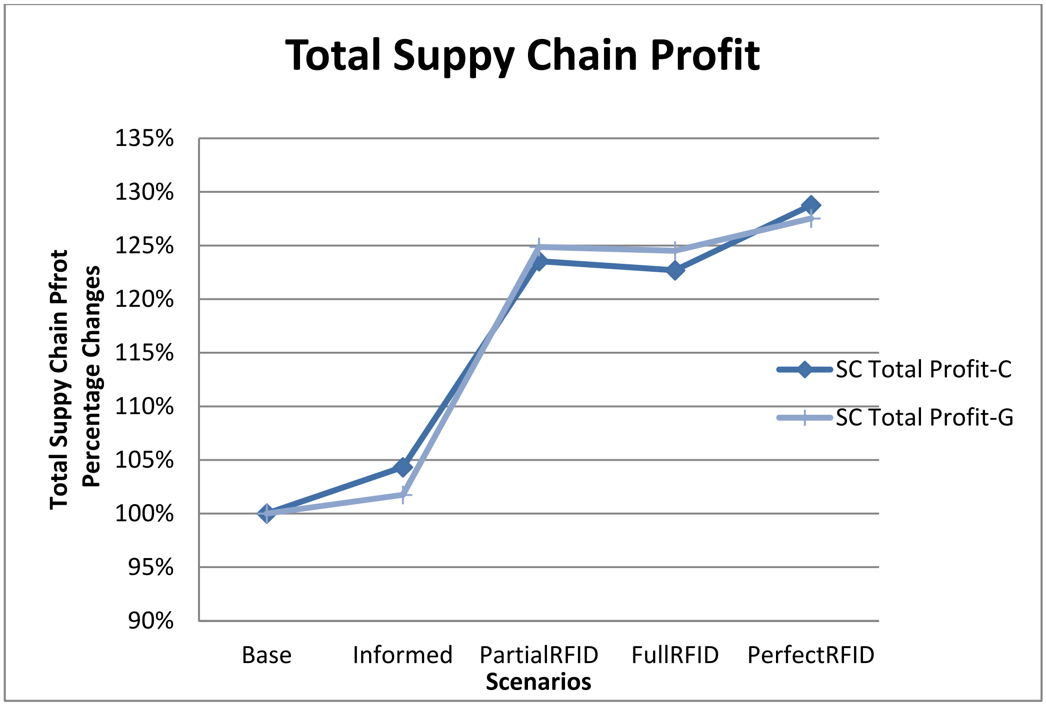

Figure 16: Demand - Low Demand Variability-High Shrinkage/misplacement

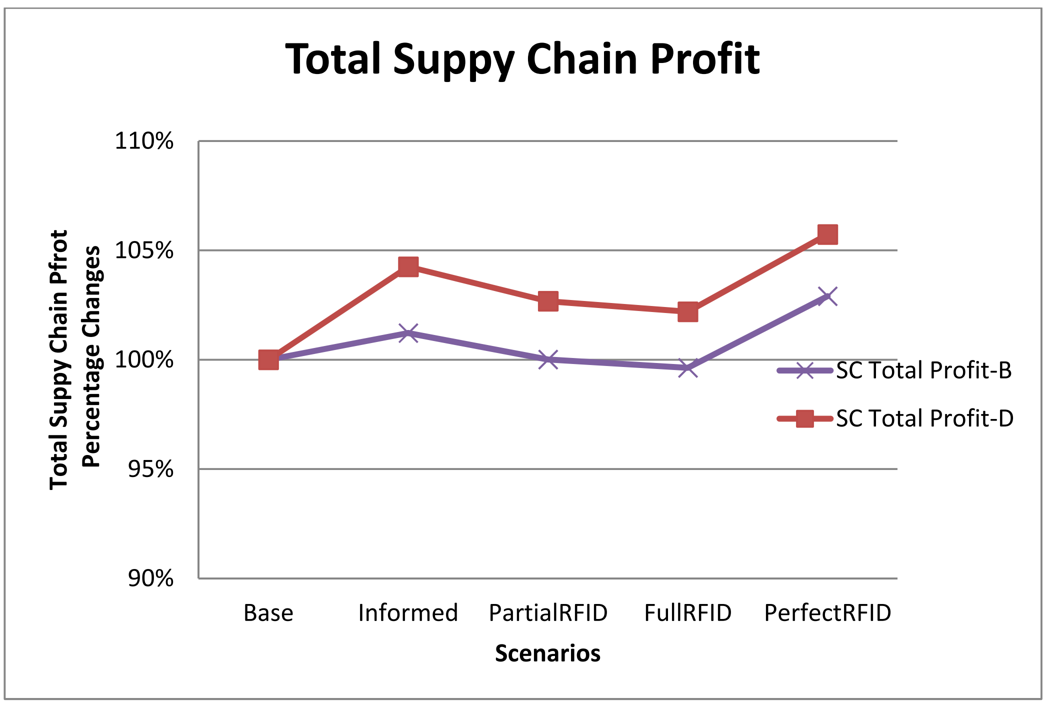

Figure 17: Demand Variability- High Demand-Low Shrinkage/misplacement

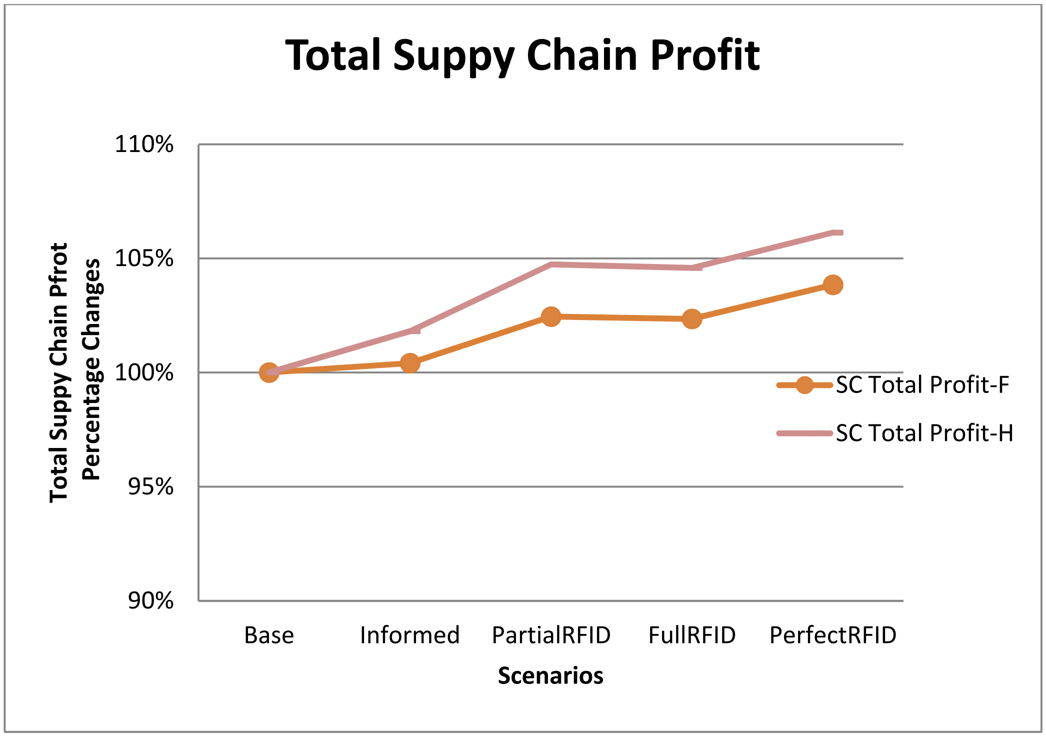

Figure 18: Demand Variability- Low Demand-Low Shrinkage/misplacement

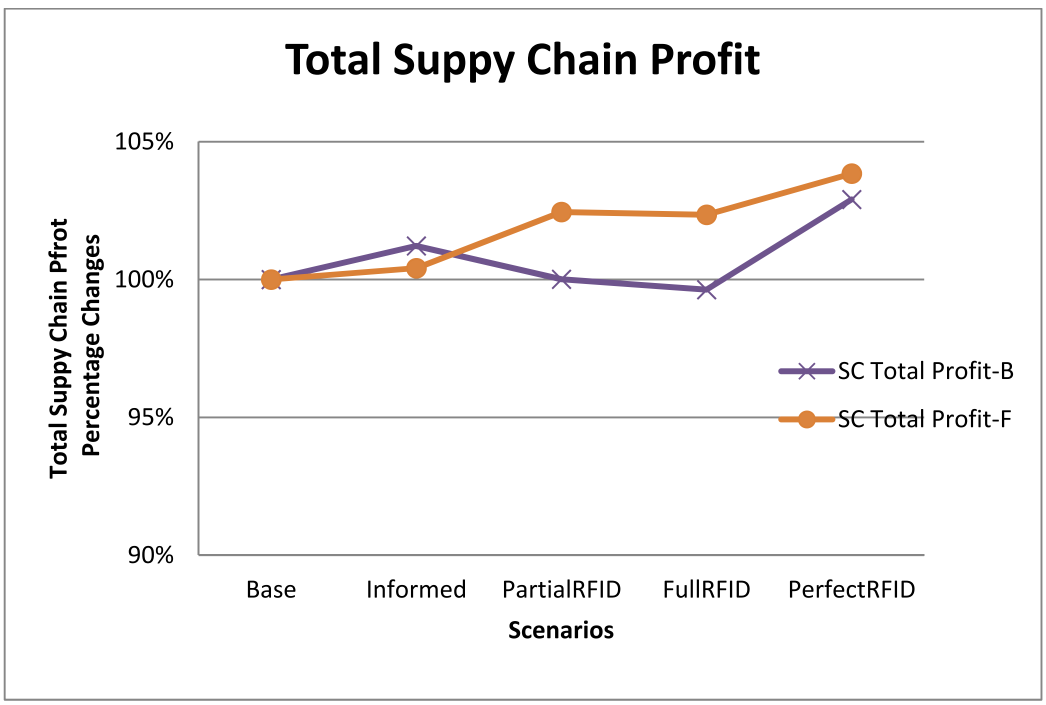

Figure 19: Demand - High Demand Variability-Low Shrinkage/misplacement

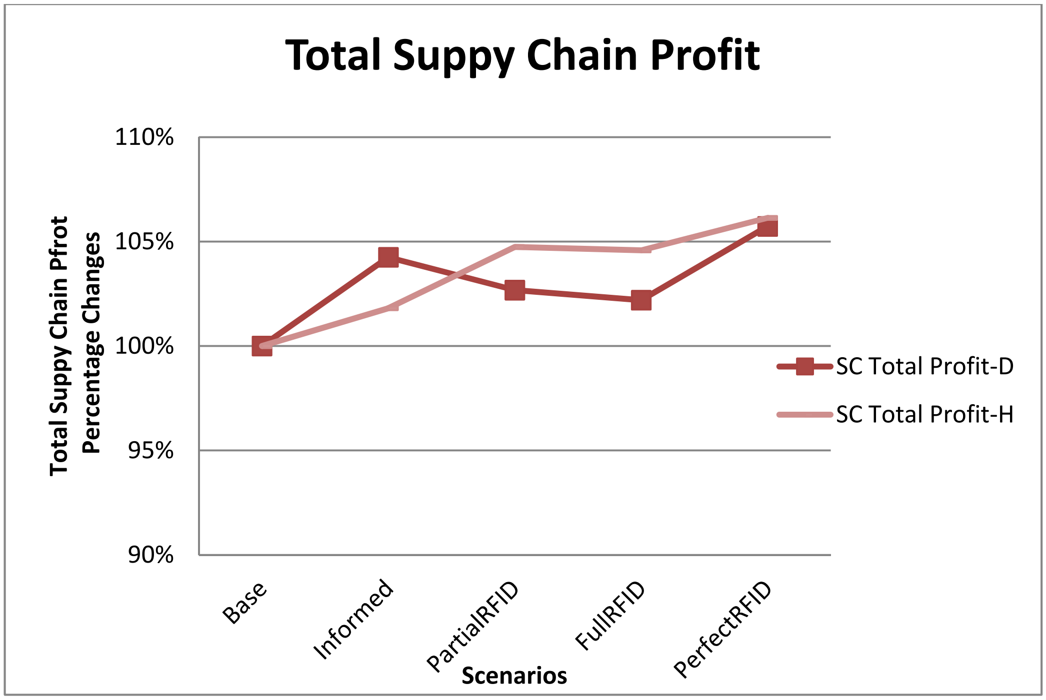

Figure 20: Demand - Low Demand Variability-Low Shrinkage/misplacement

While most of the products in our study benefit from implementing RFID, as expected, RFID may not be able to contribute to total supply chain profit for some products, such as product B in Figure 19. Although product with low shrinkage/misplacement, high demand variability and high average demand gains the highest total supply chain performance in perfect RFID scenario among five scenarios, RFID actually hurts performance in full RFID implementation scenario, compared with partial and perfect RFID cases. It is possible that the benefit from RFID cannot cover RFID cost. In Figure 19 and 20, the results indicate that for product with low shrinkage and high average demand, it is more profitable to apply informed case to address shrinkage and misplacement. This is because RFID is not very suitable to this type of product for profit improvement and there is no cost to make an adjustment in inventory record in informed case. On the other hand, there are variable costs for using RFID, so RFID variable costs are also high when average demand is high.

