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Impact of RFID information-sharing coordination over a supply chain with reverse logistics

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IMPACT OF RFID INFORMATION-SHARING COORDINATION OVER A SUPPLY CHAIN WITH REVERSE LOGISTICS

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This work is dedicated to God and my family.

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NOMENCLATURE

Indexes	Description
D	demand
e	end-user market
g	“green” recycled-material supplier
l	RFID reliability lower-bound
m	manufacturer
r	raw-material supplier
s	system
u	RFID reliability upper-bound

Variables	Description
a_i	action at time period i
AC	unit collection cost
$b_i, i \in \{m, g, r\}$	unit shortage/backorder cost of i
$B_i, i \in \{m, g, r\}$	total shortage/backorders cost of i
$C_i, i \in \{m, g, r, s\}$	total cost of i
CI	collection investment
CR	critical ratio
CS_i	current state at time period i
D	Demand
E	capacity of the end-user market
FS_i	future state at time period i
$h_i, i \in \{m, g, r\}$	unit holding cost of i
$H_i, i \in \{m, g, r\}$	total holding cost of i

$I_i, i \in \{m, g, r\}$	on-hand inventory of *i*
IR_i	immediate reward at time period i
IT	inter-arrival time
$k_i, i \in \{m, g, r\}$	setup cost per order of *i*
$K_i, i \in \{m, g, r\}$	total setup cost of *i*
$LT_i, i \in \{m, g, r\}$	leadtimes to *i*
MR	RFID measurement reliability
$O_i, i \in \{g, r\}$	total ordering cost of *i*
$O_i^j, i \in \{m\}, j \in \{g, r\}$	total ordering cost of *i* ordered from *j*
$p_i, i \in \{g, r\}$	unit procurement price of *i*
PC	unit production cost
PE	probability of exploration
$QV_i(x, a)$	Q-value at time period i given state x and action a
$Q_i, i \in \{g, r\}$	order quantity of *i*
$Q_i^j, i \in \{m\}, j \in \{g, r\}$	order quantity of *i* ordered from *j*
$r_i, i \in \{m, g, r\}$	continuous review reorder point of *i*
RC	returns collected
$RE_i, i \in \{m, g, r, s\}$	revenue of i
$s_i, i \in \{m, g, r\}$	periodic review reorder point of *i*
$S_i, i \in \{m, r\}$	order-up-to level of *i*
$TE_i, i \in \{m, g, r\}$	time-evaluation interval of *i*
TH	Time-horizon
$X_i, i \in \{m, g, r\}$	inventory position of *i*
$\pi_i, i \in \{m, g, r, s\}$	profit of i
γ	delayed reward factor
φ	unit price or unit cost
τ	return rate
β	scaling parameter, collection investment formulation
ω	scaling parameter, reorder point formulation

μ	average demand
σ	standard deviation of demand
θ	demand over leadtime

ABSTRACT

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Companies have adopted environmental practices such as reverse logistics over the past few decades. However, studies show that aligning partners inside the green supply chain can be a substantial problem. This lack of coordination can increase overall supply chain cost. Information technology such as Radio Frequency Identification (RFID) has the potential to enable decentralized supply chain coordinate their information. Even though there are research that address RFID on traditional supply chain, few researches address how to coordinate RFID information sharing in a green supply chain. We study, through simulation experiments, two types of RFID information-sharing coordination under different configurations related with their inventory policies: basic and advanced. Statistical analyses show that better results can be presented in advanced RFID configuration given new coordination and inventory policy decisions presented. In addition, these findings shows what are the RFID information-sharing coordination that can provide better system improvement depending on the supply chain scenarios and factors.

CHAPTER 1. INTRODUCTION

This thesis proposes Radio Frequency Identification (RFID) information-sharing coordination over decentralized environmental supply chains. The environmental initiative under study is reverse logistics models. The coordination defines the inventory control models, technology configuration and demand shared over the system necessary to increase the economic value of RFID implementation. Managerial insights details the system conditions in which the RFID coordination attains its maximum economic value in terms of lower cost. The thesis demonstrates that RFID technology can achieve better results over system with No RFID (base case) if systems parameters, inventory models and technology configurations are considered. We extended previous work on centralized inventory models in reverse logistics and apply parallel (manufacturing and recycling) decisions. The research shows that the information coordination depends on the RFID information-coordination used. As future work, the thesis explores dynamics over the state of the system. Inventory policies and RFID coordination are tested over three different models to study their performance over dynamic rather than static parameters setting.

This chapter begins with Section 1.1 which introduces the concept of reverse logistics. Section 1.2 introduces Radio Frequency Identification technology. The scope of the research is presented in Section 1.3, and the research contributions are detailed in Section 1.4. Section 1.5 shows the outline for the rest of thesis.

1.1 Reverse Logistics

Companies are implementing different types of environmental supply chain practices. These practices can be divided into green manufacturing/remanufacturing, waste management and reverse logistics (Srivastava, 2007).

This thesis addresses reverse logistics operations. Reverse logistics encompasses collection, sort, classification, distribution and transformation of returns from an end-user market to traditional supply chains (Fleischmann et al., 1997; Dekker et al., 2004).

We consider returns as any item that has been previously used by the customer. Examples of common returns are papers, tires, cans, bottles, and toners. Further, an end-user market can include any social, commercial, or nonprofit organization which has the returns. Enterprises, schools, universities, and government agencies can be part of an end-user market.

Reverse logistics operations can be considered either centralized or decentralized. In the centralized scenario, one entity (e.g., manufacturer) has control of the decisions and operations of the reverse logistics. Whereas in the decentralized setting, multiple entities have their own decisions such as the amount to produce, order, or collect. For this thesis, we analyze the inventory control model over decentralized scenario. Figure 1.1 shows a forward supply chain with reverse logistics.

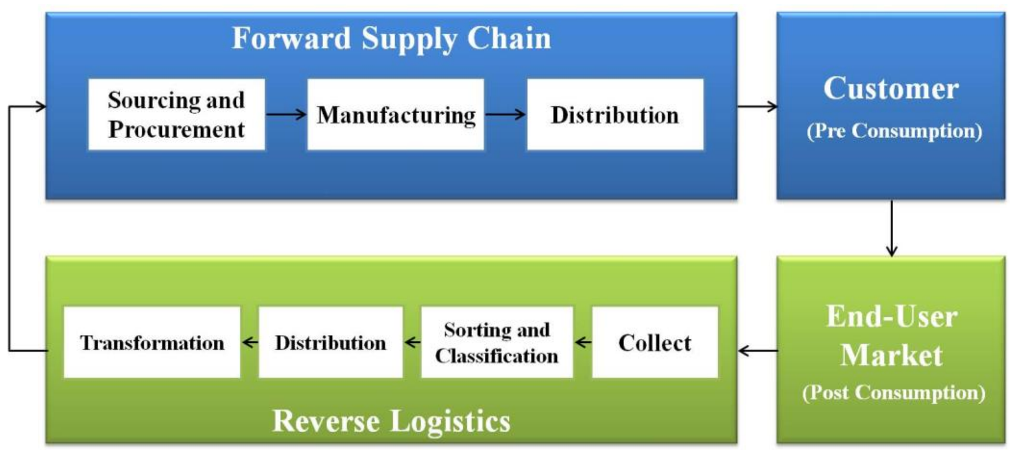

Figure 1.1 Forward Supply Chain and Reverse Logistics

1.1.1 Motivations

There are different drivers that encourage companies to implement reverse logistics such as government regulations, global competition, and public image.

1.1.1.1 Government Regulations

The government motivates green practices in many regions. In the United States, the Environmental Protection Agency (EPA) creates regulation to prevent damages to the environment. Companies such as Apple and Sony fulfill recycling policies and environmental design motivated by government regulations as well as cost savings (Chen and Sheu, 2009). In Europe, there are different acts to promote the collection of electric and electronic disposables (Aksen et al., 2009). For example, the European Parliament and Council imposed a 75% reuse and recycling collection rates by weight for household appliance (Toffel, 2004).

These regulations can be implemented by incentives or penalties. Sheu et al. (2005) examine the involvement of the government in the green supply chain in the Taiwanese notebook industry. The authors found that return ratio and unit subsidy are two significant regulatory parameters. In the study, the Taiwanese government defined the return ratio and unit subsidy to 25% and $8.7, respectively.

1.1.1.2 Global Competition

Global competition and international standards are additional motivations to implement reverse logistics (Hsu et al., 2016). Nowadays, companies implement environmental standards such as ISO 14001 to comply with international regulations (Pujari et al., 2003). Further, different trade agreements among nations also enforce environmental regulations to avoid environmental damages. Many Chinese industries had to implement green supply chain practices to achieve international customer requirements (Zhu and Sarkis, 2004).

1.1.1.3 Public Image

Green products can have additional benefits to the purchasers at the moment of buying (Mais, 2010). Michaud and Llerena (2011) investigate the willingness to pay for green remanufactured products. The authors found that consumers value more green products than conventional products when they are informed that the products are environmental friendly. Further, there are different efforts to quantitatively account for the environmental impact on products. Wal-Mart is developing an environmental index with the collaboration of other entities (e.g., suppliers, partners, universities). The goal of this index is to measure the environmental impact products have on the environment (Cooke, 2009).

1.1.2 Benefits

As previous research shows, there are different motivations to implement environmental operations. However, there are different benefits after implementing these initiatives. Reverse logistics provide two major sources of benefits: environmental and economic benefits. In terms of the environment, supply chain with reverse logistics can collect and use the returns from the end-user market. This action reduces the amount of materials deposit to landfill or incinerators which in turn protects our ecosystem. Also, the manufacturer can use returns instead of raw materials. The use of returns such as recycled materials reduces the consumption of natural resources from the environment (Wu and Dunn, 1995). In terms of economics benefits, the returns are assumed to cost less than raw materials. Therefore, the overall procurement cost of the supply chain can decrease with the attainment of higher amounts of returns. Also, on-hand inventory cost of the returns is considered to be less than traditional raw materials.

1.1.3 Challenges

Even though reverse logistics are been widely used, reverse logistics is a complex system which impact the inventory control in the supply chain. We study two principal factors for this complexity: stochastic elements and decentralization.

1.1.3.1 Stochastic Elements

There are more stochastic elements in supply chain with reverse logistics than in a traditional supply chain. As Yu et al. (2001) defines, there are three main sources of uncertainty in traditional supply chain: 1) suppliers, 2) manufacturer, and 3) customer. However, a fourth source of uncertainty arises if we consider green supply chain initiatives such as reverse logistics. The amount of returns depends on the willingness of the end-user market to provide returns. Also, the quality of the returns can vary. In addition, the life time of the products is random. Further, sorting different types of returns can increase complexity to handle the materials. Inventory availability can be reduced due to these random factors translating into higher cost. Govindan et al. (2016) describe that returns with demands are the two most considerable stochastic paramaters in literature. However, we are including more stochastic elements as we will see in Chapter 3 such as rate variance and stochastic collection leadtimes.

1.1.3.2 Decentralization

There are several players aiming to improve their individual performance. This individual optimization can produce underperformance results over the entire supply chain (Yu 2011). Inventory policies are set independently, with the desire to minimize cost and satisfying demand. This lack of coordination can affect the inventory policies of the reverse logistics and forward supply chain.

Therefore, there is a need to efficiently coordinate inventory policies in the forward and reverse channels. Information technology has come to be one of the prominent alternatives for companies to increase coordination. For this thesis, we describe how information technology such as Radio Frequency Identification (RFID) can help improve inventory policies coordination in a supply chain with reverse logistics.

1.2 Radio Frequency Identification

We focus particularly on automatic identification and data capture (AIDC) technologies. AIDC technologies enable higher performance in resource management and warehouse management systems (Smith and Offodile, 2002). There are different types of AIDC such as barcodes, contact memory, optical recognition, card technology, biometric, and radio frequency identification (Wamba et al., 2008).

Barcode is the technology that is most widely use across supply chain and industries. Barcode can reduce manual errors and enable visibility in the supply chain (Fraza, 2000). However, even though the barcode is widely use, there are business requirements that are not been addressed by barcodes. There are manual read rates problems based on the position of the barcode and reader increasing operational performance in the warehouse. This problem increases if we consider high volume industries such as Retail.

For the supply chain, RFID is one of the most used AIDC technologies (Kärkkäinen and Holmström, 2002). RFID is consider as backbone for information sharing process in supply chain due to its real-time capabilities as described by Qianli et al. (2016).

RFID technology is comprised of three main elements: RFID tags, RFID readers, and the information system. RFID tags are attached to an item, pallet, container or any physical object that needs to be tracked. These tags have a built-in chip with an Electronic Product Code (EPC) which store relevant information from the product tagged. The EPC is a series (binary) of numbers that identified the products with its information such as production, manufacturer across supply chain, and other informations. The tag has an embedded antenna to transmit product's information to the RFID reader. Figure 1.2 shows examples of RFID tags. RFID readers are installed in companies' warehouses. The readers can detect, in real-time, the tagged inventory through electromagnetic radio wave. The tag is activated through the interaction of the electromagnetic radio waves and then it sends the information to the reader. This information is captured and used in the enterprise information system of the company. Figure 1.3 shows examples of RFID readers. This RFID information can be shared to other players in the supply chain through the EPC Global Network. Please refer to Roberts (2006) for a complete overview of RFID elements and technology and Musa and Dabo (2016) for a survey of RFID in supply chain management.

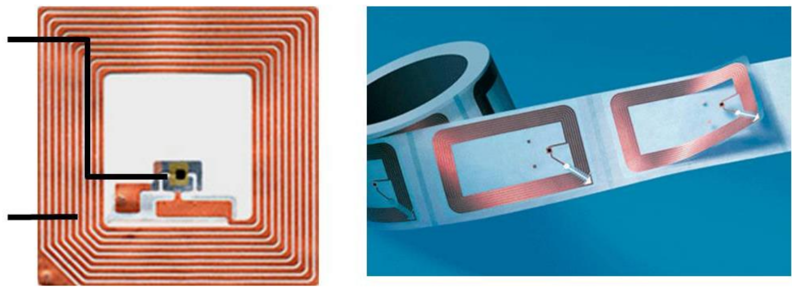

Figure 1.2 RFID Tags

Figure 1.3 RFID Readers

Table 1.1 below shows comparison of the barcode and RFID

Table 1.1 RFID versus Barcode Comparison

RFID	Barcode
Not constrained by "line-of-sight". Hence, the location/orientation of the reader does not matter as long as the gats are within the range of the reader's signal	Requires line-of-sight
Many tags can be read simultaneously	Only one read at a time
Very durable: they are resistant to heat, dirt, and solvents and hence are not physically damaged easily, making them useful in a large number of potential applications	Low durability: easily damaged
RFID tags can be self-powered (active tags). They can not only deliver information about location on demand, but also collect information (via integrated sensors), and store them locally in itself. This dynamically stored date can be retrieved for analysis later or can be transmitted by the tag to the reader on ad-hoc fashion under special circumstances	Has no power source, and cannot serve beyond being a static label
RFID tags can potentially be written multiple times, making them reusable data containers	Not reusable as data source
Expensive (relative to barcode)	Less expensive than RFID tags
Liquids and metals cause read problems	Can be used on or around water and metal with no performance loss
RFID tags must be added to current production process (such as embedded in the box) or added to the unit (box, pallet, etc.) before shipping	Can be printed before production or directly on the items

1.2.1 Motivations and Benefits

The use of RFID can be tracked from the Second World War where military personnel used RFID tags to determine object's position and speed using radio waves (Landt, 2005). More recently, companies are implementing RFID in their supply chain to increase operational performance. Wal-Mart informed to all its Top 100 suppliers to implement RFID technology to their products (Vijayaraman and Osyk, 2006). Also, Gillette applied RFID tags at the cases and pallet levels. The goal was to monitor in real-time the inventory. Gillette was able to have products on store 11 days faster than regular turn-around times during product introductions at 400 stores (O'Connor, 2006). In addition, RFID can help reduce inventory inaccuracy (Heese, 2007). Inventory inaccuracy is another key benefit (Fan et al., 2015). Inventory inaccuracy is the difference between the real inventory versus the inventory register in the system. Raman et al. (2001) found through empirical studies that 65% of the inventory records analyzed had errors in the quantity amount. Another benefit of RFID is that it does not require any line of sight to detect each inventory such as in the bar code technology. Consequently, manual work and time are reduced. Further, most of the benefits have come in terms of improvements of business processes and operational activities. Businss cases can be seen in companies such as Target, Albertson's and Best Buy (Delen et al., 2007).

As Lindau and Lumsden (1999) mentioned from 10 case studies in distribution and manufacturing companies, the main benefits of these technologies have come in operational activities such as effective tracking and shipments. Also, benefits on labor cost are presented in literature (Shin and Eksiouglu, 2015).

1.2.2 Challenges

One of the main challenges of RFID is the high variable cost from the tags comparted to bar codes. In addition, the reliability of the hardware setup has provided concerns to achieve higher benefits (Whitaker, et. al; 2007). RFID read rate is a common challenge studied in RFID literature. This problem arises due to bad positioning of the RFID tags, content of the inventory, or RFID reader's location (Birari and Iyer, 2005). Also, the integration of this new technology with the current system is a major concern due to the huge amount of data granularity and new hardware/software considerations (Angeles, 2005). Further, the variable cost of RFID tags and fixed cost of the installation are other challenges discussed in literature (Gaukler, 2011). Additional challenges are presented in decentralized system. As Lefebvre and Fosso-Wamba (2008) states, it is difficult to quantify the benefits for cost reduction, individual benefits and interoganizational benefits. These can be worsen if the players are decentralized entities.

The greatest value of RFID is when its information is properly used. For this to happen, information has to be shared among its players. However, few cases and researches address how to share and coordinate RFID information through a supply chain. This challenge increases if we consider decentralized system. Karkkainen and Holmstron (2002) defines that information sharing is one of the primary challenges in todays Supply Chain. Customers are demanding more differentiation and customization of their products. This new trends force the supply chain to manage their inventory levels more accurate and quicker among leadtimes. In addition, few researches define which players have to install RFID technology (e.g., tags and readers). In addition, few studies address who have to share the RFID information. Rare studies specify what type of RFID information needs to be shared and how these arrangements impact inventory policies. Wu et al. (2016) defines that information in supply chains is one of the five main stream of research for smart supply chains literature in the future. The authors conclude as well that it is necessary to understand what type of information is shared and who shares the information.

This thesis aims to provide a framework to enable RFID information-sharing coordination in a decentralized green supply chain. Our problem statement is the following: how to coordinate RFID information sharing through the inventory policies among players in a decentralized green supply chain to reduced total cost? This research question will be addressed in the following chapters as the next Section1.3 describes.

1.3 Scope of Research

This thesis presents RFID information-sharing coordination which aligns RFID technology (e.g., technology placement and information shared) and inventory policies in a green supply chain. We study two scenarios of RFID information-sharing coordination: basic and advanced. Simulation experiments enable us to identify which RFID technology configuration and inventory policy drives lower cost. These studies provide managerial guidelines to increase economic performance in a supply chain with reverse logistics. The study compares five different RFID information-sharing coordination. These five RFID coordination are tested over different supply chain scenarios. The study aims to identify if RFID provides better performance than system with RFID. In addition, the analysis identify under what supply chain scenario is more suitable to implement the RFID information-sharing coordination. The simulation test different factors such as demand, standard deviation of demand, leadtimes and environmental factors such as collection investment and collection leadtimes. Further, the thesis shows that it is not enough to implement RFID technology. The inventory policy will highly impact the results. Advanced RFID coordination provided better results than Basic RFID coordination. Also, the thesis shown that depending on the inventory policy, the information shared will have higher sensitivity in some policies than others. For example, in Basic RFID coordination is more impactful to share inventory levels. But for Advanced RFID coordination demand information provided better results. As an extension and future research, we study a dynamic view of the RFID coordination. We propose reinforcement learning and self-adaptive algorithms to allow RFID adaptability over dynamic scenarios. Also, we consider the case of entities independently choosing their RFID coordination.

Chapter 3. Supply Chain Description, Inventory Defintions and Performance Measures

- Environmental decentralized supply chain is modeled.
- Supply Chain Structure is presented including decentralized settings with multiple players.
- Different supply chain assumptions are defined such as demand, returns, manufacturing operations, leadtimes, and RFID.
- It is presented the different stochastic models such as capacity of the end-user market and their returns parameters.
- End-user market and recycled-material supplier interactions are described.
- Inventory definitions are established which serve as the base of the Basic RFID information-sharing coordination.
- Performance measure was establish to measure the entire supply chain chain including the cost from all players involved.

Chapter 4. RFID Technology Configuration and Information-Sharing Coordination

- RFID information-sharing coordination are studied through additional literature background related RFID and integration amoung multiple players and different RFID configuration presented in literature.

- Five RFID configuration are presented.
- Each RFID configuration shows RFID technoly implementation in each player and demand shared by each player (two dimensions).

Chapter 5. Basic RFID Information-Sharing Coordination

- Relationship between RFID configuration and inventory decisions are established.
- Simulation and design of experiment are presented.
- Statistical analysis are conduced to test results and identified main and interactions effects.
- Managerial insights are defined as to what RFID information-sharing coordination to use under particular supply chain settings.

Chapter 6. Advanced RFID Information-Sharing Coordination

- Parallel inventory models are developed adjusting information sharing.
- Different RFID coordination enables higher performance is described.
- It is shown that information relevance change depending on the inventory policy used.
- Comparisons between Basic vs Advanced coordination are analyzed.

1.4 Principal Contributions

Below are the main contributions from the thesis.

1. Many companies have difficulty managing their inventory over decentralized environmental supply chain. We detail interactions amount partners from the forward and reverse supply chains. In addition, we study the stochastic behaviors of the reverse channels. We analyze additional interactions between the end-user market and the third party reverse logistic supplier to model. These studies provide higher insight on how to manage returns and its inventory policies.

2. The real value of RFID is attained with information-sharing coordination among players. In literature, rare papers address how RFID technology has to be coordinated among players. We describe what are the different types of RFID coordination based on technology configurations and the types of information that can be shared.

3. There is a lack of understanding of how RFID technology (i.e., configurations plus information) has to be used for decision-making processes. This thesis shows that underperformance results can be presented if RFID information technology is not properly used. We develop RFID information-sharing coordination that aligns RFID technology and inventory policies. Less cost is achieved due to the coordination. Managerial insights are provided based on the results.

4. We extend the work of centralized inventory models from reverse logistics and developed new decentralized inventory models for the green supply chain. This design enables us to model the distributed players based on their respective decisions and allowed us to study coordination through RFID.

5. We provide in detail the different factors and settings from the simulation experiment. Simulation codes and design of experiments guidelines are defined with the objective to provide as much information for replicability of our results.

6. The thesis shows that implementing RFID technology is not enough to attain higher performance. Better performance such as lower cost will also depend on the information-sharing coordination with the inventory decisions. Using the advanced parallel model, the system attained better performance. Thus, it is not just only the technology implemention, but it is also the decision framework and inventory control used.

7. The analysis demonstrates that information sharing and its impact depend on the inventory policy used. In the case of Basic RFID coordination, inventory level had a higher impact. However, with Advanced RFID coordination, we see that demand information provides a higher impact. Information type it is an important criteria as part of the managerial insight and RFID implementation.

8. We developed several simulation test over different supply chain scenarios. We provided insights in which supply chain scenarios is better to implement the best RFID coordination that provides the better results. For example, it is suitable to implement RFID Full-Integrated Coordination over system with high variability of collection leadtime. Other similar managerial insights are provided to give managers more tools on key main factors and interactions.

9. Companies do not know how to change their RFID integrations under drastic changes in supply chain characteristics. We provide a reinforcement learning approach with the use of Q-learning algorithm to dynamically determine the RFID configuration. Also, we propose a self-adaptive algorithm based on control theory to enable adaptability. Results corroborate the hypothesis that higher integration provides better economic results.

10. Players in the supply chain can undergo centralized RFID implementation. However, there can be scenarios that players can individually choose their own RFID information sharing. For this scenario, we determine RFID information

sharing scenarios for each player achieving economic improvement. We model this case with the use of multi-agent reinforcement learning.

1.5 Outline of the Thesis

The thesis is divided in 8 chapters which we describe below:

Chapter 2 details the related work common to all chapters. First, we introduce the literature of environmental supply chain, especially in terms of reverse logistics models. We discuss the adoptions and barriers from environmental supply chain. We define the inventory models used in reverse logistics: optimal and heuristics. The limitations of addressing centralized inventory controls are exposed and the need of information-sharing coordination is presented. Then, we detail the use of RFID technology. We describe qualitative and quantitative studies. We explore the benefits of RFID, in which most of them has come from operational improvements. We present few researches about the need to study more RFID coordination. Particularly, we aim to extend current RFID research over environmental supply chain literature.

Chapter 3 describes the supply chain structure utilized over thesis. Players, leadtimes, flow of materials, and interactions among players are defined. In addition, we define the inventory decisions and policies used. WE define the period and continuous review inventory policies. Then, cost performance measure is described. The cost performance is defined by ordering, setup, holding, backorder, and collection investment costs.

Chapter 4 present additional background of the few papers that address RFD information sharing amoung trading partners and RFID configurations in literature. Then, we present our five RFID configurations. The Chapter details what are the players involved, who have RFID installed, who shares information and what type of information. This RFID Configuration will serve as the base for the following Chapters.

Chapter 5 presents the basic RFID information-sharing coordination. This chapter defines five RFID information-sharing coordination: NO RFID, RFID Non-Integrated, RFID Partially-Integrated Dowstream, RFID Partial-Integrated Upstream, and RFID Full-Integrated. In this chapter, simple inventory policies are used from literature. Numerical studies are conducted through simulation experiments to evaluate cost performance of the RFID information-sharing coordination. Coordination is addressed aligning RFID configurations and the inventory policies. However, opportunity to improve performance is defined.

Chapter 6 studies the advanced RFID information coordination. An improvement on the inventory policy is presented with the parallel decision making. This new model allows decentralized entities to share more information and monitor separately the raw material and recycled material inventory decisions. From the results, RFID advanced models provided lower cost. Further, from the range of information that can be shared, it is shown that demand information seems more valuable to share than solely inventory information with the use of Advanced RFID coordination.

Chapter 7 presents the concluding remarks from the previous Chapters.