In previous section, we have broken down total supply chain profit into each player's profit for product A and find that all three players can benefit from RFID. However, one question is left: are the findings from one product consistent across different products? After testing eight products in the five scenarios, we find that who gains most from RFID depends on the product, though overall supply chain still shows improved performance. On the one hand, the retailer obtains greater performance improvement than the manufacturer and the distributor when the supply chain implements RFID for products with low shrinkage. The results are consistent in our study. It is understandable that when a product's shrinkage and misplacement are not very severe at the retailer, usually they are not severe at distributor and manufacturer, either. Under this situation, though the retailer can gain benefit from RFID, it may not be very cost-effective for the distributor and the manufacturer to implement RFID in order to address shrinkage and misplacement problem, considering the cost of RFID. Among three players, the distributor always underperforms, compared to the manufacturer and the retailer. On the other hand, with RFID, high shrinkage and misplacement product creates more profit for the manufacturer than the retailer, because the manufacturer not only gains clear direct benefit from RFID for shrinkage and misplacement but also obtains indirect benefit, such higher order quantity from downstream partner of its supply chain.

For the distributor's performance, RFID does not benefit greatly; sometimes the distributor actually does worse with RFID, as shown in Figure 22 and 24. One possible explanation is that the distributor does benefit from RFID which addresses shrinkage and misplacement; however, in both partial or full RFID implementation scenarios, the order quantities placed from the retailer to the distributor are increased, the distributor then orders even more products from its upstream (i.e. the manufacturer) and holds higher inventory eventually. Thus, the bullwhip effect, which upstream players should incur higher costs because of higher inventories holds in our study.

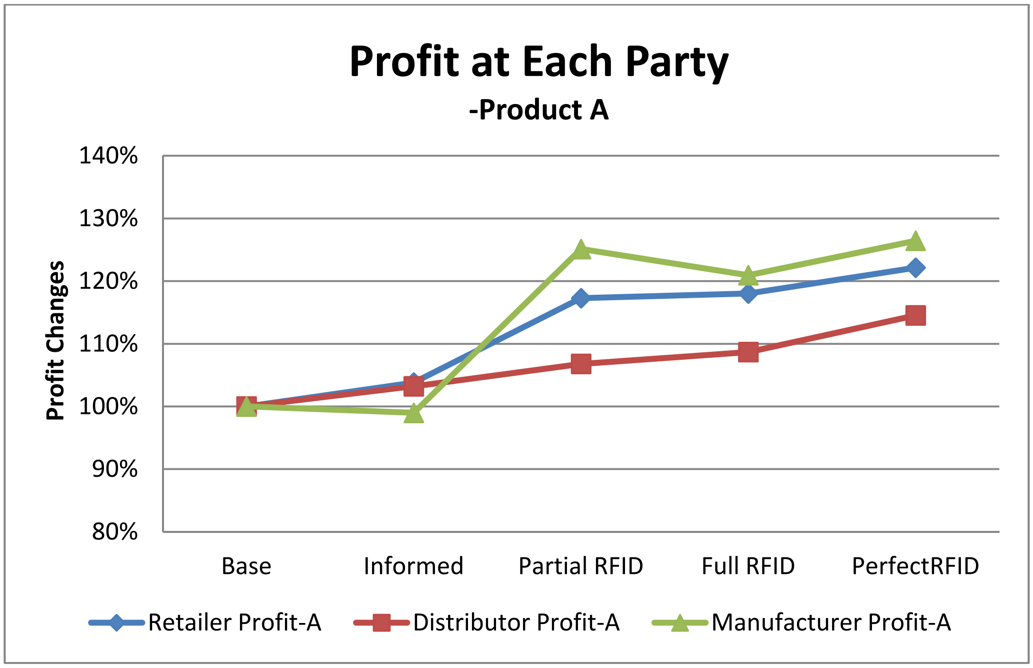

Figure 21: Each Player's Profit for Product A

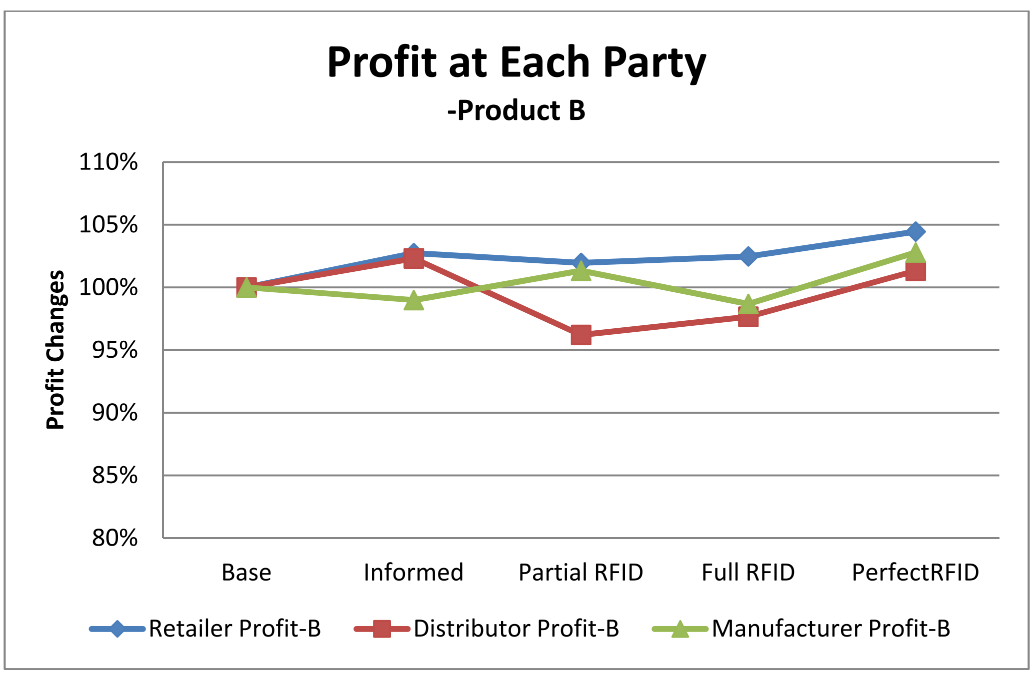

Figure 22: Each Player's Profit for Product B

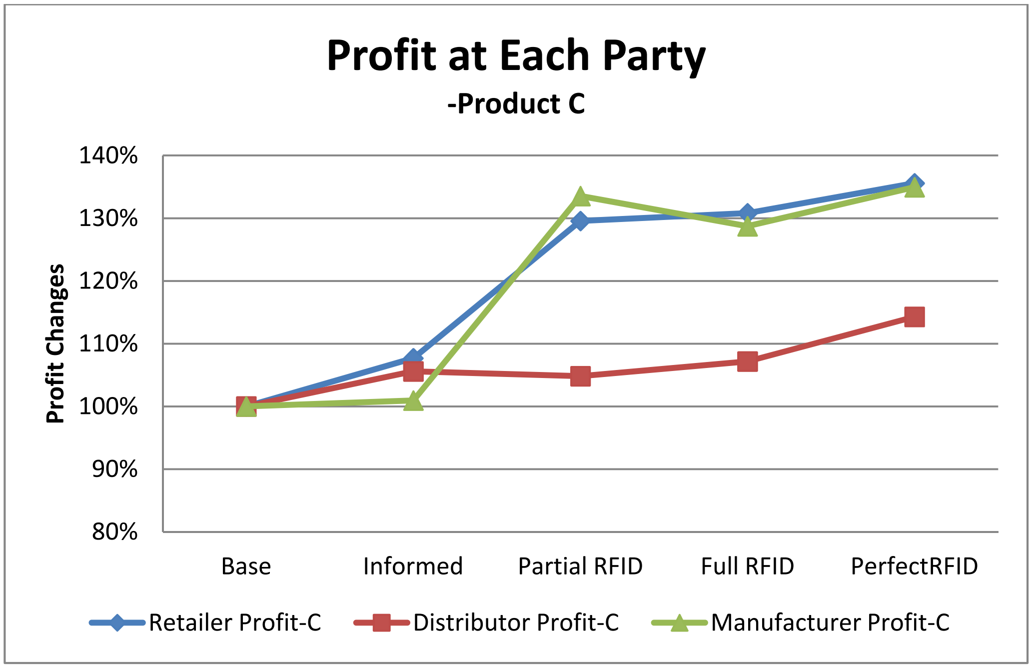

Figure 23: Each Player’s Profit for Product C

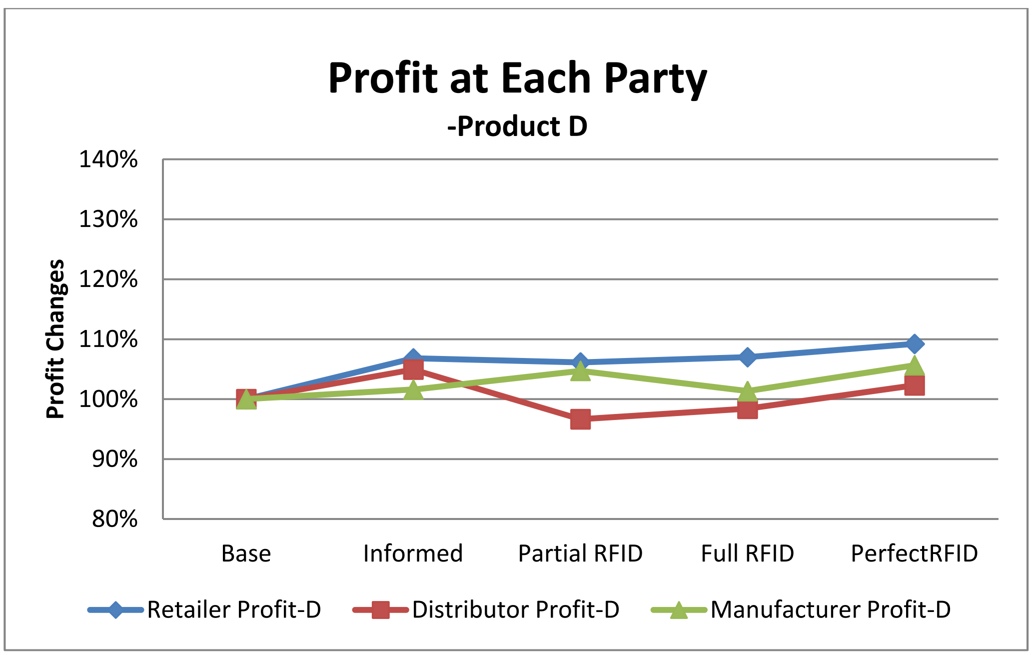

Figure 24: Each Player’s Profit for Product D

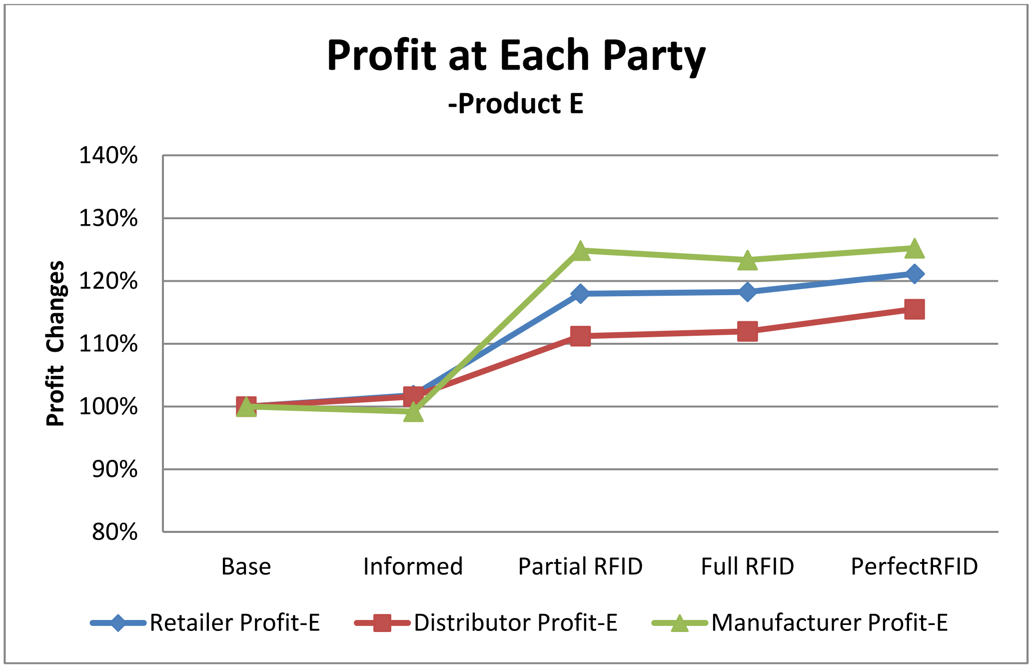

Figure 25: Each Player's Profit for Product E

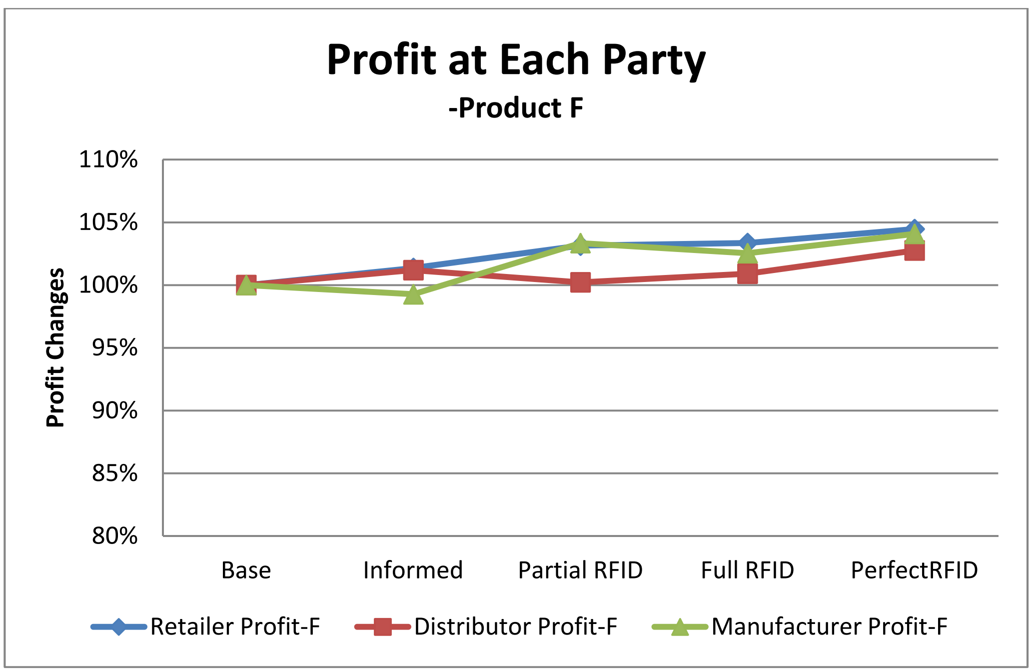

Figure 26: Each Player's Profit for Product F

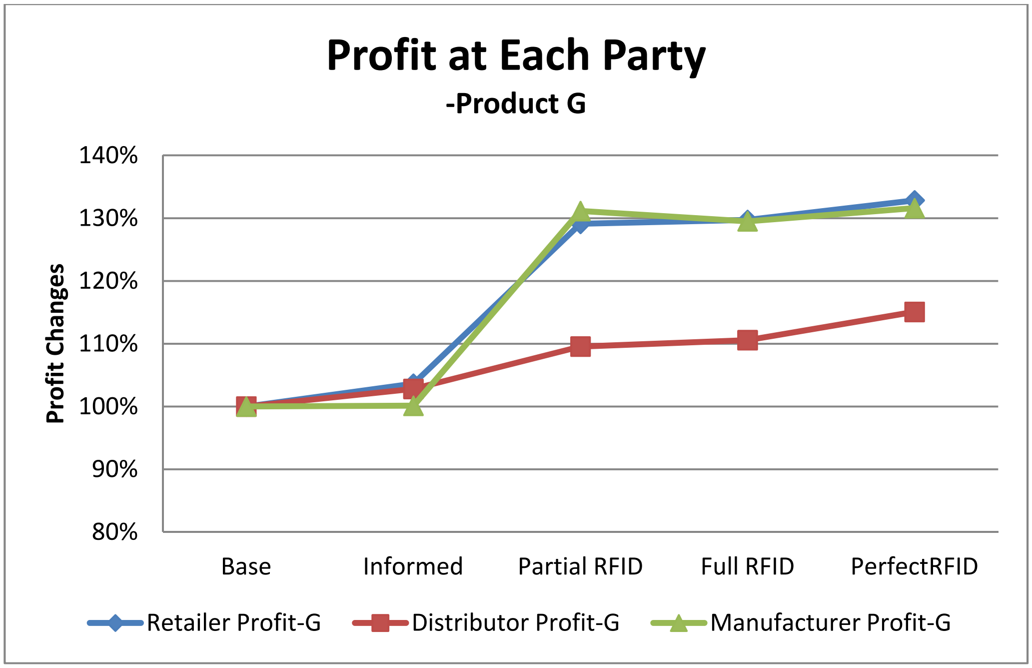

Figure 27: Each Player's Profit for Product G

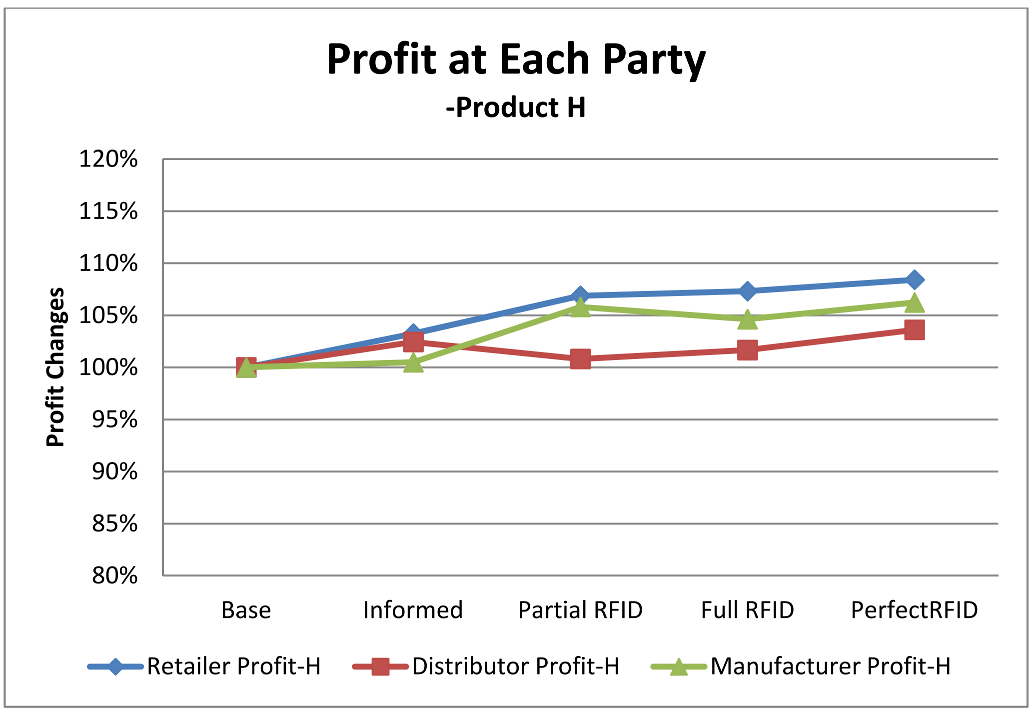

Figure 28: Each Player's Profit for Product H

Next, we consider with RFID, whether products perform consistently at each player in a supply chain as we go upstream. In Figure 29 to 31, although the magnitude of profit improvement for different products at each player is different, the pattern is similar. With RFID, products with high shrinkage and misplacement consistently better perform at each player than those with low shrinkage and misplacement. In other words, RFID helps supply chain partners generate more profit from the same set of products, which have high shrinkage and misplacement issues.

The findings also show that the retailer and the manufacturer almost always perform better than base case and informed case; however, the distributor gains better performance many times in informed case, compared with full or partial RFID cases.