Chapter 8 provides preliminary insights of how RFID information-sharing coordination can adapt over dynamic supply chain scenarios. We use the concept of Q-learning and identify several dynamic optimal strategies. In addition, the chapter considers changes in the supply chain and study how self-adaptive protocols can be implemented. Further, we identify what set of individual RFID information-sharing coordination provide an improvement for all players with the use of multi-agent reinforcement learning.

CHAPTER 2. RELATED WORK

This chapter presents the literature review for the thesis. Our research contribution aims to provide new insights over the use of RFID technology to improve green supply chain. Particularly, the research studies how RFID information sharing can change inventory decisions to enhance supply chains with reverse logistics. Therefore, the thesis is based over the following main stream of research: 1) inventory policies over reverse logistics and 2) RFID technology configuration, information sharing, and coordination.

Section 2.1 presents the literature about environmental supply chain. First, we present studies about the motivation to adopt green supply chains. Then, we show the studies about inventory policies on reverse logistics. We detail optimal and heuristics policies with their contributions and limitations. Specially, these researches address centralized inventory decision making focusing over the reverse logistics. However, green supply chains deals with more decentralized entities if we include traditional supply chain as well as reverse logistics into the study. Thus, centralized models have a limitation to model closed-loop environmental supply chains. This thesis presents decentralized inventory models enabled by the use of information technology providing an extension to current research.

Section 2.2 introduces the importance of information technology to address decentralized scenarios. A brief introduction of information sharing literature is presented. Then, RFID information sharing researches are described by qualitative and quantitative studies.

In the quantitative studies, most of the benefits have come through operational improvement in a single player. However, we show that few research address the real value of RFID in terms of RFID information sharing through the entire supply chain. We describe previous studies that model RFID information-sharing coordination and their limitations. These two stream of research creates the basis for our problem in terms of how to coordinate RFID information sharing to reduce cost over a green supply chains.

2.1 Environmental Supply Chain

2.1.1 Adoption and Results of Green Supply Chain Initiatives

The section illustrates examples of the adoption of green supply chain and motivations towards more environmental enterprises. Zhu and Sarkis (2004) report that early adoption of green supply chain management in China has been motivated by globalization and competition. Chinese companies need to fulfill environmental requirements from its foreign customer in order to enter new markets. Overall, these green supply chain practices tended to have an improvement in economic and environmental performance. Zhu et al. (2007) empirically analyze 89 automobile enterprises in China and their Green Supply Chain adoption. From the study, globalization and external factors such as government regulations and customer pressures are forcing companies to implement green initiatives. However, the results show that there has been slightly improvement in operational and environmental performance. Consequently, companies are lagging in terms of economic outputs. This underperformance is more prominent over decentralized supply chain. Lee (2008) studies different drivers that stimulate small and medium-sized Korean suppliers to embark environmental supply chain practices. The study shows that buyers, green supply chain support, and suppliers own readinesses are significant factors that affect performance. Further, Gandhi (2016) explores the relationship between implementing green supply chain practices and green supply chain performances. The authros conclude that there still needs more research that relateds green implementation and what are the overall impact on the system.

From previous studies, environmental initiatives not always attain high economic benefits under decentralized supply chain. Researchers began to study in deep factors that enable successful green supply chain implementations. Hu and Hsu (2006) study environmental practices in the Taiwanese electrical and electronic industry through an extensive survey and statistical test. The analysis shows four critical factors that are relevant towards successful implementation of green supply chains: supplier's management, product recycling, organization involvement, and life cycle management. Salam (2008) investigates four factors from the electric and electronic industry in Thailand that can lead to the transformation towards Green Supply Chain. The factors are product performance, purchase price, organizational environmental commitment, and trading partners. From the later, the results identified that coordination among suppliers is essential for successful green transformation. Further, researchers identify that companies need to integrate green strategies with their business strategies to increase the overall performance. Nagel (2000) compares two types of green initiatives: green procurement and environmental supply chain management. The authors conclude that green procurement is more easily to implement and provides environmental improvement. However, green procurement will not lead to a long-run business and leadership benefits. Interaction and coordination among trading partners has to be considered in order to guarantee changes in the planning, strategy, and production of the green components such as recycling and reusing.

Further, the following research addresses the importance of green supply chain management to guarantee higher economic success in order to reduce the barriers and obstacles. Beullens (2004) states companies have problems to show economic justification in reverse logistics due to obstacles in quality, quantity, and timing of collection that can hinder margins. For example, the author describes that product recovery is a difficult task to manage due to the interactions among players and randomness. Ravi and Shankar (2005) study eleven barriers to implement reverse logistics in the auto industry in India. The results show that lack of awareness of reverse logistics practices and lack of commitment from the top management are the primary barriers to implement reverse logistics. Other factors such as quality problems, lack of strategic planning, and financial constraints are strong barriers to integrate reverse logistics. Zhu et al. (2008) present different measurements in which companies can manage environmental practices to achieve higher results. The authors describe internal environmental management, green purchasing, cooperation with customers, eco-design, and investment in recovery are main measurements to enhance green initiatives. From the results, the authors explain that multidimensional engagement has to be considered to increase green performance. For example, green purchasing alone cannot fulfill maximum realization of green initiatives. These studies demonstrate that successful green supply chain comes with the effective integration of the trading partners. In addition, more studies on the relations and interactions of the decentralized supply chain are needed given the continues preassures of leadership and institutions (Dubey et al., 2015).

From previous studies, we can infer that coordination and collaboration among trading partner is a key factor towards successful environmental initiatives (Tachizawa et al., 2015). As research shows, companies have not been able to achieve efficient coordination through the traditional and reverse logistics patterns. Therefore, this thesis aims to include technology such as RFID to increase efficiency over decentralized coordination.

The above literature of the adoption and results of green supply chain has provided us key insights. Globalization and green requirements from buyers are primary pressures companies are facing to incorporate green practices. Achieving high economic and environmental performance as a win-win strategy is blurred in the results. For example, there is a lack of alignment between strategic business decisions and environmental operations. Further, more support and incentives have to be given to the green suppliers in order to stimulate readiness and efficiency to successful implement green practices. In addition, the studies detail that more research on coordination and alignment is needed related with the trading patterns to achieve higher economic results.

This thesis addresses the problem of providing more alignment between reverse logistics and decentralized inventory decision-making. The thesis explores the use of RFID technology to help coordinate suppliers and manufacturers in order to manage more effectively the reverse channel. Further, this stream of research identifies the need for higher strategic integration between business and environmental practices. Green activities alone, such as green purchasing, will not lead to strategic competitive advantages. In this endeavor, companies face different set of decisions such as partner, technology, and organization selection. However, the current literature does not address these issues. These selections can lead to positive or negative outcomes for the company. For this matter, better coordination among players can help achieve green and economic performance. More research is needed to understand how to motivate better coordination in green practices. Thus, the research aims to provides proactive methods to implement green as requested in literature (Li et al., 2016). Also, the need to provide managerial guidelines in terms of information technology selection is critical based on previous research results.

2.1.2 Inventory Policies over Green Supply Chains

For this research, we focus our attention over inventory policies with reverse logistics. Our reasons to aim over inventory policies are that a solution must be around a particular corporate decision. Inventory decisions have a direct impact over inventory cost, holdings cost, shortage cost, and set-up cost. Therefore, our improvements and solutions are from the inventory policy literature which is a key factor to succesfull green initiatives (Niknejad and Petrovic, 2014; Bazan et al., 2016,).

Green supply chain management considers green manufacturing/remanufacturing operations, reverse logistics, and waste management. Inside these operational activities, inventory policies play an important role in research and practitioners (Srivastava, 2007). Our research is focus on inventory policies over green supply chain. We detail the inventory control problem from optimal and heuristics models. The limitations of the inventory controls presented in literature are that they consider centralized models (e.g., one entity making de inventory decisions). This section forms the base for our decentralized inventory control model for our thesis.

Simpson (1978) studied a manufacturer with serviceable inventory, repairable inventory and disposal options. The author found that optimal decisions are based on three parameters with the use of backward dynamic programming. The limitations of the study are the use of zero leadtimes and zero setup costs. Inderfurth (1997) investigated a similar case with positive and equal setup cost, and deterministic leadtimes. The author showed that an optimal policy can be achieved under positive but identical leadtimes and proper definition of inventory positions.

These two papers described previously address optimal approaches. However, these are simple models with strong assumptions such as zero or equal deterministic leadtimes, and equal setup cost constraints. For these reasons, authors began to use heuristic models (Dyckhoff et al., 2004). van der Laan and Salomon (1997) introduced the PUSH and PULL heuristic models with remanufacturing operations. In the PUSH model, returns are used for serviceable inventory only when there are enough recycle items recovered to complete the entire batch. In the PULL model, if the inventory position is below than or equal to the reorder point to-remanufacture, and if sufficient recycle items are available, a remanufacturing order is produced. However, if there are not enough returns and inventory position is below than or equal to the reorder point to-manufacture, a manufacturing batch is ordered. Better performance was attained when leadtimes were relatively equal. The model was not suitable enough to address different leadtimes which in return impacted economic performances. van der Laan et al. (1999) extended previous research and analyzed stochastic leadtimes in the model. Results showed that manufacturing leadtimes have more significant impact than remanufacturing leadtimes. The authors found that, in some cases, larger remanufacturing leadtimes and larger variability in the manufacturing leadtimes can decrease cost, which is counter-intuitive. To address this phenomenon, Inderfurth and van der Laan (2001) studied leadtime effects and provided a policy improvement taking leadtimes as a decision variable. The limitations of this article are that obtaining the optimal solution is quite time-consuming and the problem does not consider different leadtimes. Also, leadtimes are considered as one of the decision variables. In real cases, leadtimes are mostly fixed or depends on the supply chain structure or geographic position.

Kiesmüller (2003) provides a novel solution from previous inventory control models on reverse logistics. The author split the decisions over two inventory positions for manufacturing and remanufacturing instead of using one inventory position for both. Each inventory position will have the necessary on-hand inventory and outstanding orders information required to obtain better performance. The results show that the solution with two inventory positions has better performances than the other heuristics. The limitations of the paper are that in dynamic models this solution is not appropriate because it only takes into account local decisions of one player (i.e., the manufacturer). In addition, stochastic leadtimes were not considered. Teunter et al. (2004) extended the work by Kiesmüller (2003) specially addressing fast remanufacturing leadtimes. The model consisted of positive leadtimes, positive setup cost, stochastic demand and returns. The limitations of the research are that the authors do not consider more complex scenarios such as stochastic leadtimes and the authors only considered centralized decisions involving one entity.

These previous researches on inventory control over reverse logistics focus on single entity with manufacturing and remanufacturing operations. In contrast, our research considers a decentralized two-echelon supply chain and its inventory management interactions among players. Therefore, this thesis aims to provide more understandings of the system behavior of a decentralized supply chain instead of a single entity. This is consistent with Beamon (1999) where defines that inventory controls and centralized vs. decentralized relations are part of the main issues towards green supply chain. Further, previous models consider the returns as a simple stochastic random variable based on a probability distribution. Our model accounts for more dynamic aspect of the collection behavior in reverse logistics. We model the reverse logistic dynamics through the notion of end-user market and collection investment addressing more realistic reverse logistics scenarios.

Our paper proposes to extend the research of inventory control over reverse logistic to consider: 1) more interactions among parameters (i.e., positive setup cost and stochastic leadtimes), and 2) decentralized decisions (i.e., multiple decision-makers). Next, we study the literature of information sharing.

2.2 Information Sharing

Globalization and the propagation of the supply chain have made environmental supply chain models more distributed. Each decentralized entities tries to maximize their individual benefit. This has created new research models to examine multiple decentralized entities in the supply chain. However, this phenomenon gives rise to coordination problems among players in the distributed supply chain. One alternative to coordinate this complex supply chain is the use of information-sharing methods. Below are some examples of information-sharing methods as a way to coordinate decentralized systems.

Yu et al. (2002) analyze different information sharing scenarios and their impact over a two-level supply chain. Huang et al. (2003) conduct a survey related with production information sharing on the supply chain. Reddy and Rajendran (2005) evaluate dynamic inventory order-up-to level and different information sharing that helped minimize total inventory, shortage and transportation cost in a supply chain with non-stationary demand. Further, Gavirneni (2006) studies how inventory information sharing between a supplier and a retailer can improve the price strategies in order to achieve higher supply chain performance. The authors developed simple linear contracts and review the Stackelberg games to find equilibrium between the players.

Tatoglu et al. (2016) continue the research for small and medium-sized enterprises (SME). They shows that SME for example in the case of Emerging Markets needs to treat Supply Chain initiatives and Information Technology together in order to be able to compete in the market and globally. The authors stated the importante to achieve higher operational performance it is important the coordination and integration mechanisim over the system.

However, the authors do not provide an approach of how this coordination can be execute and which is part of the goals of this research.

Even though there are previous researches about the use of information sharing, they usually addressed single-period using analytical techniques. Further, there are rare research papers in literature that address how information sharing can change inventory control policies over multiple periods' settings. In addition, these papers do not address the technologies that can provide this information sharing. For this thesis, we focus on Radio Frequency Identification (RFID) over green supply chain to coordinate inventory controls. For the supply chain, RFID has come to be one of the most used AIDC technologies (Kärkkäinen and Holmström, 2002). The following section presents relevant studies about RFID.

2.2.1 Radio Frequency Identification

This section shows literature from RFID technology related with qualitative and quantitative studies.