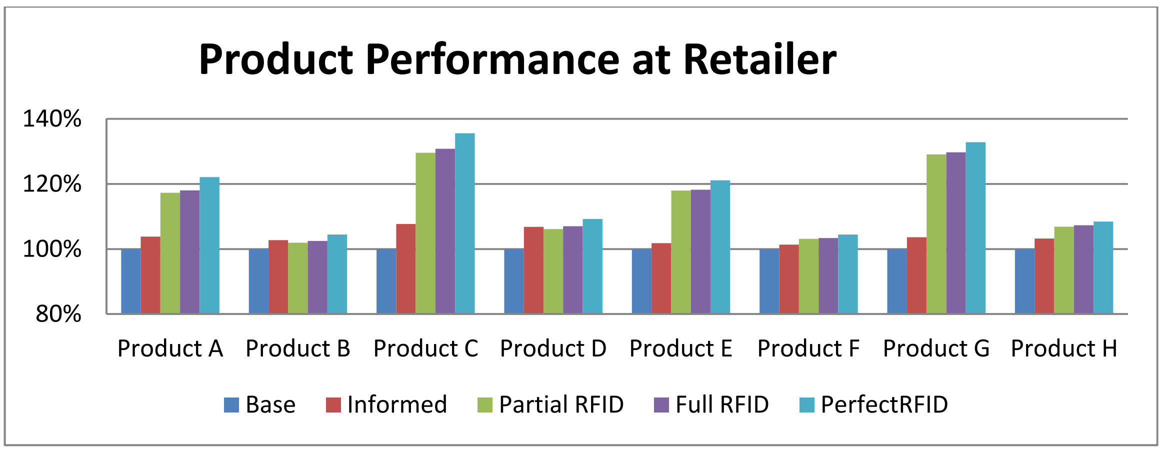

Figure 29: Product Performance at Retailer

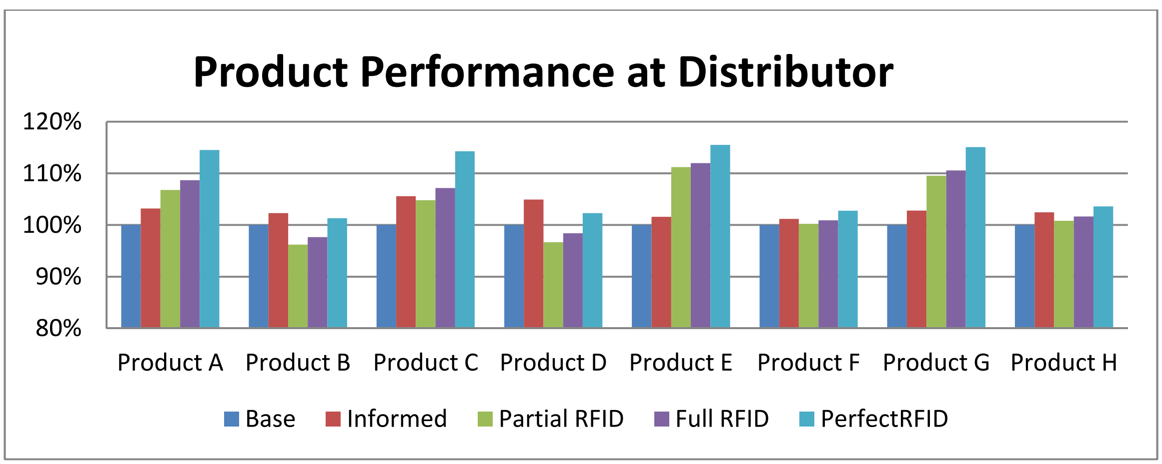

Figure 30: Product Performance at Distributor

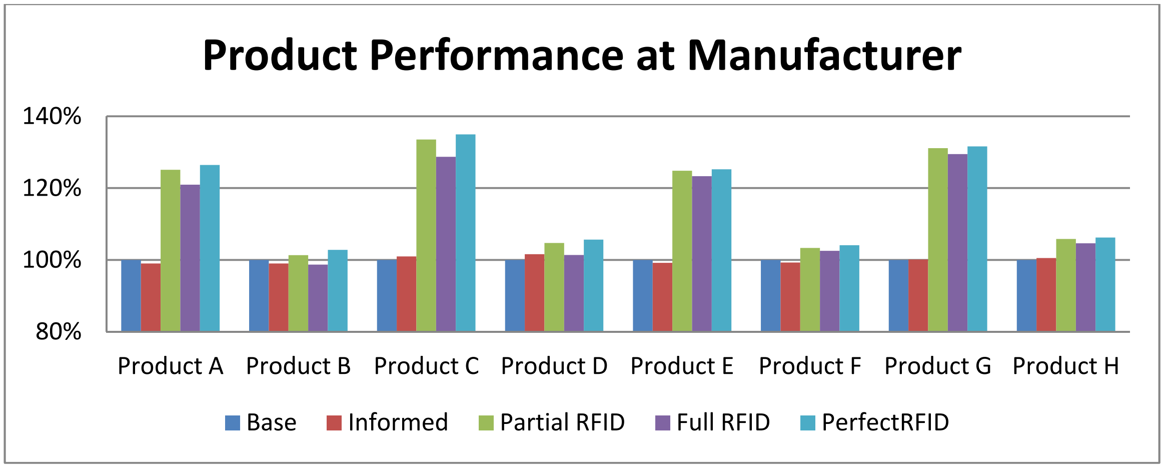

Figure 31: Product Performance at Manufacturer

5.6.3. The Impact of RFID Perfection

Based on the finding from previous sections, product average demand is not as important as shrinkage/misplacement and demand variability for RFID impact, and the results of low demand products have very similar pattern to those of high demand products. Thus, we only pick one of the two groups: low demand group to investigate the impact of RFID read rate on total supply chain performance.

Figure 32 to 35 show some interesting results. First, when a product has high shrinkage and misplacement no matter the demand variability is high or low, total supply chain profit is positively associated with RFID read rate, showed in Figure 32 and 34. There exists a simple, almost perfect linear relationship between total supply chain profit and RFID read rate. The finding confirms that RFID read rate is important to improve total supply chain profit. In other words, total supply chain profit linearly increases when RFID read rate increase for products with high shrinkage and misplacement problems. Figure 33 and 35 indicate that when going into products with low shrinkage and misplacement, we find the similar results but the positive linear relationship becomes flat when RFID read rate reaches high level.

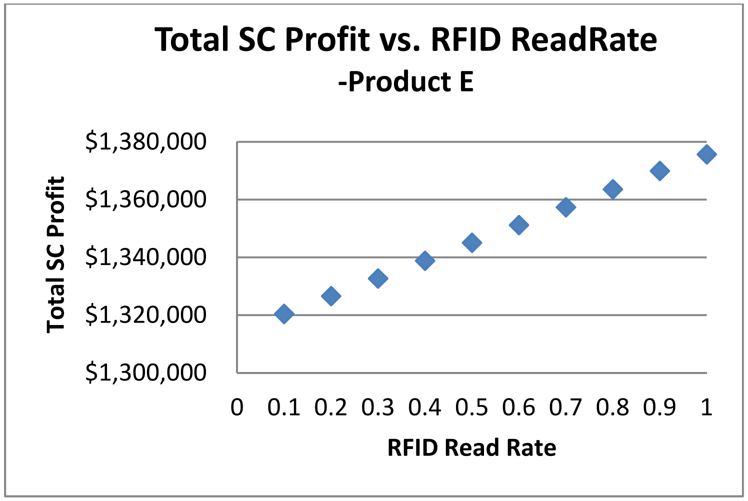

Figure 32: Total SC Profit vs. Read Rate for Product E

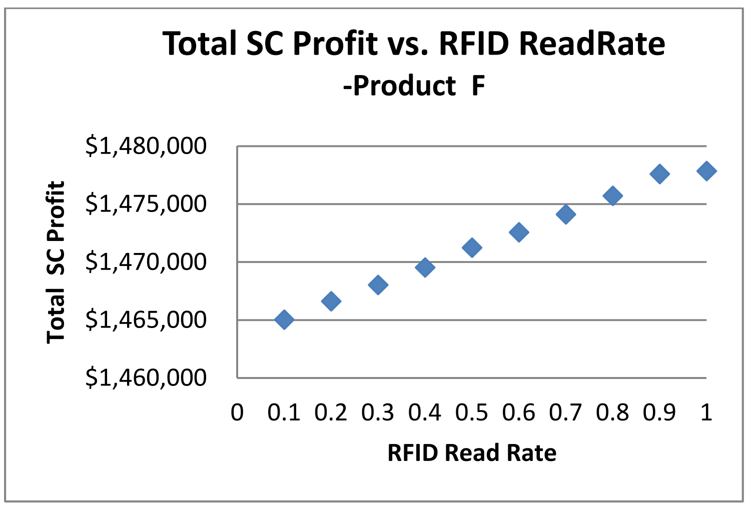

Figure 33: Total SC Profit vs. Read Rate for Product F

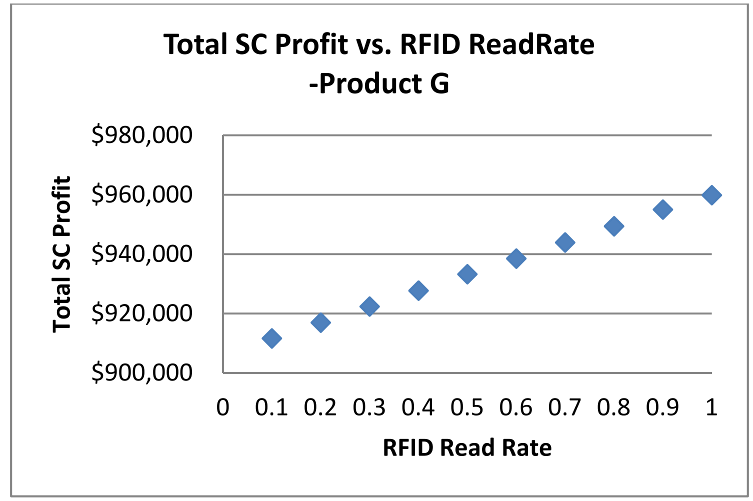

Figure 34: Total SC Profit vs. Read Rate for Product G

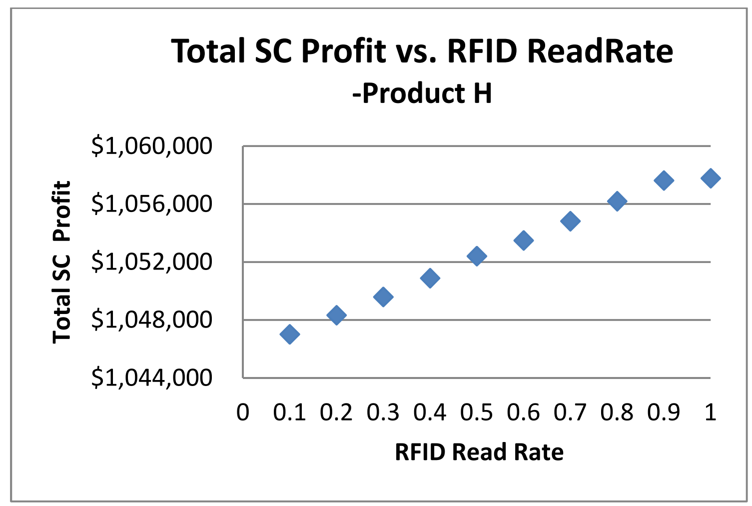

Figure 35: Total SC Profit vs. Read Rate for Product H

5. 7. Discussion

In this chapter, the dissertation investigates how RFID can impact the performance of a three level supply chain in which inventory inaccuracy occurs along the entire supply chain. The main issues addressed by RFID are shrinkage and misplacements in inventory. While there are many RFID value studies in practitioner publications, academic research with a ground-up approach is generally lacking. Building upon prior studies, we examine RFID impact in a multi-level supply with multiple periods and multiple inventory inaccuracy sources under multiple products. We found that (1) RFID can benefit in both partial and full RFID implementation scenarios and for certain types of products, partial RFID implementation even better performs than full RFID implementation; (2) with total supply chain improvement, the retailer and the manufacturer gain more performance improvement than the distributor in the supply chain; (3) product category is critical for RFID to create value from inventory management perspective; (4) while high RFID read rate is important to realize more profit from RFID, the importance is different for different products.

From a research perspective, our study contributes to literature from several aspects. First, our study addresses a severe inventory management problem, inventory inaccuracy through RFID and another possible method. A small rate of shrinkage or misplacement in inventory can significantly affect the replenishment process and create high level of stockouts. This study applies a ground-up approach to model detailed operating characteristics of an RFID-enabled supply chain to capture the value of RFID, instead of making unsubstantiated claims at a higher level about the impact of RFID. In our study, we consider inventory inaccuracy errors caused by both shrinkage and misplacement and their impact on inventory management through a simulation study. We then introduce RFID to address these shrinkage and misplacement issues to examine the value of RFID. Our study provides solid support to RFID value in SCM. Among five scenarios in our study, we find that both RFID and informed cases can compensate to inventory inaccuracy problem and improve total supply chain performance.

Second, the study investigates RFID value in a multi-echelon supply chain with different types of products in multiple time periods. This study also models one possible situation for RFID in a supply chain: partial RFID implementation in which RFID readers and tags are not installed across the supply chain, so the visibility of the supply chain inventory is partial. This study is one of the first studies which incorporate RFID technology in such a complicated setting. We find the interesting results: for some products partial RFID implementation is better for overall supply chain profit. The finding suggests practitioners to rethink how to arrange RFID implementation for different products in their supply chains.

Third and the most important, to our best knowledge, the present study is the first time that a research takes the developing feature of RFID into account when investigating RFID impact in supply chain contexts. As a new technology, RIFD is not going to be perfect on day one. Hence, there could be misreads and missing reads because of the current development status of RFID application in SCM. This consideration makes the study more realistic and fills the gap in existing literature in which RFID is treated as a perfect technology and can provide 100% supply chain visibility. Our model offers the mechanism of how imperfect RFID works in inventory management system and provides understanding in the impact of RFID read rate on total supply chain performance.

Fourth, by considering RFID cost in a complex supply chain and using total supply chain profit as the performance measure to analyze RFID value, the study provides more insights of RFID value, as suggested by Atali et al. (2005) and Lee et al. (2005). Our study clearly models the structure of profit and how RFID costs and benefits are shared among all players in a supply chain. Overall, the study is a step toward concretely measuring the value of RFID in supply chain and can be used with other technology implementation which can eliminate or at least reduce inventory accuracy.

From a practitioner perspective, our study has demonstrated the mechanism of how RFID impacts supply chain operation and performance from an inventory management perspective. Our findings provide implications for managers. First, the results indicate that company can benefit from RFID from an inventory management, depending product type. Through a concrete, bottom-up simulation study, we offer managers a useful simulation model to assess RFID value with their own products before they conduct any costly experimental or laboratory exploration when they consider RFID in their supply chain. Because this study models RFID as an imperfect technology in SCM, the value of RFID is not overestimated as in existing literature. Our model provides a first picture on possible profit improvement RFID can bring in. To do so, managers just need to apply their own data in our simulation model and evaluate whether introducing RFID is beneficial or not for their entire supply chain.

In particular, our study subtracts a constant term when calculating inventory record for inventory position calculation among all three players in informed case, and informed case is a better basis to compare RFID value. This informed case does not exaggerate the value of RFID and provides managers an alternative method to address inventory inaccuracy problem with very low or no cost. We also model RFID as imperfect technology, it can only provide incomplete or inaccurate information, and thus managers make the best decision by considering the probabilistic uncertainty of the information.

Further, our study shows that retailer and manufacturer consistently gain more benefits than distributor from implementing RFID. For majority of products, our study shows that retailer gains the larger profit improvement. This may explain why most of times RFID adoption is initiated from retailers and they push its upstream partners to adopt this technology. For manufacturers, our study also shows significant improvement with RFID. Plus, for products with high demand variability and shrinkage/misplacement problems, manufacturers even benefit most. Downstream partners, such as Wal-Mart can apply our results to convince its manufacturers to implement RFID for inventory management.

Furthermore, in contrast to what was expected, partial RFID implementation case better performs than full RFID scenario, in terms of total supply chain performance. When getting into the profit changes at each party in the supply chain, we find that the performance changes at the retailer and the distributor are positive when moving from partial RFID implementation to full RFID implementation and only the manufacturer's performance change is negative. However, the absolute changes are still big, compared to base case and informed case. It implies that the manufacturer should gain large indirect benefit from others' RFID implementation such as more accurate orders. In other words, order quantities are increased from the retailer to its upstream supply chain partners when retailer has RFID information. Retailers can use our results to convince its manufacturers to implement RFID even for the products with low shrinkage and misplacement problems.

Next, our results indicate that RFID benefits largely depend on product type, in terms of demand variability and shrinkage/misplacement. This finding suggests that some products are more suitable to implementing RFID for its inventory but others may not. When companies evaluate RFID for inventory management, managers should consider whether their products are suitable to this technology, in terms of the magnitude of average demand, demand variability, and more important, the severity of shrinkage and misplacement. Of course, RFID prefers to products with high shrinkage and misplacement. Low demand variability also makes RFID contribute more to profit imporovement. This finding not only implies that companies produce products with low demand variability should consider RFID but also that companies who targets to minimize cost may also use RFID. For example, when a company wants to keep its cost low, it may like to hold fewer inventories and at the same time satisfy customer demand. Under this situation targeting cost-effective, RFID may help. RFID can correct errors in inventory record and make inventory record closer to salable inventory. Plus, RFID can increase salable inventory by detecting and returning misplacement to correct locations.

Further, our finding suggests that it is important to consider RFID development status when implementing RFID for inventory management because total supply chain profit is positively associated with RFID read rate and the relationship is linear. However, it is worthy to know that for products with low shrinkage and misplacement, the speed of profit growth is slower after RFID read rate reaches to a certain level.

5.7 Limitations and Future Research

This study richens our understanding of the mechanisms of how RFID impact total supply chain performance from an inventory management perspective. As every research has its own limitations, this research also has some limitations. First, we do not consider order cost and set order-up-to level equal to reorder point. Although it is reasonable setting, it would be worthwhile to include order cost and then set order-up-to level to a higher value. Second, we assume lead time between each player of the supply chain is stable and consistent by following previous research on RFID value study (e.g. Lee et al. 2004). However, lead time is a critical reason for SCM and uncertainty. It would be closer to reality if we would set lead time as certain distribution to reflect the uncertainty in lead time. Third, although we have tried our best to use as many published values as possible for parameters in this study, it would be even better if we could find a set of product information from industry. It would make our study even closer to reality. Fourth, we only set up a base supply chain model, and then apply RFID or informed method into the base case to compare performance changes with base case. It would be worthy to introduce optimization in our model. Fifth, in order to use a same basis to compare the value of RFID, we did not investigate RFID tag cost when we examine the relationship between read rate and total supply chain profit. Last, we did not investigate the impact of price on RFID value since we did not include any optimization in our model. It would be interesting to find a critical RFID price for benefiting from RFID.

Our study can be extended in several ways. As discussed earlier, future research can add more uncertainty to the study. For example, lead time can be modeled as certain distribution to represent its uncertainty. Those settings will make research more closely reflect reality. Second, it would be interesting to add optimization into the model to find the best business value of RFID in SCM, which aligns with the purpose of typical analytical studies. Third, the partial RFID implementation scenario (the distributor installs RFID tags and the retailer can also use the tags to collect information on the product) examined in our study is only an example of many partial RFID implementation cases. Since we find there is difference between the partial RFID implementation and full RFID implementation, it would be interesting to explore other possible partial RFID implementations. For example, the retailer installs RFID and only it can get direct benefit from RFID, but other players can benefit indirectly. Finally, we assume RFID costs are shared equally among its direct users in our study. It would be worthwhile to investigate the cost sharing policy to maximize total supply chain profit.

CHAPTER 6: CONCLUSION

The main objective of this dissertation is to examine the diffusion and impact of RFID in supply chains. Multiple methodologies, including empirical modeling and analytical simulation approach have been applied to study the phenomena. In this dissertation, RFID diffusion includes multiple stages: adoption and infusion, which are empirically investigated in Chapter 3 and Chapter 4, respectively. Chapter 4 also examines the consequence of RFID infusion: firm process performance from a supply chain perspective. In Chapter 5, the impact of RFID technology on supply chain performance is examined by applying an analytical model and simulation approach to unlock RFID value for SCM.

Drawing on the literature in technology diffusion and SCM, an integrated model of RFID adoption is first proposed and examined with empirical data collected from 159 industry professionals in Chapter 3. The results indicate that trading partner issues (i.e. trading partner power and RFID capability) are important for a firm to make a decision to adopt RFID. This finding confirms our expectation because RFID has its unique features and its implementation can heavily involve trading partner's cooperation. The study also suggests that currently a firm more likely adopts RFID along supply chain when the transaction volume is low. This may imply the early stage of RFID adoption, so firms can actively involve in RFID activities but limit its investment for any possible risk.

After examining RFID adoption, Chapter 4 takes one step further to study RFID infusion. A comprehensive RFID infusion model is proposed and is validated with data collected from 169 supply chain and IT professionals. In addition, the research also investigates performance gains from using RFID. The results indicate that adoption cost, complexity, organizational readiness, external pressure and trading partner readiness significantly influence RFID infusion, and RFID implementation maturity is positively associated with RFID use. The results demonstrate the value of RFID from RFID use.

Both empirical studies find that trading partner issues play important roles in RFID diffusion. Trading partner power, RFID capability and coordination contribute to RFID adoption and infusion. These findings confirm the necessity to investigate the issues related to trading partner side for the diffusion of supply chain technology, such as RFID. The results also demonstrate the role of product type for performance improvement that RFID can bring in. The results of these two empirical studies do not show the impact of technology maturity on RFID diffusion. This is different from practitioners' concerns for RFID diffusion.

Chapter 5 focuses on the impact of RFID on supply chain performance from an inventory accuracy perspective. It is desirable to investigate RFID value at supply chain level because supply chain trading partners should work cooperatively to reap the full benefits from RFID. The simulation study shows that whether each player of a supply chain and the entire supply chain can benefit from RFID heavily depends on the type of the product implemented with RFID. It is consistent with the finding in Chapter 4. For total supply chain improvement, the retailer and the manufacturer gain more performance improvement than the distributor in the supply chain. The simulation work also indicates that while RFID development status is important to realize more profit from RFID, the importance is also different on products. This result supports our findings from two empirical studies.

In the dissertation, the first two empirical studies broaden our view in what factors are critical for RFID adoption and infusion and the third study helps unlock the value of RFID in supply chains. Each study has its own focus on RFID diffusion's early stage-adoption, later stage- infusion and firm performance, and its impact at firm and supply chain performance levels.

The dissertation has made several contributions to academic literature on technology diffusion and IT value. At the same time, it also provides managerial implications for industry practitioners. First, empirical studies not only extensively evaluate possible important factors for RFID adoption and infusion from literature but also identify possible factors (e.g. technology maturity, absorptive capability, industry collaboration) which may be important but have not been investigated yet in literature. With a larger data set, generalizability of the results is improved. Second, this dissertation consolidates segmented findings for RFID infusion into a more comprehensive model by integrating innovation diffusion theory, IT business value, and SCM literature. Third, the study confirms the importance of supply chain trading partner issues for supply chain technology diffusion. Finally, this dissertation also contributes to literature on inventory management with a simulation model that investigates detailed operating characteristics of an RFID enabled supply chain.

This dissertation improves our understanding of RFID diffusion in supply chains and its impacts on the partners in a supply chain. However, there are some limitations of my empirical and simulation studies. First, the two empirical studies applied cross-sectional survey methodology, which cannot allow us to make any causality arguments in the hypothesized relationships. It would be interesting to collect longitudinal data to examine RFID diffusion in a longer time period and to examine the causality in the relationships among the variables. Second, the empirical studies did not find technology maturity and attractiveness to be statistically significant for RFID diffusion. Future research can refine the instruments for the constructs and also test these variables for other emerging supply chain technologies. Third, the infusion study only considered product unpredictability as a control variable. The simulation work in this dissertation suggests that it would be interesting to empirically examine managers' perception about what product features are more suitable for RFID infusion. Fourth, the simulation study did not consider the fixed costs for RFID implementation and use (i.e., the costs for the RFID readers and system integration). However, the results from RFID infusion study suggest that high adoption cost drives RFID use. By introducing the fixed cost in the simulation work, future research can make the cost structure closer to the one in reality and examine the importance of fixed costs in RFID value creation. Fifth, this dissertation only conducted sensitivity analysis for RFID read rate on total supply chain profit. Further sensitivities analyses can be done for other parameters, such as counting periods, holding cost, and product price in future research. Finally, the dissertation only investigated one example for partial RFID implementation. Future research could investigate other possible partial RFID implementations and compare the differences among them.

With the completion of this dissertation, Chapter 3, 4 and 5 will generate three journal publications. The first journal paper focuses on RFID adoption, the second examines RFID infusion and its consequence, and the third presents a study for RFID value creation with simulation approach. With a process-oriented view, combining RFID adoption and infusion parts will generate the fourth paper to extend our understanding on RFID diffusion with a process-oriented view. Table 19 summarizes the publication plan for the dissertation.

Table 19 Publication Plan

Working Title of Paper	**Presented or Published**	**Target Journals**
Investigation of Radio Frequency Identification (RFID) Adoption in Supply Chain	HICSS 42 JOCEC	DSI DSS EJIS
Usage and Value of Radio Frequency Identification (RFID) in Supply Chains: An Empirical Study	HICSS 42 WEB 2009	MISQ JMIS
A Simulation Study on The Impact of RFID on Firm and Supply Chain Performance from An Inventory Accuracy Perspective	ICIS2011	MS POM
The Process of RFID Diffusion in Supply Chains: A Multi-Stage Study		ISR JMIS

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APPENDIX A: SURVEY INSTRUMENT

I. RFID Study-Adoption Section

(The specific construct measured is given within brackets for each item and are removed in the actual survey)

1) Has your company considered adopting RFID in the selected product line/supply chain? (RFID adoption)

- o Considered and will be adopting.
- o Considered and may be adopting.
- o Considered and may not be adopting.
- o Considered and will not be adopting.
- o I don't know.