2.2.1.1 RFID Qualitative Studies

Radio Frequency Identification (RFID) provides more inventory visibility through real-time control and information. Most RFID research has been done in term of empirical samples or qualitative analysis in order to evaluate the benefits of the RFID implementation. Smith (2005) mentions the benefits, disadvantages and challenges faced by suppliers due to mandates from retailers (e.g., Wal-Mart) to change their companies to a Radio Frequency (RF) – based technology organization. Green et al. (2009) develop a survey to measure the RFID utilization and its impact on supply chain productivity and organizational performance. Visich et al. (2009) present six empirical cases in which RFID has provided benefits in the organization. For example, the authors discuss the benefits of RFID such as to control the inventory of raw material, work-in-progress, and finished products. Another benefit from RFID presented in the study is the automation of replenishment signals for new orders.

2.2.1.2 RFID Quantitative Studies

Previous papers consider the impact and benefits of RFID systems. However, most of them do not provide quantitative methodologies that measure analytically the benefits of RFID. Lee and Özer (2007) echo this statement by providing a detailed review on the necessity to close the gap on the quantitative measurements to study RFID technologies. Also, Wamba et al. (2016) mention that more studies are needed on technological, organizational, environmental and managerial characteristics over the small and mid-sized enterprise to successfully implement RFID. Gaukler et al. (2007) study item-level RFID implementation in a supply chain between a manufacturer and retailer with scale parameter to account for the lost demand without RFID (i.e., representing inefficient restocking of the shelves). Szmerekovsky and Zhang (2008) analyze RFID under a vendor management inventory system with one manufacturer and one retailer. The difference in this paper from Gaukler et al. (2007) is that demand is truncated by the shelf space rather than a scalar parameter. Bottani and Rizzi (2008) study the implementation of RFID in the fast-moving consumer good supply. The authors compare RFID Nonintegrated and Integrated configurations.

Most of the quantitative benefits has come from operational works and automate processes. Wamba et al. (2008) studied how RFID technology and the EPC Network can impact the mobile e-commerce in a retail industry. The authors presented the use of RFID information over three dimensions: intra-organizational, inter-organizational, and in-transit information. Intra-organization integration referred to information obtained from the RFID tags and readers inside the warehouse which helped automate several business processes (e.g., automatic scan of trailers shipment with RFID tag and readers). The inter-organizational integration described the automatic delivery of an advanced shipping notice from the upstream to downstream player. The in-transit information described the access of real-time data of the shipments transportation with the use of the Global Position System (GPS) for tracking purposes.

Wamba and Boeck (2008) performed a similar analysis of RFID technology and EPC Network in the retail industry focusing on the automation of information-based activities.

The authors showed that RFID information automation can help the supply chain entities eliminate manual work and time in the warehouse such as shipping and receiving processes. These benefits with RFID technology were achieved by the automatic readings of the tags and real-time validations. For example, the validations from the tags read versus the advanced shipping notice.

Chow et al. (2007) proposed an integrated logistics information management system (ILIMS) with the inclusion of RFID technology and EPC Network. ILIMS with RFID-EPC Network empowered the members in the supply chain to improve daily activities such as transactions, operations, and logistics documents. For example, fulfillment processes of the in-bound and out-bound logistics operations are automated with the information system integration. This enables the supply chain to handle higher transaction volume in their logistics operations. Also, measurements such as inventory, out-of-stock, leadtime, and total cost were improved. Particularly related with the RFID technology, the RFID helped to have an efficient monitoring and tracking of the cases and pallets reducing error in the intra-organization and inter-organizational dimensions.

These previous papers show benefits of RFID information sharing over improvement of operational tasks and automation of business processes. Similar with Lindau and Lumsden (1999), major benefits are found in the RFID literature in terms of the operational improvements such as tracking and shipments. However, few papers in literature comprehensively study how RFID information coordination among decentralized players can enable higher economic results. Further, few papers address how RFID information-sharing coordination can enhance decision-making processes such as in the inventory policies. We study the value of RFID as a way to increase coordination in a decentralized green supply chain. As Dutta et al. (2007) mention, the real value of RFID integration is on creating new business architecture through higher integration and visibility among the supply chain members. Below are some papers that address RFID integration that allows coordination.

Bottani and Rizzi (2008) studied the economic impact of RFID technology and the EPC Network in a fast-moving consumer goods supply chain. The authors defined the RFID-supply chain configuration for non-integrated and integrated scenario. In the non-integrated scenario, the players had installed RFID tags and readers, but no information is shared. In the integrated scenario, RFID tags and readers are installed. The players are able to share information through the EPC Global Network.

Bottani et al. (2009) developed six business intelligent (BI) modules based on RFID information in a case study in the fast-moving consumer goods industry. These BI modules are: product flow, flow time management, shelf life management, inventories, track and trace, and case history. In the inventory module, the managers of each entity in the supply chain can check how many inventories are in any product selected that has the EPC code and standards. However, there was no a clear guideline of how this information impacted the inventory policies decisions.

Su and Roan (2011) studied a beer game-type supply chain and how RFID technology can reduce inventory and cost within the supply chain as well as the impact on dynamics. The authors presented two information sharing approaches: with demand information sharing and without demand information sharing. With demand information, the retailer provided real-demand information to the supplier to calculate their order levels. However, the without demand information, the supplier just relied on their order history. These demand information sharing were tested over different supply chain scenarios such as demand patterns, leadtime, and degree of RFID application. The authors study two cases: with and without demand. However, there can be other types of information to be shared such as inventory levels.

These previous papers provided insights on how information sharing from RFID can further improve coordination in a supply chain. However, there has not been a defined taxonomy on these kinds of RFID information-sharing coordination. Further, there has not been a clear guideline on how coordination can change a decision-making process such as in the inventory policies. In addition, most of the research studies one type of information such as demand. For this thesis, we want to extend previous traditional supply chain work over supply chain with reverse logistics. Finally, few papers study RFID coordination impact with reverse logistics partners involved. Our goal is to delineate RFID information-sharing coordination and provide insights on when to use each of this coordination to enable higher economic and environmental results. Figure 2.1 illustrates the literature framework that serves as a motivation for the rest of the thesis.

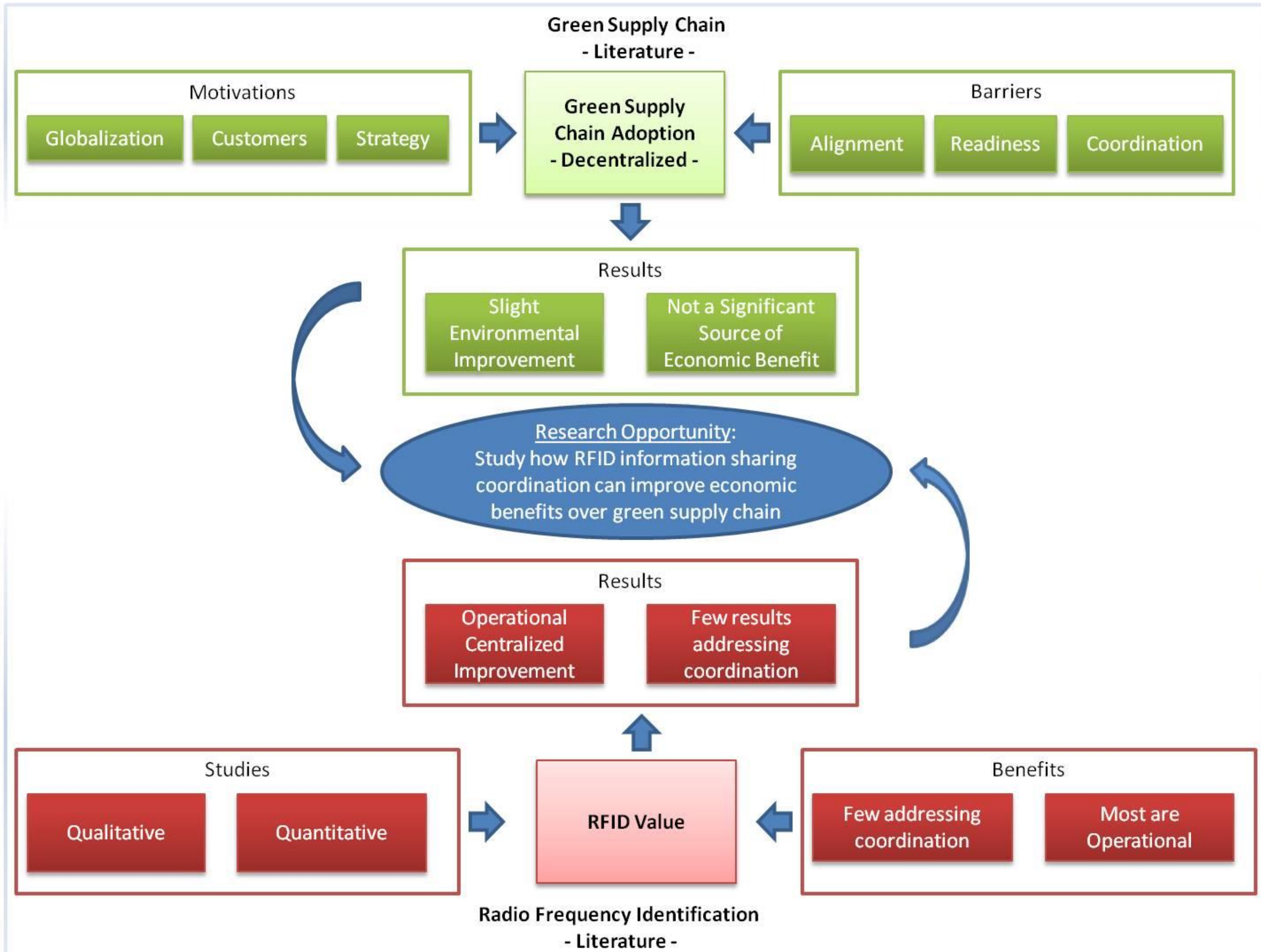

Figure 2.1 Literature Framework

CHAPTER 3. SUPPLY CHAIN MODEL

This chapter describes the supply chain used for the thesis. First, we describe the supply chain structure in terms of players involved and their interactions. Then, we define the assumptions considered within this supply chain such as demand, return, leadtimes, manufacturing operations and RFID settings. Further, we describe the inventory policies used in the supply chain. We present the periodic and continuous inventory policies which helps to develop the Basic RFID Coordination of Chapter 5. Finally, the chapter defines the performance measures for the thesis. Cost definitions such as ordering, setup, holding, and shortage cost are described.

Chapter 3 helps create the base of the supply chain structure and common modeling for the thesis. In Chapter 4, we propose five ways to configure RFID technology in supply chains. This RFID technology-configuration describes which player has installed RFID technology and how the RFID information flows within the supply chain. Then, we study and compare the simple RFID coordination from Chapter 5 versus the advanced RFID coordination from Chapter 6.

3.1 Supply Chain Structure

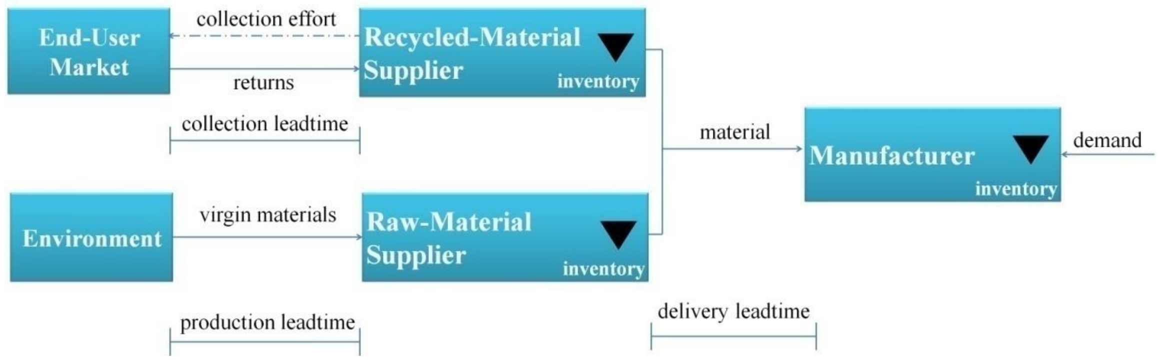

Figure 3.1 Supply Chain with Reverse Logistics

Figure 3.1 considers a two-echelon supply chain. This model is defined by the downstream and upstream sides of the supply chain. The downstream is represented by the manufacturer and the upstream by the suppliers. For the thesis, two separate and independent suppliers are considered. Each player in the supply chain set their inventory decisions to minimize their cost independently. This kind of two-echelon supply chain is a common framework to study supply chain and inventory policies (Cachon and Fisher, 2000; Gavirneni et al., 1999). Academics and practitioners also address supply chains with multiple echelons. Research with more echelons can serve to understand, for example, networks and optimization design problems which are out of the scope of the thesis. Some papers that address multiple echelons are Clark and Scarf, 1960; Lee and Whang, 1999; Chen and Lee, 2004; Wu and Cheng, 2008. For our research, two-echelon supply chain serves as a suitable model structure to study inventory models and the interactions among players.

The manufacturer receives stochastic demands from customers with a probability distribution function. The manufacturer fulfills incoming demands through its serviceable inventory. This serviceable inventory is from products manufactured from purchased materials. The manufacturer can purchase materials either from the recycled-material supplier or raw-material supplier. For the thesis, join sourcing from the recycled-material supplier and raw-material supplier is not included in the analysis.