2) Please indicate the extent to which you agree or disagree with each of the following statements.

The use of RFID in the selected supply chain can provide the following benefits for the selected product line/supply chain. (Perceived benefits)

Strongly Disagree Disagree Neutral Agree Strongly Agree

Reduce inventory costs

Improve customer service

Improve access to information

Increase visibility of supply chain operations

Improve operational efficiency

Improve the coordination with supply chain partners

Improve the quality of decision making

Increase competitiveness of the supply chain

3) Please indicate the extent to which you agree or disagree with each of the following statements about RFID technology and its potential impact on your supply chain.

Strongly Disagree Disagree Neutral Agree Strongly Agree

If you were to use RFID, your supply chain has to make significant changes to its current processes. **(Compatibility)**

Using RFID does not require significant changes to your current supply chain information systems. **(Compatibility)**

Using RFID would not be easy for your employees to adjust to. **(Compatibility)**

RFID components, software, and services are readily available in the market. (**Technology maturity)**

The costs of RFID components, software, and services have reduced to a reasonable and stable level. **(Technology maturity)**

RFID technology is routinely used by many organizations in their supply chains. **(Technology maturity)**

A commonly agreed standard exists for RFID components, software, and services. **(Technology maturity)**

RFID technology has become stable enough for use in supply chain activities, in terms of readability, failure rate, and so far. **(Technology maturity)**

4) Please indicate the extent to which you agree or disagree with each of the following statements.

RFID implementation involves:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
coordinating with multiple user units. **(Complexity)**					
multiple software environments. **(Complexity)**					
multiple technology platforms. **(Complexity)**					
integration with multiple other systems. **(Complexity)**					

5) Please indicate the extent to which you agree or disagree with each of the following statements.

In general, information technology is important in your company:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
for improving efficiency and productivity. **(IT sophistication)**					
for effective decision-making. **(IT sophistication)**					
for effective customer service. **(IT sophistication)**					
for improved competitiveness. **(IT sophistication)**					

6) Please indicate the extent to which you agree or disagree with each of the following statements.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The current IT resources of your company are enough to support implementing RFID technology. **(IT sophistication)**					
The information technology professionals of your company have the necessary skills to implement and manage RFID applications. **(IT sophistication)**					

Your company's top management actively promotes the potential of RFID for your supply chain. **(Top management support**)

Your company' top management provides stable and sufficient funding to implement RFID. **(Top management support**)

7) Please indicate the extent to which you agree or disagree with each of the following statements.

It will be challenging for your company to find external consultants:

Strongly Disagree Disagree Neutral Agree Strongly Agree

to train your employees for using RFID. **(External support)**

to solve RFID technology problems. **(External support)**

to help with RFID implementation. **(External support)**

8) Please indicate the extent to which the following statements apply to your competitors and your industry.

Strongly Disagree Disagree Neutral Agree Strongly Agree

In your industry, the adoption of RFID technology is critical to remain competitive. **(Competitive pressure)**

You believe using RFID in the selected supply chain will give your company an edge over your competitors. **(Competitive pressure)**

9) Please indicate the amount of influence your trading partner in the selected product line/supply chain had in your company's decision whether or not to adopt RFID. (Partner power)

- No influence
- Some influence
- Moderate influence
- Strong influence
- Very Strong influence

10) Please select from the following options the one which most fits the role played by your trading partner in adopting/using RFID in the selected supply chain. (Partner power)

No encouragement or pressure: Your trading partner did not attempt to encourage RFID adoption.

Information Exchange: Your trading partner provided information regarding RFID.

Recommendation: Your trading partner recommended your company to adopt RFID.

Request: Your trading partner asked that your company adopt RFID.

Promise: Your trading partner made promises regarding the benefits to your company by adopting RFID (promises could include discounts, faster orders, etc.).

Strong Pressure: Your trading partner made clear that not adopting RFID could have negative business consequences for your company (such as discontinuing the relationship, hints that non-RFID customers would receive poor service, etc.).

11) Please indicate the extent to which each of following statements applies to your trading partner if your trading partner in the selected product line/supply chain already has RFID.

Strongly Disagree Disagree Neutral Agree Strongly Agree **Does not apply**

RFID technology of the trading partner in the selected product line is interoperable with your company's information systems. **(Partner RFID capability)**

Your trading partner has RFID technology ready to conduct business with your company. **(Partner RFID capability)**

Your trading partner has conducted business with its other trading partners with using RFID. **(Partner RFID capability)**

Your trading partner has benefited greatly from using RFID technology. **(Partner RFID capability)**

12) Please indicate the extent to which each of the following percentages applies to your company/trading partner in the selected product line/supply chain.

<10%, 10% to <20%, 20% to <30%, 30% to <40%, 40% to <50%, 50% to <60%, 60% to <70%, 70% to <80%, 80% to <90%, >=90%

As a percentage of your company's total annual revenue from the selected product line, approximately, the percentage of the transaction with your trading partner is: **(Transaction volume)**

As a percentage of your trading partner's total annual revenue from the selected product line, approximately, the percentage of their transaction with your company is: **(Transaction volume)**

13) Please select the closest percentage for your company's IT operational budget, as a percentage of your company's total annual revenue: (Financial resources)

<1%, 1% to <2%, 2% to <3%, 3% to <4%, 4% to <5%, >=5%

14) Please select the closest percentage for your company's IT staffing (IT and IT support), as a percentage of your company's total workforce: (Financial resources)

<2%, 2% to <4%, 4% to <6%, 6% to <8%, 8% to <10%, >=10%

15) Considering your company's overall IT budget, how significant is the financial cost of developing and implementing RFID system? (Financial resources)

- o Not at all significant
- o Somewhat significant
- o Significant
- o Quite significant
- o Extremely significant

16) What is the extent of RFID adoption by your competitors in your industry currently? (Competitive pressure)

- o None has adopted.
- o Very few have adopted.
- o Some have adopted.
- o Many have adopted.
- o Almost all have adopted.

Background Questions

17) Job title (select one).

President, Managing Director, CEO

Corporate Officer, CIO, CTO, VPs

IT Director, Manager, Planner

Business Director, Manager, Planner

Others

18) Years with your current company.

< 1 year

1 to <3 years

3 to <5 years

5 to <8 years

>= 8 years

19) Total years of your work experience.

< 5 years

5 to <10 years

10 to <15 years

15 to <20 years

>= 20 years

20) Industry category which best describes the focus of your company (select one).

Manufacturing
Logistics/Transportations
Warehousing
Wholesaler/distributor
Retailing
Healthcare
Others (please specify)

21) Number of employees in your company.

<100
100 to < 500
50 to <1,000
1,000 to <3,000
3,000 to <5,000
5,000 to <10,000
>= 10,000

22) Annual revenues of your company.

<$1 million
$1 to <$10 million
$10 to <$50 million
$50 to <$100 million
$100 to <$500 million
>= $1 billion

23) Location of your company/division.

US
Canada
Europe
South America
Asia except China
China
Oceania
Africa
Other

24) Please indicate the extent of your knowledge of RFID technology, in general.

- Extremely familiar
- Very familiar

- Familiar
- Somewhat familiar
- Not familiar

25) Please indicate the extent of your knowledge of RFID technology in the selected product line/supply chain.

- Extremely familiar
- Very familiar
- Familiar
- Somewhat familiar
- Not familiar

26) Please indicate how familiar you are with the supply chain operations of your trading partner for the selected product line/supply chain.

- Extremely familiar
- Very familiar
- Familiar
- Somewhat familiar
- Not familiar

27) Please provide the name of your company. This will help the researchers aggregate multiple responses that are received from the same organization. (optional).

II. RFID Study-Infusion Section

1) Has your company adopted or piloted RFID technology in the selected product line/ supply chain?

- Yes, adopted RFID.
- Yes, piloted RFID.

2) How long has your company been using RFID for the selected product line/supply chain?

Less than 6 months, 6 months -1 year, 1-3 years, 3-5 years, More than 5 years

3) How long has your company been using RFID for supply chain activities, in general?

Less than 6 months, 6 months -1 year, 1-3 years, 3-5 years, More than 5 years

4) From the following <u>uses of RFID</u>, please select the one that best describes your company's use of RFID in the selected product line/supply chain.

- Apply only RFID tags.**(Implementation Maturity)**

- Apply RFID tags and use readers and software to help decision-making for internal supply chain operations.**(Implementation Maturity)**
- Apply RFID tags and use readers and software to help decision-making for external supply chain operations with a single supply chain partner. **(Implementation Maturity)**
- Apply RFID tags and use readers and software to help decision-making for internal and external supply chain operations with a single supply chain partner.**(Implementation Maturity)**

- Apply RFID tags and use readers and software to help decision-making for internal and external supply chain operations with multiple supply chain partners.**(Implementation Maturity)**
- **Other (please describe briefly)**

5) Please select one of the following <u>classes of RFID implementation</u> that best fits with the RFID implementation in the selected product line/supply chain.

- **<u>Pilot/Case studies.</u>** At this level, your company assesses RFID readiness and verifies the validity of RFID implementation. **(Implementation Maturity)**

- **<u>Tagging and Tracking</u>.** At this level, your company only tries to meet the requirements of your leading partners for RFID use. Some improvements can be realized in some business processes such as inventory, order fulfillment, packing and shipping, but RFID is primarily a cost. **(Implementation Maturity)**

- **<u>Application integration.</u>** At this level, your company integrates RFID data into its activities. The integration can aggregate and route the RFID data into other enterprise applications that perform business tasks such as order management, inventory/warehouse management, accounting, ERP and CRM. **(Implementation Maturity)**

- **<u>Business process improvement</u>.** At this level, your company's RFID data is used for business process improvements. An analytical framework helps aggregate RFID data, evaluates business impacts, and converts these insights into certain actions that lead to business process improvements. **(Implementation Maturity)**

- **<u>Collaborative business intelligence</u>.** At this level, your company incorporates predictive business intelligence from RFID use into your company operations.

Predictive business intelligence enables your company to immediately identify problems and address them before they occur. **(Implementation Maturity)**

6) For this question, please use the following definitions for the <u>stages of RFID implementation.</u>

Adaptation: RFID application is installed and available to use in your company's supply chain activities and related work; business process are changed and developed for the RFID applications; and your employees are trained both in new procedures and in the RFID applications.

Acceptance: RFID application is employed in your supply chain activities and related work; and your employees are induced to commit to RFID use.

Routinization: RFID application is widely used as an integral part in your company's supply chain activities and related work and is no longer perceived as something out of the ordinary in your company.

Based on the above descriptions, please select one of the following <u>stages of RFID implementation</u> that best fits your company's RFID implementation. (Implementation Maturity)

Adaptation

Limited acceptance

Acceptance

Limited routinization

Routinization

7) Please indicate the extent to which you agree or disagree with each of the following statements about how the use of RFID has impacted your company.

Strongly Disagree Disagree Neutral Agree Strongly Agree

Reduced the probability of out of stock. **(Performance)**

Increased sales from the trading partner in the selected product line/supply chain. **(Performance)**

Improved internal process efficiency. **(Performance)**

Increased staff productivity. **(Performance)**

Improved operations flexibility. **(Performance)**

Reduced inventory cost. **(Performance)**

Improved coordination with trading partner in the selected product line/supply chain. **(Performance)**

8) Please indicate the extent to which you agree or disagree with each of the following statements.

Strongly Disagree Disagree Neutral Agree Strongly Agree

Your company frequently seeks information about new technologies. **(Absorptive Capability)**

Your company frequently acquires new technologies from external sources. **(Absorptive Capability)**

Your company quickly recognizes the value of new technologies in improving your business. **(Absorptive Capability)**

Your company constantly seeks to exploit current and new technologies. **(Absorptive Capability)**

Companies in your industry are actively working together (e.g., consortium) for developing RFID standards.**(Industry Collaboration)**

Leading RFID adopters in your industry have continuously shared their RFID knowledge, experience and findings with other companies.**(Industry Collaboration)**

9) Please indicate the extent to which you agree or disagree with each of the following statements about your company.