The recycled-material supplier has an inventory of returns which help fulfill manufacturer's orders. These returns are collected from the end-user market. The raw-material supplier has also inventory to fulfill manufacturer's orders. The raw-material supplier sources from the environment (i.e., virgin materials). As Wu et al. (2015) state, recovery and recycling systems are key factors towards succesfull reverse logistics.

There are three leadtimes considered in the model. The delivery leadtime is the time taken for the suppliers to provide the materials to the manufacturer. The collection leadtime considers the time taken to collect returns. This collection leadtime aggregates all the relevant activities for the collection process such as collection, sort, classification, distribution, and transformation. Finally, the production leadtime represents the time taken for the raw-material supplier to produce new materials from the raw materials in the environment.

The supply chain described above can be found in several real-case scenarios. Hewlett-Packard (H-P) work with a third party vendor Micro Metallics Corporation in order to make the collection, transformation of returns (i.e., monitors) to recycled material, and distribute to H-P for manufacturing (Pagell et al., 2007). Xerox is another company that includes different type of suppliers with raw materials and recycled materials (Bechtel and Jayaram, 1997). BMW includes recycling materials in its operations. BMW has a manufacturing production for recycling materials. For example, the material they use is plastics instead of metals to increase recycling consumption (v. Hoek, 2001).

3.1.1 Assumptions

This section provides the assumptions for the supply chain structure described above. The section defines the demand, return, manufacturing operations, leadtimes, and RFID assumptions.

3.1.1.1 Demand

The manufacturer creates products to satisfy demands which are considered stochastic following a Poisson Process, $D \sim POIS(\mu_D)$ similar to Zanoni et al. (2006). These demands are served through the manufacturer's inventory. The demands arrive every inter-arrival time, IT. The inter-arrival time is assumed to be deterministic over the entire time-horizon TH. These assumptions enable to model our demand as independent and identical distributed random variables. Figure 3.2 shows an illustration of our demand assumptions.

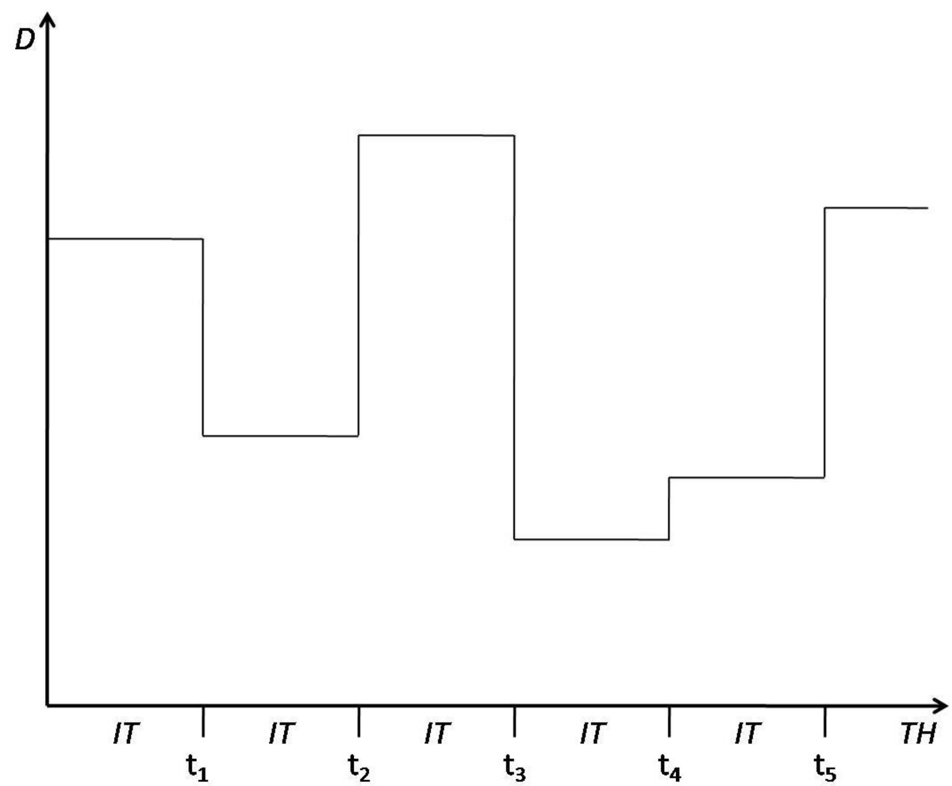

Figure 3.2 Demand Modeling

3.1.1.2 Returns

The returns RC are determined by the capacity of the end-user market E and the return rate τ, such that $RC = E * \tau$. Note that E is a random variable with mean μ_e and standard deviation σ_e . The return rate τ $(0 < \tau < 1)$ in the reverse channel is defined by the collection investment CI. The collection investment CI represents the amount of efforts (e.g., promotion, advertising) the recycled-material supplier applies to the end-user market to create the necessary incentives to receive targeted returns. The return rate helps assess the investment made by the recycled-material supplier to receive returns. The intuition is that with an adequate CI, the end-user market will be motivated to provide their used products for recycling purposes. We model the return rate similar to the work by Savaskan et al. (2004) in which $\tau = \sqrt{CI/\beta}$, where β is a scaling parameter. This expression is used in various models such as advertising response and product awareness (Lilien et al., 1992; Fruchter and Kalish, 1997; Zhao, 2000), sales force effort responses (Coughlan, 1993), and operations investing in setup cost reduction (Porteus, 1986; Fine and Porteus, 1989).

The assumptions of the returns is that they are going to produce material with the same quality as the raw material. We are not considering two types of qualities since will be out-of-scope of the current research. Future investigation can address the creation and fulfillment of secondary markets based on two qualities.

There is a cost sharing strategy between the manufacturer and the recycled-material supplier. The collection investment will have two components: green and manufacturer investments (i.e., $CI = CI_g + CI_m$). Therefore, manufacturer also contributes to the CI.

<u>3.1.1.3 Manufacturing Operations</u>

We neglect manufacturing and recycling unit cost. These costs are neglected since they are linearly correlated with the returns and raw material ordered. In practical settings, the manufacturing cost or recycling cost can be incorporated. In addition, since our effort is to understand cost results based on the implementation of RFID over several technology configurations and inventory policies, the inclusion of manufacturing cost or recycling cost will not add any significant new insight.

<u>3.1.1.4 Leadtimes</u>

Collection leadtime represents the time taken for the recycled-material supplier to collect the returns from the end-user market. As stated above, this leadtime is the aggregation of all the collection activities from collection to transformation. The collection leadtime LT_g is considered to be stochastic, $LT_g \sim Gamma\ (\mu_{LTg}, \sigma_{LTg})$ similar to Zanoni et al. (2006). The production leadtime LT_r and delivery leadtime LT_m are deterministic. We set LT_g stochastic and the rest leadtime deterministic to measure the randomness of the recycling operations that is mentioned in Section 1.1.3. LT_r and LT_m should reflect stable transportation leadtimes.

Many authors describe the operation benefits of RFID to reduce processing time (Cachon and Fisher, 2000; Visich et al., 2009). For this paper, we are not considering processing leadtime since literature has shown that RFID can reduce operational times such as order processing and warehouse activities. Previous literature argue that there is a slighty improvement or benefits with inter-organizational RFD information usage (Cachon and Fisher, 2000). We will study the benefits that can be presented over inter-organizational RFID information sharing were supply chain have additional sources of uncertainty such as green initiatives.

<u>3.1.1.5 RFID</u>

RFID tags and readers have RFID measurement reliability. Read rate and reliability are the principal problems presented in RFID implementations. From previous implementations from mandates in Wal-Mart, RFID read rate accuracy have been recorded to be 80%. (Soon and Gutierrez, 2008). Every time the readers send a signal, there could be an error involved within the reading of the tags (e.g., due to unsuccessful implementation or inefficient location of the readers). The RFID measurement reliability MR is modeled as a random variable, $MR\ \sim Unif(RFID_L, RFID_U)$.

Variable and Fixed cost can represent overall RFID installation (Whang, 2010). We neglect the variable cost of RFID such as RFID tags cost as well as the fixed cost such as the installation cost of the readers. We are addressing the maximum value of RFID coordination. Therefore, we study the benefits of implementing RFID and address its coordination. This study will create generalized guidelines and show the monetary value of RFID in the long-run. Practitioners can run similar simulations to identify the total value of RFID over its supply chain and account for variable and fixed cost to determine its return of investment. In addition, we do not consider any cost of coordination since we are addressing the value of the RFID application. We assume that the RFID information is available instantaneously for the players without any delays.

3.2 Inventory Definitions

We use two type of inventory commonly applied on inventory literature: continuous review and periodic review. We will see in Chapter 5, that the later is applied for cases were no RFID is implemented and the former were RFID is implemented. These two inventory policies are used in Chapter 5 for the basic RFID coordination approach. As we will see, this basic inventory model, do not guarantee the highest economic performance possible for the entire system. Chapter 6 then will present an extention of traditional inventory policies that helps attain higher economic performance.

Definition 3.1 Continuous Review$(\boldsymbol{Q},\boldsymbol{r})$ Inventory Policy: the entity requests an order quantity Q whenever the inventory position X is below or equal to the reorder point r, $X \leq r$. Equation 3.1 shows the inventory decisions and Figure 3.3 presents an illustration of the policy.

$$Q = \begin{cases} Q & if\ X \leq r \\ 0 & otherwise \end{cases} . \qquad \text{Eq. 3.1}$$

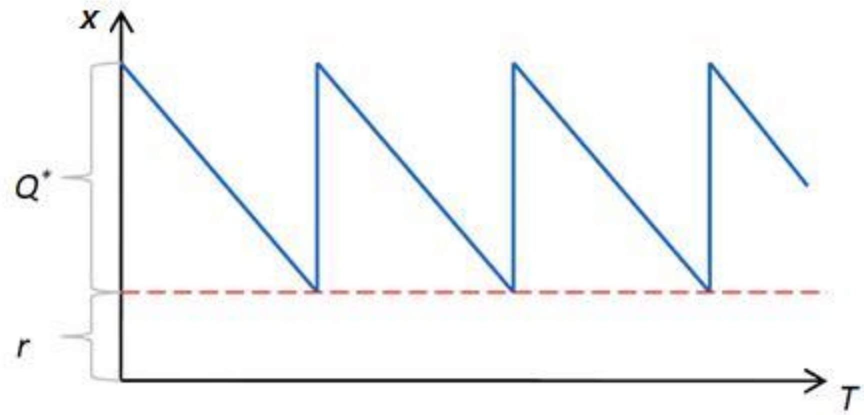

Figure 3.3 Continuous Review (Q,r) Inventory Policy

The general (Q,r) inventory policy is calculated as follows (Nhamias, 2001; Hopp and Spearman, 2008). We first compute the optimal order quantity,

$$Q^* = \sqrt{\frac{2KD}{h}} \ . \qquad \text{Eq. 3.2}$$

The parameters to obtain the optimal order quantity Q^* are setup cost K, demand information D, and unit holding cost h. Then, to obtain optimal reorder point r^*, we compute the critical ratio CR such as,

$$CR = \frac{Unit\ Shortage\ Cost}{(Unit\ Holding\ Cost + Unit\ Shortage\ Cost)} \ , \qquad \text{Eq. 3.3}$$

and get the z value from $\Phi(z) = CR$ where $\Phi(z)$ is the standard normal distribution,

$$r^* = \theta + z\sigma \ , \qquad \text{Eq. 3.4}$$

in which θ denotes the demand over leadtime and σ the standard deviation over leadtime. The demand over leadtime is the mean demand μ_D during a unit period times the leadtime. The standard deviation over leadtime is the square root of the leadtime times the standard deviation of the demand σ_D. Equations 3.5 and 3.6 show the formulations for the demand and standard deviation over leadtime, respectively.

$$\theta = \mu_D * LT \ , \qquad \text{Eq. 3.5}$$

$$\sigma = \sqrt{LT} * \sigma_D \ . \qquad \text{Eq. 3.6}$$

The second inventory policy is the periodic review (s,S) inventory policy described as follow.