Strongly Disagree Disagree Neutral Agree Strongly Agree

Your company has processes to ensure that the plans/solutions of your company are aligned with those of your supply chain partner. **(Coordination)**

Your company has processes to ensure that the input of your company is used by your supply chain partner in developing its plans and solutions. **(Coordination)**

Your supply chain partner in the selected product line understands your capabilities for conducting business with it. **(Coordination)**

Your personnel understand the capabilities of your supply chain partner for conducting business with your company. **(Coordination)**

Your relationship with the trading partner is very important to the achievement of your organizational goals. **(Partner Dependency)**

The trading partner's relationship with your company is very important to the trading partner's achievement of its goals. **(Partner Dependency)**

It would be difficult for your company to replace the profits generated from this trading partner of the selected product line. **(Partner Dependency)**

It would be difficult for the trading partner of the selected product line to replace the profits generated from your company. **(Partner Dependency)**

10) Please select from the following options the one that fits the status of your trading partner in the selected product line/supply chain.

With respect to transaction volume, your trading partner is: (Partner Dependency)

one of your company's top five trading partners

one of your company's top ten trading partners

in the top 50% of your trading partners

a low volume trading partner

a very low volume trading partner

11) Please indicate the extent to which you agree or disagree with each of the following statements about RFID technology in the selected product line/supply chain.

Strongly Disagree Disagree Neutral Agree Strongly Agree

Your company has integrated RFID technology with back office enterprise systems and databases. **(Depth)**

Your company has integrated RFID technology with the databases of suppliers. **(Depth)**

Costs of implementing RFID (including hardware, software, training, organizational restricting, business process reengineering) are high, relative to your annual revenue. **(Implementation cost)**

Cost of integrating RFID with other information systems in your company is relatively high compared to your annual revenue. **(Implementation cost)**

12) For each of the following, please select the closest percentage option in the selected product line.

<10%, 10% to <20%, 20% to <30%, 30% to <40%, 40% to <50%, 50% to <60%, 60% to <70%, 70% to <80%, 80% to <90%, >=90%

Shipment volume that uses RFID, as a percentage of your total monthly shipment volume of the selected product line is: **(Volume)**

Use of RFID tags, as a percentage of your total monthly tagging volume of the selected product line is:**(Volume)**

SKUs that use RFID, as a percentage of your total SKUs of the selected product line is:**(Volume)**

13) Please indicate the extent to which you agree or disagree with each of the following statement.

Your company has used RFID for the following activities in the selected product line/ supply chain:

Strongly Disagree Disagree Neutral Agree Strongly Agree

Sharing operational data with suppliers/trading partners **(Breadth)**

Production scheduling and planning **(Breadth)**

Inventory decisions, including quantity, location and quality of inventory **(Breadth)**

Account Payable **(Breadth)**

Coordinating demand planning and forecasting **(Breadth)**

Sourcing planning, including current inventory and forecast demand, in collaboration with suppliers **(Breadth)**

14) Please indicate the extent to which you agree or disagree with each of the following statements about the selected product line.

Strongly Disagree Disagree Neutral Agree Strongly Agree

There is a high margin of error in product forecasts. **(Product demand predictability)**

Product has a short life cycle (less than 1 year). **(Product demand predictability)**

15) Please indicate the extent to which you agree or disagree with each of the following statements.

The use of RFID in the selected supply chain provides the following benefits for the selected product line/supply chain. (Perceived benefits)

Strongly Disagree Disagree Neutral Agree Strongly Agree

Reduce inventory costs

Improve customer service

Improve access to information

Increase visibility of supply chain operations

Improve operational efficiency

Improve the coordination with supply chain partners

Improve the quality of decision making

Increase competitiveness of the supply chain

16) Please indicate the extent to which you agree or disagree with each of the following statements about RFID technology and its potential impact on your supply chain.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Your supply chain has made significant changes to its current processes in order to use RFID. **(Compatibility)**					
Using RFID requires no significant changes to your current supply chain information systems. **(Compatibility)**					
Using RFID was easy for your employees to adjust to. **(Compatibility)**					
RFID components, software, and services are readily available in the market. **(Technology maturity)**					
The costs of RFID components, software, and services have reduced to a reasonable and stable level.**(Technology maturity)**					
RFID technology is routinely used by many organizations in their supply chains. **(Technology maturity)**					
A commonly agreed standard exists for RFID components, software, and services. **(Technology maturity)**					
RFID technology has become stable enough for use in supply chain activities, in terms of readability and failure rate. **(Technology maturity)**					

17) Please indicate the extent to which you agree or disagree with each of the following statements.

RFID implementation involves:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
coordinating with many user units. **(Complexity)**					
many software environments. **(Complexity)**					
many technology platforms. **(Complexity)**					
integration with many other systems. **(Complexity)**					

18) Please indicate the extent to which you agree or disagree with each of the following statements.

Information technology is important in your company:

Strongly Disagree Disagree Neutral Agree Strongly Agree

for improving efficiency and productivity. **(IT sophistication)**

for effective decision-making. **(IT sophistication)**

for effective customer service. **(IT sophistication)**

for improved competitiveness. **(IT sophistication)**

19) Please indicate the extent to which you agree or disagree with each of the following statements.

Strongly Disagree Disagree Neutral Agree Strongly Agree

The current IT resources of your company are enough to support implementing RFID technology. **(IT sophistication)**

The information technology professionals of your company have the necessary skills to implement and manage RFID applications. **(IT sophistication)**

Your company's top management actively promotes the potential of RFID for your supply chain**.** **(Top management support**)

Your company' top management provides stable and sufficient funding to implement RFID. **(Top management support**)

20) Please indicate the extent to which you agree or disagree with each of the following statements.

It will be challenging for your company to find external consultants:

Strongly Disagree Disagree Neutral Agree Strongly Agree

to train your employees for using RFID. **(External support)**

to solve RFID technology problems. **(External support)**

to help with RFID implementation. **(External support)**

21) Please indicate the extent to which the following statements apply to your competitors and your industry.

Strongly Disagree Disagree Neutral Agree Strongly Agree

In your industry, the adoption of RFID technology is critical to remain competitive. **(Competitive pressure)**

You believe using RFID in the selected supply chain will give your company an edge over your competitors. **(Competitive pressure)**

22) Please indicate the amount of influence your trading partner in the selected product line/supply chain had in your company's decision whether or not to adopt RFID. (Partner power)

No influence

Some influence

Moderate influence

Strong influence

Very Strong influence

23) Please select from the following options the one which most fits the role played by your trading partner in adopting/using RFID in the selected supply chain. (Partner power)

No encouragement or pressure: Your trading partner did not attempt to encourage RFID adoption.

Information Exchange: Your trading partner provided information regarding RFID.

Recommendation: Your trading partner recommended your company to adopt RFID.

Request: Your trading partner asked that your company adopt RFID.

Promise: Your trading partner made promises regarding the benefits to your company by adopting RFID (promises could include discounts, faster orders, etc.).

Strong Pressure: Your trading partner made clear that not adopting RFID could have negative business consequences for your company (such as discontinuing the relationship, hints that non-RFID customers would receive poor service, etc.).

24) Please indicate the extent to which each of following statements applies to your trading partner if your trading partner in the selected product line/supply chain already uses RFID.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	**Does not apply**
RFID technology of the trading partner is interoperable with your company's information systems. **(Partner RFID capability)**						
Your trading partner has RFID technology ready to conduct business with your company. **(Partner RFID capability)**						

Your trading partner has conducted business with its other trading partners with using RFID. **(Partner RFID capability)**

Your trading partner has benefited greatly from using RFID technology. **(Partner RFID capability)**

25) For each of the following, please select the closest percentage option for the selected product line.

<10%, 10% to <20%, 20% to <30%, 30% to <40%, 40% to <50%, 50% to <60%, 60% to <70%, 70% to <80%, 80% to <90%, >=90%

The transaction volume with your trading partner as a percentage of your company's total annual revenue from the selected product line is: **(Transaction volume)**

The transaction volume with your company as a percentage of your trading partner's total annual revenue from the selected product line is: **(Transaction volume)**

26) Please select the closest percentage for your company's IT operational budget, as a percentage of your company's total annual revenue: (Financial resources)

<1%, 1% to <2%, 2% to <3%, 3% to <4%, 4% to <5%, >=5%

27) Please select the closest percentage for your company's IT staffing (IT and IT support), as a percentage of your company's total workforce: (Financial resources)

<2%, 2% to <4%, 4% to <6%, 6% to <8%, 8% to <10%, >=10%

28) Considering your company's overall IT budget, how significant is the financial cost of developing and implementing RFID system? **(Financial resources)**

Not at all significant

Somewhat significant

Significant

Quite significant

Extremely significant

29) What is the extent of RFID adoption by your competitors in your industry currently?(Competitive pressure)

None has adopted.

Very few have adopted.

Some have adopted.

Many have adopted.

Almost all have adopted.

Background Questions (the same as those in Adoption study)

APPENDIX B: PARTIAL RFID IMPLEMENTATION MODEL FORMULATION

At the beginning of period *t*,

$D^{\#}_{r,t} = A^{\#}_{r,t} + G^{\#}_{r,t} + K^{\#}_{r,t}$ $A^{\#}_{r,t}, G^{\#}_{r,t}$ and $K^{\#}_{r,t}$ follow certain distributions.

The retailer reviews the inventory position and places the order if necessary under the replenishment policy $(s^{\#}_{r}, S^{\#}_{r})$.

$$O^{\#}_{r,t} \begin{cases} S^{\#}_{r} - (\hat{I}^{\#}_{r,t} + \sum_{j=1}^{L} O^{\#}_{r,t-j}) & if\ \hat{I}^{\#}_{r,t} + \sum_{j=1}^{L} O^{\#}_{r,t-j} < s^{\#}_{r} \\ 0 & Otherwise \end{cases}.$$

When formulating realized sales in the period, Kang and Gershwin (2005) is referred.

$$a^{\#}_{r,t} = \begin{cases} A^{\#}_{r,t} & if\ D^{\#}_{r,t} \le I^{\#}_{r,t} + R^{\#}_{r,t} \\ \left(I^{\#}_{r,t} + R^{\#}_{r,t}\right)\left(\frac{A^{\#}_{r,t}}{D^{\#}_{r,t}}\right), & Otherwise \end{cases},$$

$$g^{\#}_{r,t} = \begin{cases} G^{\#}_{r,t} & if\ D^{\#}_{r,t} \le I^{\#}_{r,t} + R^{\#}_{r,t} \\ \left(I^{\#}_{r,t} + R^{\#}_{r,t}\right)\left(\frac{G^{\#}_{r,t}}{D^{\#}_{r,t}}\right), & Otherwise \end{cases},$$

$$k^{\#}_{r,t} = \begin{cases} K^{\#}_{r,t} & if\ D^{\#}_{r,t} \le I^{\#}_{r,t} + R^{\#}_{r,t} \\ \left(I^{\#}_{r,t} + R^{\#}_{r,t}\right)\left(\frac{K^{\#}_{r,t}}{D^{\#}_{r,t}}\right), & Otherwise \end{cases},$$

where $R^{\#}_{r,t} = DL^{\#}_{d,t-L}$; $R^{\#}_{r,t}$ is received products at the retailer at period t, which was shipped from the distributor to the retailer in period *t-L*.

At the end of period *t*, the inventory state of the retailer evolves according to the following equations:

$i_t^{\#} \equiv Mod(t, N^{\#})$.

Because RFID's perfection is rang from (0.85, 1.00), so the retailer still needs to conduct physical counting but at less frequency. φ is an integer which shows a relatively longer counting cycle under RFID.

Because RFID technology can help detect any theft at the end of each period, all theft will be subtracted from inventory record; however for misplaced items, only proportion of them can be detected and returned to salable inventory because of perfect level of RFID system. ω represents the perfect level of RFID (i.e. read rate). If the read rate is 95%, the rate means 5% of misplaced items cannot be detected.

$$B_{r,t+1}^{\#} = \begin{cases} 0 & if\ i_t^{\#} = 0 \\ B_{r,t}^{\#} + (1-\omega)k_{r,t}^{\#} & Otherwise \end{cases}.$$

$$\hat{I}_{r,t+1}^{\#} = I_{r,t+1}^{\#} \begin{cases} I_{r,t}^{\#} + R_{r,t}^{\#} - a_{r,t}^{\#} - g_{r,t}^{\#} + B_{r,t}^{\#} & if\ i_t^{\#} = 0 \\ I_{r,t}^{\#} + R_{r,t}^{\#} - a_{r,t}^{\#} - g_{r,t}^{\#} - (1-\omega)k_{r,t}^{\#} & Otherwise \end{cases}.$$

For the retailer, the single period profit incurred in period t is:

$$\pi_{r,t}^{\#} = \begin{cases} p_r^{\#} a_{r,t}^{\#} - (c_r + \alpha^{\#} c_g) O_{r,t}^{\#} - h_r \hat{I}_{r,t+1}^{\#} - z_r\left(A_{r,t}^{\#} - a_{r,t}^{\#}\right) - c_{r,q}\left(g_{r,t}^{\#} - B_{r,t}^{\#}\right) - c_{r,c} & if\ i_t^{\#} = 0 \\ p_r^{\#} a_{r,t}^{\#} - (c_r + \alpha c_g) O_{r,t}^{\#} - h_r \hat{I}_{r,t+1}^{\#} - z_r\left(A_{r,t}^{\#} - a_{r,t}^{\#}\right) - c_{r,q}[g_{r,t}^{\#} + (1-\omega)k_{r,t}^{\#}] & Otherwise \end{cases},$$

where $p_r^{\#} = p_r^{o}$ and $\alpha^{\#}$ is the proportion of RFID tag cost, $c_g$shared by the retailer in the partial implementation scenario. z_r is the penalty cost per unit for unsatisfied customers to the retailer.

In T simulation periods, the profit for the retailer is:

$\pi_r^{\#} = \sum_{t=1}^{T} \pi_{r,t}^{\#}$.

While, the distributor's formulation is similar to the retailer, there are still some differences worthy to mention. The study assumes that there are less demand for shrinkage and misplacements for the distributor because only employees are responsible for these two types of inventory errors, compared with the retailer in which both end-customer and employees can take the product away without paying for it. Thus, the study models the distributions of demand for shrinkage and misplacement with smaller means and variances than those for the retailer. For backorder, the study does not consider backorder for the retailer, but it allows the distributor to take backorder when an order from the retailer cannot be met. This assumption is more realistic.

$G^o_{d,t}$ and $K^o_{d,t}$ follow certain distributions.

$$DL^{\#}_{d,t} = \begin{cases} O^{\#}_{r,t} + BL^{\#}_{d,t-1} & if\ O^{\#}_{r,t} + BL^{\#}_{d,t-1} \leq I^{\#}_{d,t} + R^{\#}_{d,t} \\ I^{\#}_{d,t} + R^{\#}_{d,t} & Otherwise \end{cases},$$

$$BL^{\#}_{d,t} = O^{\#}_{r,t} + BL^{\#}_{d,t-1} - DL^{\#}_{d,t},$$

where $R^{\#}_{d,t} = DL^{\#}_{m,t-L}$; $R^{\#}_{d,t}$ is received products at the distributor at period t, which was shipped from the manufacturer to the distributor in period *t-L*.

The distributor reviews the inventory position and places the order if necessary under the replenishment policy $(s^{\#}_d, S^{\#}_d)$.

$$O^{\#}_{d,t} \begin{cases} S^{\#}_d - (\hat{I}^{\#}_{d,t} + \sum_{j=1}^{L} O^{\#}_{d,t-j} - BL^{\#}_{d,t-1}) & if\ \hat{I}^{\#}_{d,t} + \sum_{j=1}^{L} O^{\#}_{d,t-j} - BL^{\#}_{d,t-1} < s^{\#}_d \\ 0 & Otherwise \end{cases}.$$

When formulating realized theft and misplacement in the period, Kang and Gershwin (2005) is referred.

$$g^{\#}_{d,t} = \begin{cases} G^{\#}_{d,t} & if\ G^{\#}_{d,t} + K^{\#}_{d,t} \leq I^{\#}_{d,t} + R^{\#}_{d,t} - DL^{\#}_{d,t} \\ \left(I^{\#}_{d,t} + R^{\#}_{d,t} - DL^{\#}_{d,t}\right)\left(\frac{G^{\#}_{d,t}}{G^{\#}_{d,t}+K^{\#}_{d,t}}\right), & Otherwise \end{cases},$$

$$k^{\#}_{d,t} = \begin{cases} K^{*}_{d,t} & if\ G^{\#}_{d,t} + K^{\#}_{d,t} \leq I^{\#}_{d,t} + R^{\#}_{d,t} - DL^{\#}_{d,t} \\ \left(I^{\#}_{d,t} + R^{\#}_{d,t} - DL^{\#}_{d,t}\right)\left(\frac{K^{\#}_{d,t}}{G^{\#}_{d,t}+K^{\#}_{d,t}}\right), & Otherwise \end{cases},$$

At the end of period *t*, the inventory state of the distributor evolves according to the following equations:

$i_t^\# \equiv Mod(t, N^\#)$,

$$B_{d,t+1}^\# = \begin{cases} 0 & if\ i_t^\# = 0 \\ B_{d,t}^\# + (1-\omega)k_{d,t}^\# & Otherwise \end{cases},$$

$$\hat{I}_{d,t+1}^\# = I_{d,t+1}^\# = \begin{cases} I_{d,t}^\# + R_{d,t}^\# - DL_{d,t}^\# - g_{d,t}^\# + B_{d,t}^\# & if\ i_t^\# = 0 \\ I_{d,t}^\# + R_{d,t}^\# - DL_{d,t}^\# - g_{d,t}^\# - (1-\omega)k_{d,t}^\# & Otherwise \end{cases},$$

For the distributor, the single period profit incurred in period *t* is:

$$\pi_{d,t}^\# = \begin{cases} p_d^\# O_{r,t}^\# - (c_d + c_g)O_{d,t}^\# - h_d \hat{I}_{d,t+1}^\# - z_d BL_{d,t}^\# - c_{d,c} - c_{d,q}(g_{d,t}^\# - B_{d,t}^\#) & if\ i_t^\# = 0 \\ p_d^\# O_{r,t}^\# - (c_d + c_g)O_{d,t}^\# - h_d \hat{I}_{d,t+1}^\# - z_d BL_{d,t}^\# - c_{d,q}[g_{d,t}^\# + (1-\omega)k_{d,t}^\#] & Otherwise \end{cases}.$$

where $p_d^\# = (c_r + \alpha^\# c_g)$, z_d is the penalty cost per unit for unsatisfied order to the distributor, and $1 - \alpha^\#$ is the proportion of RFID tag cost c_g shared by the distributor.

In T simulation periods, the profit for the distributor is:

$\pi_d^\# = \sum_{t=1}^{T} \pi_{d,t}^\#$.

For the manufacturer, the study assumes that there is even less demand for shrinkage and misplacement for the manufacturer than those for the distributor. The manufacturer also takes backorder when it cannot satisfy the distributor's order and will deliver the backorder in a future period by adding lead time *L*.

$G_{m,t}^\#$ and $K_{m,t}^\#$ follow certain distributions.

$$DL_{m,t}^\# = \begin{cases} O_{d,t}^\# + BL_{m,t-1}^\# & if\ O_{d,t}^\# + BL_{m,t-1}^\# \le I_{m,t}^\# + M_{t-L}^\# \\ I_{m,t}^\# + M_{t-L}^\# & Otherwise \end{cases},$$

$BL_{m,t}^\# = O_{d,t}^\# + BL_{m,t-1}^\# - DL_{m,t}^\#$, where $M^{\#}_{t-L}$ is the production amount at the manufacturer at period t-L and available at period t. Because the manufacturer does not have capability constricts, it can obtain any materials it needs to produce the products. The only issue is the lead time L.

The manufacturer reviews the inventory position and places the order if necessary under the replenishment policy $(s^{\#}_m, S^{\#}_m)$

$$M^{\#}_t \begin{cases} S^{\#}_m - (\hat{I}^{\#}_{m,t} + \sum_{j=1}^{L} M^{\#}_{t-j} - BL^{\#}_{m,t-1}) & if\ \hat{I}^{\#}_{m,t} + \sum_{j=1}^{L} M^{\#}_{t-j} - BL^{\#}_{m,t-1} < s^{\#}_m \\ 0 & Otherwise \end{cases}.$$

When formulating realized theft and misplacement in the period, Kang and Gershwin (2005) is referred.

$$g^{\#}_{m,t} = \begin{cases} G^{\#}_{m,t} & if\ G^{\#}_{m,t} + K^{\#}_{m,t} \le I^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t} \\ \left(I^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t}\right)\left(\frac{G^{\#}_{m,t}}{G^{\#}_{m,t}+K^{\#}_{m,t}}\right), & Otherwise \end{cases}.$$

$$k^{\#}_{m,t} = \begin{cases} K^{\#}_{m,t} & if\ G^{\#}_{m,t} + K^{\#}_{m,t} \le I^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t} \\ \left(I^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t}\right)\left(\frac{K^{\#}_{m,t}}{G^{\#}_{m,t}+K^{\#}_{m,t}}\right), & Otherwise \end{cases}.$$

At the end of period *t*, the inventory state of the manufacturer evolves according to the following equations:

$$i^{\#}_t \equiv Mod(t, N^{\#}),,$$

$$Q^{\#}_{m,t+1} = \begin{cases} 0 & if\ i^{\#}_t = 0 \\ Q^{\#}_{m,t} + g^{\#}_{m,t} & Otherwise \end{cases},$$

$$B^{\#}_{m,t+1} = \begin{cases} 0 & if\ i^{\#}_t = 0 \\ B^{\#}_{m,t} + k^{\#}_{m,t} & Otherwise \end{cases},$$

$$\hat{I}^{\#}_{m,t+1} = \begin{cases} I^{\#}_{m,t+1} = \hat{I}^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t} - Q^{\#}_{m,t} - g^{\#}_{m,t}, & if\ i^{\#}_t = 0 \\ \hat{I}^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t} & Otherwise \end{cases},$$

$$I^{\#}_{m,t+1} = \begin{cases} \hat{I}^{\#}_{m,t+1} & if\ i^{\#}_t = 0 \\ I^{\#}_{m,t} + M^{\#}_{t-L} - DL^{\#}_{m,t} - g^{\#}_{m,t} - k^{\#}_{m,t} & Otherwise \end{cases}.$$

For the manufacturer, the single period profit incurred in period *t* is:

$$\pi^{\#}_{m,t} = \begin{cases} p^{\#}_{m} O^{\#}_{d,t} - c_m M^{\#}_{,t} - h_m \hat{I}^{\#}_{m,t+1} - z_m BL^{\#}_{m,t} - c_{m,c} - c_{m,q} \sum_{j=0}^{N^{\#}-1} g^{\#}_{m,t-j} & if\ i^{\#}_{t} = 0 \\ p^{\#}_{m} O^{\#}_{d,t} - c_m M^{\#}_{,t} - h_m \hat{I}^{\#}_{m,t+1} - z_m BL^{\#}_{m,t} & Otherwise \end{cases}.$$

where $p^{\#}_{m} = c_d$, and z_m is the penalty cost per unit for unsatisfied order to the manufacturer.

In T simulation periods, the profit for the manufacturer is:

$$\pi^{*}_{m} = \sum_{t=1}^{T} \pi^{*}_{m,t}$$

For the overall supply chain, the total profit in T simulation periods is:

$$\Pi^{*} = \sum_{\eta=\{r,d,m\}} \sum_{t=1}^{T} \pi^{*}_{\eta,t},$$