Definition 3.2 Periodic Review (s, S) Inventory Policy: the entity requests an order quantity Q whenever the inventory position X is below or equal to the reorder point s. Equation 3.7 shows the inventory decisions and Figure 3.4 presents an illustration of the policy.

$$Q = \begin{cases} (S - I) & if\ X \leq s \\ 0 & otherwise \end{cases} \quad . \qquad \text{Eq. 3.7}$$

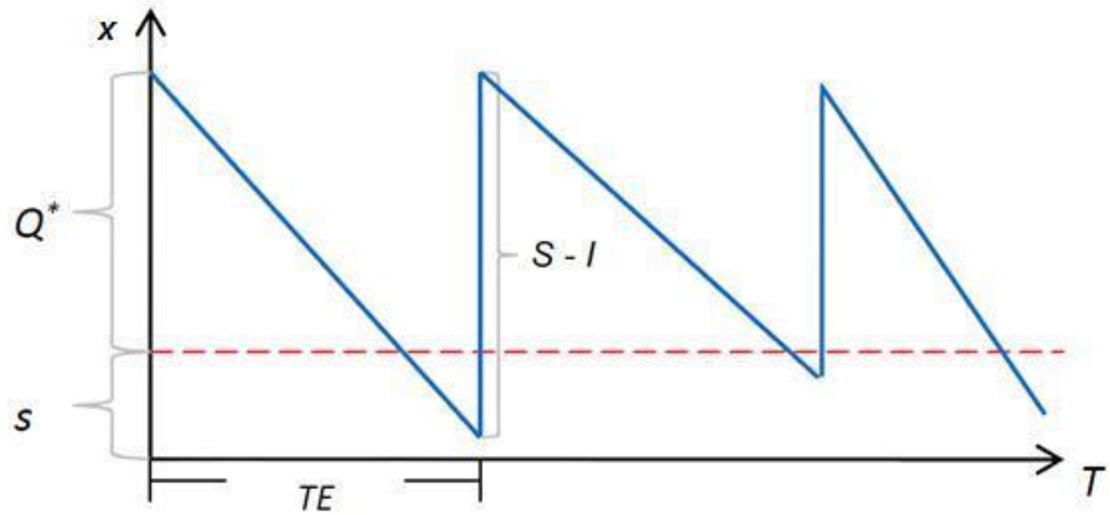

Figure 3.4 Periodic Review (s,S) Inventory Policy

The manager has to check the inventory every time-evaluation interval, TE. Since this is not a continuous review policy, there can be stock-outs (i.e., demand not fulfilled) before requesting additional orders. For this reason, we have to include the on-hand inventory to request the new quantity. Therefore, at every TE, the manager checks the inventory. If the inventory position X is below or equal to the reorder point s, we order the difference between the reorder up-to level minus the current on-hand inventory $Q = S - I$. The reorder level s is equal to the reorder point in the continuous review, $s = r$. Periodic reviews are relevant in today´s literature and practice (Bouras, et al. 2016).

The reorder up-to level is calculated as follows,

$$S = Q^{*} + s \quad , \qquad \text{Eq. 3.8}$$

where Q^* can be obtain from Equation 3.2. TE is determined by the optimal order quantity Q^* divided by the mean demand μ_D,

$$TE = \frac{Q^*}{\mu_D} \ . \qquad \text{Eq. 3.9}$$

The recycled-material supplier has to collect what is available in the end-user market. Therefore, this entity does not have an optimal order quantity such as the manufacturer or the raw-material supplier. We define a heuristic policy for the recycled-material supplier as follows.

Definition 3.3 Collection Inventory Policy: the recycled-material supplier collects returns RC whenever its inventory position X is below or equal to the reorder point, either r for continuous review or s for periodic review. Equation 3.10 shows the collection inventory decisions of the policy where RC is the amount of returns described in section 3.1.1.2.

$$Q_g = \begin{cases} RC(CI,E) & if\ X \leq r\ in\ the\ contious\ review \\ RC(CI,E) & if\ X \leq s\ in\ the\ periodic\ review \\ 0 & Otherwise \end{cases} . \qquad \text{Eq. 3.10}$$

The reorder point r or s can be computed according to Equation 3.4.

3.3 Performance Measures

The performance measure is the total cost from the system. We define *system* as the supply chain under consideration as shown in Figure 3.1 The index notations used are m for the manufacturer, g for the "green" recycled-material supplier, r for the raw-material supplier, and s for the system. Table 3.1 shows in detail the measures and decision variables for each entity to calculate the total cost of the system.

Table 3.1 Cost Measures and Decisions Variables

Variables and Decisions	Manufacturer		Recycled-material supplier		Raw-material supplier	
	Cost measures	*Notations*	Cost measures	*Notations*	Cost measures	*Notations*
Ordering cost	Procurement cost recycled material	O_m^g	Collection cost	O_g	Production cost	O_r
	Procurement cost raw material	O_m^r				
Setup cost	Setup cost recycled material	K_m^g	Setup cost	K_g	Setup cost	K_r
	Setup cost raw material	K_m^r				
Holding cost	Holding Cost	H_m	Holding cost	H_g	Holding cost	H_r
Shortage cost	Shortage Cost	B_m	Shortage cost	B_g	Shortage Cost	B_r
Collection investment	Collection Investment	CI_m	Collection investment	CI_g	n.a.	
Order quantity	Order quantity from recycled material	Q_m^g	Order quantity to collect	Q_g	Order quantity to produce	Q_r
	Order quantity from raw material	Q_m^r				
Inventory	On-hand inventory from serviceable	I_m	On-hand inventory from returns	I_g	On-hand inventory from raw materials	I_r
Unit cost	Unit cost recycled materials	p_g	Unit collection cost	A	Unit production cost	P
	Unit cost raw materials	p_r				

The total cost of the system C_s is comprised of the total cost of the three entities over the time horizon, $C_s = C_m + C_g + C_r$.

The total cost of each entity is calculated by the sum of the ordering, setup, holding, and shortage cost. The manufacturer and recycled-material supplier incurs in collection investments.

The ordering cost is calculated by the order quantity multiplied by unit cost. For the case of manufacturer, the ordering cost is then,

$$O_i^j = Q_i^j * \gamma, \qquad \text{Eq. 3.11}$$

$$i \in \{m\}, j \in \{g, r\}, \gamma \in \{p_g, p_r\}.$$

For the case of the suppliers, the ordering cost is as follows,

$$O_i = Q_i * \gamma, \qquad \text{Eq. 3.12}$$

$$i \in \{g, r\}, \gamma \in \{A, P\}.$$

The manufacturer incurs setup cost every time an order is requested,

$$K_i^j = k_i^j * \delta(Q_i^j), \qquad \text{Eq. 3.13}$$

$$i \in \{m\}, j \in \{g, r\},$$

$$\delta(Q_i^j) = 1 \; if \; Q_i^j > 0, 0 \; otherwise.$$

Similarly, the setup cost for the suppliers is,

$$K_i = k_i * \delta(Q_i), \qquad \text{Eq. 3.14}$$

$$i \in \{g, r\},$$

$$\delta(Q_i) = 1 \; if \; Q_i > 0, 0 \; otherwise.$$

The holding cost for a unit time is equal to the on-hand inventory I_i multiplied by the unit holding cost h_i,

$$H_i = I_i * h_i, \qquad \text{Eq. 3.15}$$

$$i \in \{m, g, r\}.$$

The shortage cost for a unit time is computed as the demand not fulfilled multiplied by the unit shortage cost b_i. The demand notation is D; thus, the manufacturer shortage cost is,

$$B_i = \delta\,(D - I_i) * (D - I_i) * b_i, \qquad \text{Eq. 3.16}$$

$$i \in \{m\},$$

$$\delta(D - I_i) = 1 \; if \; (D - I_i) > 0, 0 \; otherwise.$$

The shortage cost for the suppliers is as follows,

$$B_j = \delta\left(Q_i^j - I_j\right) * \left(Q_i^j - I_j\right) * b_j, \qquad \text{Eq. 3.17}$$

$$i \in \{m\}, j \in \{g, r\},$$

$$\delta\left(Q_i^j - I_j\right) = 1 \; if \; (Q_i^j - I_j) > 0, 0 \; otherwise.$$

Collection investment CI occurs every time the recycled-material supplier collects returns from the end-user market.

CHAPTER 4. RFID TECHNLOGY CONFIGURATION AND INFORMATION-SHARING COORDINATION

This Chapter presents the RFID information sharing main assumptions and descriptions. We propose the two C dimensions 1) Configuration and 2) Coordination. We propose that in order to have a clear coordination with RFID technology it is important to understand the RFID technology configuration first. We begin describing several papers that address information-sharing coordination. However, as we will see, the main limitation is that the paper is not technology-oriented and thus lack of technology configuration. For this reason, we present a set of literature review for information-sharing among trading partners. Then, we present the few literature in terms of RFID over this topic. This review shows that it is important to study more RFID configurations and thus RFID coordination in order to maximize the full benefits of the technology.

4.1 Related Work

4.1.1 Information-Sharing Coordination among Trading Partners

Information-sharing coordination is the agreement among player of what type of information they share and who shares the information. As Lee and Whang (2000) mentioned "a basic enabler for tight coordination is information sharing". Coordination enables partnership among players in the supply chain.

There can be different type of information shared such as inventory level, sales data, order status, sales forecast, and production/delivery schedules (Lee and Whang, 2000). Who share the information can be modeled with the level of information sharing. Traditional (no information) and full information sharing are two common levels used in literature.

For example, Cachon and Fisher (2000) compared the use of information sharing in which the supplier had complete visibility of the demand; whereas, the retailer did not have any benefit from the full information sharing level. The author described that there are reduction over the processing leadtime. Therefore, benefits for full information sharing relies more on operational benefits (e.g., faster leadtime and cheaper order processing) rather than expanding information among players. The author did not describe any type of technology. Lee et. al (2000) study the benefits of information from a manufacturer and a retailer using auto correlated demand coefficient. The retailer shares demand (i.e, parameters of the probability distribution) and period-to-period inventory information. The authors tested the demand information using different probability distributions. The authors consider periodic review for their inventory models. The benefits rely only on the manufacturer such as inventory reduction and expected cost reduction. These benefits increase with higher demand variability.

Lee and Whang (2000) described that there are three levels of information sharing: information transfer model, 3th party model, and information hub model. The first, a player (i.e., usually the downstream) share its information to the manufacturer or supplier. The second, a third party is assigned to collected and manage all the information. And the third model, described that a software automatically handles the information sharing. Yu et al. (2001) define three levels as well. The first is the “decentralized control” where no information sharing nor ordering information is taken place. The retailer uses demand information and the manufacturer uses order information. Each one of them utilized their own information to make a forecast. The second level is called the “coordinated control” in which the retailer share demand information and together with the order information from the retailer. The manufacturer then will made inventory decisions based on these two information. The third level is “centralized control” were with the use of EDI, both partners will have the same information. Further, the author assumes that a VMI can take place. From the results, the retailer perceive a benefit only over the centralized control since the manufacturer processing leadtime will be reduced due to lower variability of orders. The manufacture will benefit for additional information sharing lowering inventory levels and expected cost. One of the limitations of the paper is that the author used EDI without any assumptions or limitations to be considered.

Previous research shows that there are no or limited benefits for the retailer (i.e., downstream player) which is a limitation in order to support the use of information technology investment over the entire supply chain. For the scope of the thesis, we are not considering any type of cooperative agreements among the players. However, the objective is to optimize the overall performance measure (e.g,. minimize total system cost). From the findings, we can then search for cooperative win-win agreements among the players such as incentives.

In addition, previous research does not clearly present any technology to implement the information sharing. This is a limitation since inside the coordination we need to define in more detail how this information can change the business decisions (e.g., inventory decisions). There are different technologies that enable information sharing such as client-server architecture, TCP/IP, relational DBMS, ERP, object oriented programming, wireless communication, internet and EDI (Lee and Whang, 2000). We use RFID technology for our research. Another assumption is that RFID can be a good enabler to eliminate imperfect information sharing. As Lee and Whang (2000) describes, sharing information may not be perfect since partners maybe tempt to convey not the true information.

Morgan et al. (2016) perform a survey from an empirical evidence 267 respondents analysis the influence of collaboration and information technology to develop reverse logistics initiatives. The authors shows relationships between collaboration versus IT competency. The research provide three main insights. First, companies needs to become expert or develop strong reverse logistics compenties. Second, collaboration is needed in order for the reverse logistic to be successful which is aligned to our purpose of our research. And third, having strong competencies on IT and reverse logistics produce better logistics performance. However, this study do not refer to specific supply chain settings and the overall impact of implementing an RFID configuration in a supply chain. In addition, the results indicates that with lower collaboration, lower IT implementation is needed to reach to results. We will show on Chapter 5 and Chapter 6 that other key dimensions are needed such as the RFID technology configuration, RFID coordination and what is the supply chain structure. Understanding these three factors will enable managers to identify the right IT investment based on their supply chain.

The following section presents information-sharing coordination but with the use of RFID technology. As describe by Qianli et al. (2016), one of the main challenges nowadays is the implementating technology of RFID. Therefore, it is important to understand what are the option of these implementation, what are the RFID configurations possible and what are the results depending on the supply chain structure. Our research aims to help over this implementation of RFID. Below related work that describes RFID technology configurations.

4.1.2 RFID Technology Configurations over Supply Chains

Ustundag and Tanyas (2009) study the impact of RFID on Supply Chain and its cost. The author presented a simulation approach over a three echelon including manufacturer, distributor and retailer. The model included item-level RFID tags in the manufacturer and readers. However, it was not clear if the other players used RFID in their warehouse or their configurations. The authors used error rates to quantify the benefits of RFID. The limitation of this study is that the authors do not analyze the real effects of using RFID. The model lack of RFID configurations and coordination settings. Bottani et al. 2010 study the impact of RFID based on reducing the Bullwhip Effect. The configuration and study is grounded on the Bottanie et al. (2008) study. The benefits of the study is that it shows that RFID can reduce the Bullwhip Effect due to its real-time information sharing reducing imperfect demand signals. Further, the manufacturer is the entity with the highest benefits. Also, case-tag level was more beneficial than pallet level due to its information granularity.

Boeck and Wamba (2007) study RFID and its impact on the buyer-seller relationships in a four echelon supply chain (i.e., bottler, distributor 1, distributor 2, Retailers). In this case, the authors found that item-level decisions affect the benefits of each of the players. For example, item-level RFID was beneficial to the retailer. However, for the distributors, they use mainly case-item level. Further, shrinkage reduction was one of the must cited benefits from the buyer-seller relationship. Also, it was accounted that the tag placement is tended to be pushed to the first upstream player, in this case the bottlers. From the study, the installation of RFID readers is on the entire supply chain except the retailer.

Soon and Gutierrez (2008) study the impact of RFID mandate on supply chains. The authors considered three-tiers supply chain: 1) manufacturer, 2) logistic provider, 3) retailer. The authors describes the first benefits presented in practice and should be attained is the intra-organizational performance. However, there should be as well more collaboration amount partners to attain inter-organizational performance. In addition, the authors state that it is important that management decide what information will be shared and who will be received these information. The authors define these set of guidelines since in practice most of the cost relies on the upstream player. Higher level of collaboration its needed to increase a cooperative scenario among players in order to reduce total system cost.

Whang 2010 studies the timing to adopt RFID. The author analyses a two-tier supply chain. The author explains that there is a free-ride problem in which if the upstream player install the RFID tags, then the downstream player will beneficiate from it. However, there is no equilibrium. RFID technology coordination and cost-split are two mechanism that can eliminate the free-ride problem.

Whitaker et. al (2007) perform a field study over several US firms and its implementation of RFID deployment. From the results, the authors find that higher benefits with RFID can be achieved if the firms have mature IT deployment such as ERP. Further, companies need to invest heavily in the early stage to fully potentiate RFID deployment. The authors also discover that mandates overall have positive return on the investment from companies following late adoption of RFID since it does have a business sponsorship. Managers should be versatile and knowledgeable about the RFID protocols and standards.

Previous research has shown different set of RFID configurations. From a stream of research authors identify that there is more benefits for manufacturer to install RFID rather than the retailer. Further, there are different configurations in terms of who share the information (i.e., levels). The previous research have not yet presented a cohesive study that address the dual-dimensions of configuration and coordination. The former determine who has the technology configuration installed and the later, who shares the information among players. Our thesis aims to provide a stronger dual-decision for configuration and coordination. In addition, we need to extend these study to our green supply chain system.

The following section presents the RFID technology configuration proposed for the research. Then, the following Chapter presents the RFID coordination in order to complete the dual decision of RFID configuration-coordination that is lacking currently in literature.

4.2 RFID Technology Configuration

We present five different RFID configurations. No RFID (NO) configuration is the first case, in which no RFID tags and RFID readers are installed in the warehouse. For our thesis, this will be our base case. The following analyzes the RFID Non-Integrated (NI) configuration in which RFID is implemented over the entire supply chain; however, no information sharing occurs among entities. The next scenario is the RFID Partial-Integrated Downstream (PID) configuration in which the player have installed RFID tags and readers in their warehouses, but only the downstream player (i.e., manufacturer) is sharing information. The next scenario is the RFID Partial-Integrated Upstream (PIU) configuration where RFID tags and readers are installed, but only the upstream players (i.e., suppliers) are sharing their information. Finally, we analyze the RFID Full-Integrated (FI) configuration where all the players have RFID and can share their information. Figure 4.1 to Figure 4. 5show the RFID configurations.

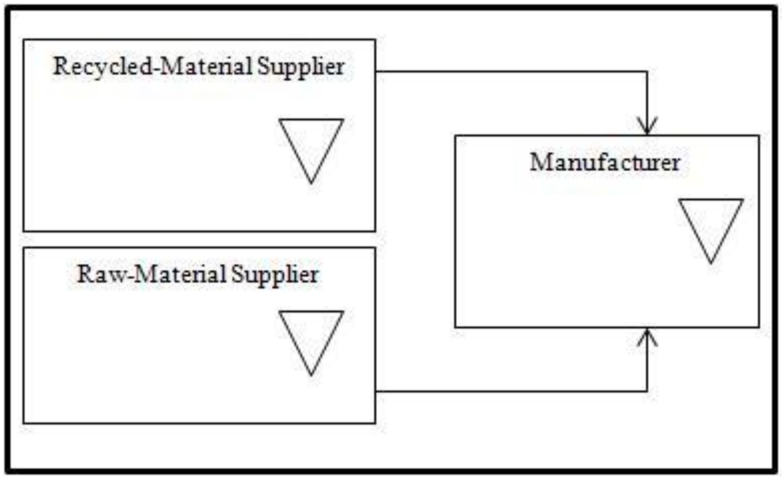

Figure 4.1 No RFID Configuration

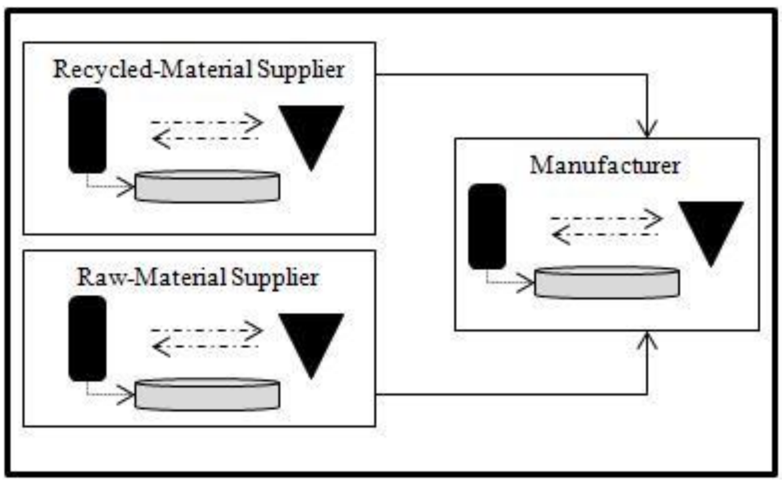

Figure 4.2 RFID Non-Integrated Configuration

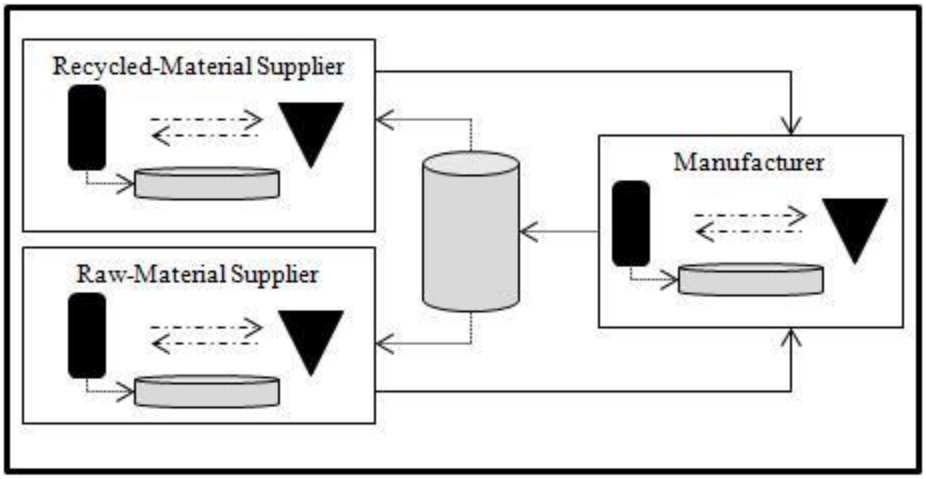

Figure 4.3 RFID Partial-Integrated Downstream Configuration

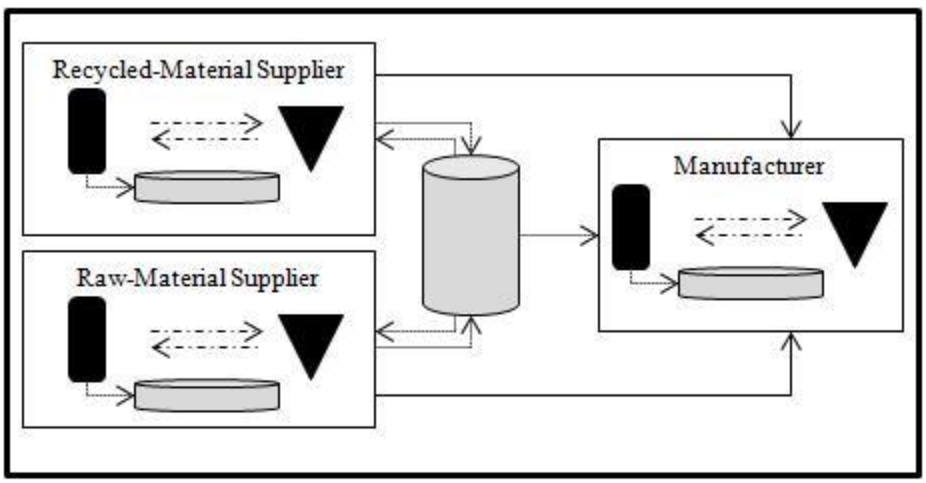

Figure 4.4 RFID Partial-Integrated Upstream Configuration

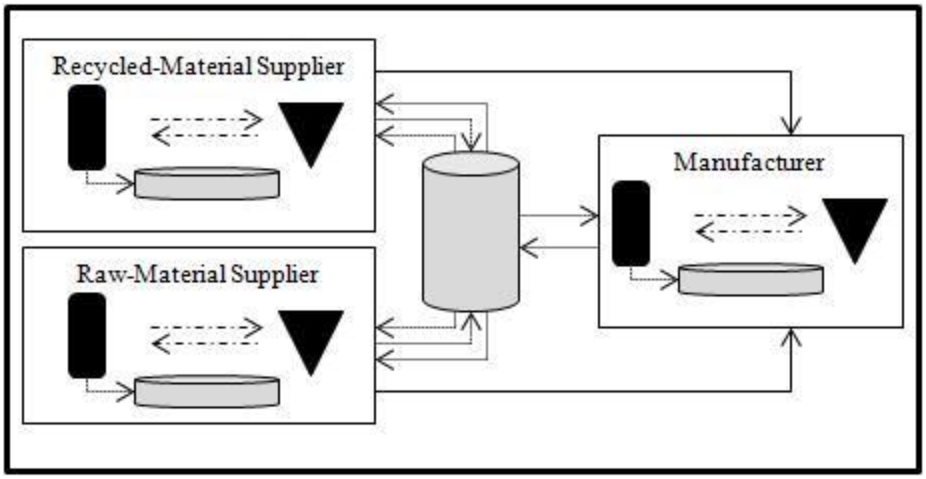

Figure 4.5 RFID Full-Integrated Configuration

The previous section defined our RFID configuration. However, still it is need to define the RFID coordination to complete the dual-dimesion of configuration and coordination. The following chapter presents the basic Radio Frequency Identification (RFID) information-sharing coordination.

CHAPTER 5. BASIC RFID INFORMATION-SHARING COORDINATION

Previous sections illustrate that RFID technology configuration and information coordination as a dual dimension has not been study rigorously in research. Our previous section defined our RFID configuration used for the thesis which are the following: 1) No RFID (NO), 2) RFID Non-Integrated (NI), RFID Partial-Integrated Downstream (PID), RFID Partial-Integrated Upstream (PIU), and RFID Full-Integrated (FI).

This section will integrate the RFID technology configurations with the information coordination among players. We define coordination in this thesis as the set of guidelines that defines what information is shared and who shares de information based on each RFID configuration. More importantly, how this information is embedded in the supply chain decision process as well as the impacts of the total system cost. In this thesis, we focus our decisions on inventory control models.

Section 5.1 presents an introduction for the Chapter. Section 5.2 shows our proposal. We provide experimental results in Section 5.3, and summary in Section 5.4.

5.1 Introduction

There are few studies that analyze how companies have to align RFID configuration and coordination of inventory policies to obtain higher value of the technology. In addition, few studies provide a guideline on what RFID configuration-coordination to use based on your supply chain structure.

We aim to close this gap and study how companies can coordinate information to obtain higher benefits with the implementation of RFID technologies. In addition, the model considers green supply chain elements. Therefore, the goal is to attain lower cost to motivate the incorporation of green initiatives such as reverse logistics. We propose several basic RFID information-sharing coordination integrating inventory policies from literature and identify the RFID coordination that provides the lowest system cost over several supply chain structures. The benefits of the approach are: 1) test different RFID configurations, 2) propose RFID information coordination, 3) provide managerial guidelines on when to use each RFID coordination based on the supply chain, 4) address complex system including decentralized entities with reverse logistics operations.

5.2 Approach

These approaches define the inventory information coordination among each RFID configurations from Chapter 4. We use three inventory policies presented on Chapter 3 and adapt them to the RFID configuration. The objective is to measure if RFID technology can provide economic benefits using simple inventory policies approaches; thus, creating the monetary incentives to undergo environmental practices.

We define the coordination between the inventory policies and the RFID configurations. Table 5.1 shows a summary of the coordination.

Table 5.1 Summary of RFID Information-sharing coordination

RFID Configuration	Inventory Policy	Information Sharing	Entities Sharing	Type of Information	Inventory Decision Enhanced	Nomenclature
NO	Periodic	N.A.	None	None	None	None
NI	Continuous	No	None	None	None	None
PID	Continuous	Yes	Downstream	Demand	Reorder point of recycled-material supplier	$\bar{r}_g$
					Reorder point of raw-material supplier	$\bar{r}_r$
					Order Quantity of raw-material supplier	$\bar{Q}_r$
PIU	Continuous	Yes	Upstream	Inventory	Inventory position of manufacturer to produce	$\bar{X}_m^r$
					Inventory position of raw-material supplier	$\bar{X}_r$
FI	Continuous	Yes	Downstream & Upstream	Demand & Inventory	Reorder points, order quantities, and inventory positions	$\bar{r}_g$, $\bar{r}_r$, $\bar{Q}_r$, $\bar{X}_m^r$, $\bar{X}_r$

5.2.1 No RFID Coordination

The RFID technology is not installed in any of the inventory warehouse of the players. Therefore, they have to use periodic review inventory policies since they are not able to monitor in real-time their warehouses.

Table 5.2 Inventory Position and Decision with No RFID Coordination

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m(t) := I_m(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_m} Q_m^r(t-i)$	$Q_m^g = \begin{cases} S_m - I_m(t) & \text{if } X_m(t) \le s_m \text{ and } I_g(t) \ge (S_m - I_m(t)) \\ 0 & \text{Otherwise} \end{cases}$ $Q_m^r = \begin{cases} S_m - I_m(t) & \text{if } X_m(t) \le s_m \text{ and } I_g(t) < (S_m - I_m(t)) \\ 0 & \text{Otherwise} \end{cases}$
Recycled-material supplier	$X_g(t) := I_g(t) + \sum_{i=1}^{LT_g} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & \text{if } X_g(t) \le s_g \\ 0 & \text{Otherwise} \end{cases}$
Raw-material supplier	$X_r(t) := I_r(t) - B_r(t) + \sum_{i=1}^{LT_r} Q_r(t-i)$	$Q_r(t) = \begin{cases} S_r - I_r(t) & \text{if } X_r(t) \le s_r \\ 0 & \text{Otherwise} \end{cases}$

If the inventory position X_m is less than or equal to the reorder point s_m , and there is enough on-hand inventory for the green supplier $I_g \geq (S_m - I_m)$, then the manufacturer orders to the green supplier $Q_m^g = (S_m - I_m)$. Otherwise, the manufacturer orders to the raw-material supplier $Q_m^r = (S_m - I_m)$. The recycled-material supplier collects returns R whenever its inventory position is less than or equal to its reorder point, $X_g(t) \leq s_g$. The raw-material supplier orders $Q_r(t) = S_r - I_r(t)$ whenever its inventory position is less than or equal to its reorder point, $X_r \leq s_r$.

We can see that the manufacturer and recycled-material supplier do not have backorder options. As shown in Chapter 3, the manufacturer and the recycled-material supplier incur in a shortage cost. However, the raw-material includes backorders inventory $B_r(t)$.

5.2.2 RFID Non-Integrated Coordination

The RFID technology is installed in the entire supply chain. This means, all the entities have the RFID tags on their products and readers in their warehouses. Therefore, all the players are able to use continuous review inventory policies. However, they do not share RFID information with each other.

Table 5.3 Inventory Position and Decision with RFID Non-Integrated

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m(t) := MR * I_m(t) + \sum_{i=1}^{LTm} Q_m^g(t-i) + \sum_{i=1}^{LTm} Q_m^r(t-i)$	$Q_m^g = \begin{cases} Q_m^g & \text{if } X_m(t) \leq s_m \\ & \text{and } MR * I_g(t) \geq Q_m^g \\ 0 & \text{Otherwise} \end{cases}$ $Q_m^r = \begin{cases} Q_m^r & \text{if } X_m(t) \leq s_m \\ & \text{and } MR * I_g(t) < Q_m^r \\ 0 & \text{Otherwise} \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LTg} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & \text{if } X_g(t) \leq r_g \\ 0 & \text{Otherwise} \end{cases}$
Raw-material supplier	$X_r(t) := MR * I_r(t) - B_r(t) + \sum_{i=1}^{LTr} Q_r(t-i)$	$Q_r(t) = \begin{cases} Q_r(t) & \text{if } X_r(t) \leq r_r \\ 0 & \text{Otherwise} \end{cases}$

The manufacturer request Q_m^g whenever the inventory position $X_m(t)$ is below or equal to its reorder point s_m. The recycled-material supplier has a similar inventory position and decisions than the No RFID scenario just in a continuous review. The raw-material supplier has a similar inventory position and decision than the No RFID case, but the order quantity is such as Q_r given the continuous review policy.

5.2.3 RFID Partial-Integrated Downstream Coordination

This coordination is similar to 5.2.2, but now the players are able to exchange information through the EPC Global Network. In this case, the manufacturer shares demand information to the suppliers. Thus, the suppliers instead of using historical demand information from past orders, they are able to use real demand information. The two suppliers will have an enhanced inventory policy. The demand over leadtime and standard deviation over leadtime will have now the real demand information,

$$\bar{\theta} = \mu_D * LT, \qquad \text{Eq. 5.1}$$

$$\bar{\sigma} = \sqrt{LT} * \sigma_D. \qquad \text{Eq. 5.2}$$

Thus, their reorder points are enhanced,

$$\bar{r}^* = \bar{\theta} + z\bar{\sigma}\ , \qquad \text{Eq. 5.3}$$

In addition, the raw-material supplier can use this demand information to enhance its optimal order quantity,

$$\bar{Q}^* = \sqrt{\frac{2K\mu_D}{h}}\ . \qquad \text{Eq. 5.4}$$

Table 5.4 Inventory Position and Decision with RFID Partial-Integrated Downstream

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m(t) := MR * I_m(t) + \sum_{i=1}^{LTm} Q_m^g(t-i) + \sum_{i=1}^{LTm} Q_m^r(t-i)$	$Q_m^g = \begin{cases} Q_m^g & \text{if } X_m(t) \le s_m \text{ and } MR * I_g(t) \ge Q_m^g \\ 0 & \text{Otherwise} \end{cases}$ $Q_m^r = \begin{cases} Q_m^r & \text{if } X_m(t) \le s_m \text{ and } MR * I_g(t) < Q_m^r \\ 0 & \text{Otherwise} \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LTg} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & \text{if } X_g(t) \le \bar{r}_g \\ 0 & \text{Otherwise} \end{cases}$
Raw-material supplier	$\bar{X}_r(t) := MR * I_r(t) - B_r(t) + \sum_{i=1}^{LTr} Q_r(t-i)$	$\bar{Q}_r(t) = \begin{cases} \bar{Q}_r(t) & \text{if } X_r(t) \le \bar{r}_r \\ 0 & \text{Otherwise} \end{cases}$

Since the manufacturer is the one that is providing the information, the enhancements in the inventory will be in the suppliers. Now, the recycled-material supplier calculates an enhanced reorder point $\bar{r}_g$ given that the reorder point depends on demand information. Therefore, the recycled-material supplier instead of using historic orders from the manufacturer, it will use real demand information. Similar, the raw-material supplier calculates an enhanced reorder point $\bar{r}_r$ and it calculates an enhanced optimal order quantity $\bar{Q}_r$ given this information depends on the demand.

5.2.4 RFID Partial-Integrated Upstream Coordination

All the players have RFID installed; however, only the suppliers share information through the EPC Global Network. The manufacturer can have the complete visibility of the supplier's warehouse. Therefore, the manufacture can include the supplier's inventory to calculate an enhanced inventory position such as,

$$\bar{X}_m = I_m + I_g + I_r. \qquad \text{Eq. 5.5}$$

In addition, the suppliers exchange inventory information between them. In this case, the supplier that needs to acquire more "readiness" is the raw-material supplier to compensate the stochastics behaviors in the reverse logistics. Thus, the raw-material will include in its inventory position the recycled-material information such as,

$$\bar{X}_r = I_r + I_g. \qquad \text{Eq. 5.6}$$

Table 5.5 Inventory Position and Decision with RFID Partial-Integrated Upstream

Player	Inventory Position	Inventory Decision
Manufacturer	$\bar{X}_m(t) := MR * I_m(t) + MR * I_g(t) + MR * I_r(t) + \sum_{i=1}^{LTm} Q_m^g(t-i) + \sum_{i=1}^{LTm} Q_m^r(t-i)$	$Q_m^g = \begin{cases} Q_m^g & \text{if } X_m(t) \le s_m \text{ and } MR * I_g(t) \ge Q_m^g \\ 0 & \text{Otherwise} \end{cases}$ $Q_m^r = \begin{cases} Q_m^r & \text{if } X_m(t) \le s_m \text{ and } MR * I_g(t) < Q_m^r \\ 0 & \text{Otherwise} \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LTg} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & \text{if } X_g(t) \le r_g \\ 0 & \text{Otherwise} \end{cases}$
Raw-material supplier	$\bar{X}_r(t) := MR * I_r(t) + MR * I_g(t) - B_r(t) + \sum_{i=1}^{LTr} Q_r(t-i)$	$Q_r(t) = \begin{cases} Q_r(t) & \text{if } \bar{X}_r(t) \le r_r \\ 0 & \text{Otherwise} \end{cases}$

The manufacturer will count the on-hand inventory of the recycled-material and raw-material supplier in its inventory position to produce $\bar{X}_m$. Further, the raw-material supplier acts as an alternative supplier in the case there is not enough returns on the green supplier's inventory. Therefore, the productions depend on the on-hand inventory of the recycled-material supplier. The raw-material supplier will then include on-hand inventory of the recycled-material supplier in its inventory position $\bar{X}_r$.

5.2.5 RFID Full-Integrated Coordination

This case provides continuous review inventory policy for all the players. In addition, the manufacturer exchanges demand information enhancing the reorder points for the suppliers and optimal order quantity for the raw-material supplier. The suppliers will continue to exchange information similar to Section 5.2.4.

Table 5.6 Inventory Position and Decision with RFID Full-Integrated

Player	Inventory Position	Inventory Decision
Manufacturer	$\overline{X}_m(t) := MR * I_m(t) + MR * I_g(t) + MR * I_r(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_m} Q_m^r(t-i)$	$Q_m^g = \begin{cases} Q_m^g & \text{if } X_m(t) \le s_m \\ & \text{and } M * I_g(t) \ge Q_m^g \\ 0 & \text{Otherwise} \end{cases}$ $Q_m^r = \begin{cases} Q_m^r & \text{if } X_m(t) \le s_m \\ & \text{and } M * I_g(t) < Q_m^r \\ 0 & \text{Otherwise} \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LT_g} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & \text{if } X_g(t) \le \overline{r}_g \\ 0 & \text{Otherwise} \end{cases}$
Raw-material supplier	$\overline{X}_r(t) := MR * I_r(t) + MR * I_g(t) - B_r(t) + \sum_{i=1}^{LT_r} Q_r(t-i)$	$\overline{Q}_r(t) = \begin{cases} \overline{Q}_r(t) & \text{if } \overline{X}_r(t) \le \overline{r}_r \\ 0 & \text{Otherwise} \end{cases}$

In this integration, the manufacturer has an enhanced inventory position $\overline{X}_m(t)$. The recycled-material supplier has an enhanced reorder point $\bar{r}_g$. And the raw-material supplier has an enhanced inventory position $\bar{X}_r$, a reorder point $\bar{r}_r$, and an optimal quantity $\bar{Q}_r$.

5.3 Numerical Experiments

5.3.1 Simulation Approach and Design of Experiment

Simulation approach is used to study the system behavior of green supply chains over five types of RFID information-sharing coordination described in Section 5.2. The objective of the simulation study is to determine under what supply chain conditions it is better to use each of the five RFID Information-sharing coordination. We test several independent variables to assess their impact on the system cost and reach managerial insights. Simulation approach is a good method used for academics and practitioners to study RFID. Below we present two examples of simulation approaches and their simulation assumptions used to study RFID systems similar to our problem.

Fleisch and Tellkamp (2005) study the impact of inventory inaccuracy reduction with more visibility of physical inventory (thanks to automatic identification technologies). The authors assume a consumer package goods supply chain consisting on retailer, distributor and producer. The author used various independent factors that affects inventory inaccuracy such as theft, incorrect deliveries and misplaced items. End-customer demand is independently and identically normally distributed. Other exogenous random variables are measured using uniform distribution such as theft and incorrect deliveries. Each simulation has 200 as time-horizon were each simulation is run 20 times.

Ustundag and Tanyas (2008) uses simulation model to map how RFID can reduce cost through more efficiency, accuracy, visibility and security level in a three-level supply chain. The authors model end-customer demand as independently and identically normally distributed random variable with mean of 1000 daily items (retail textile company in Turkey). The shortage cost due to lost sales is based on a 5% margin per product. The setup or order cost was $40 and the inventory holding cost is based on a 5% annual interest rate. The authors use three independent factors at three level each (i.e., product value, demand uncertainty, leadtime). Similar to our research, the authors use Total Cost as the dependent variable. The authors used 27 (3^3) combinations and each simulation were run 250 times over a time-horizon 360 days.

For our research, our objective is to test several supply chain scenarios over our five RFID Information-sharing coordination using several independent variables and test their impact on the dependent variables (i.e., total system cost). Our goal is not to provide an optimal design of experiment or test several design. We propose the following design of experiment. A 1/16 design with resolution V provides $2^{11-4} = 128$ runs for the fractional factorial. Therefore, we test 128 different supply chains described in 11 different factors at two levels each. We used Minitab Software to obtain the design of experiment described above. Each run is replicated 100 times in Arena Simulation Software similar to the simulation model from Sarac et al. (2015) that study a three-level supply chain with RFID and its impact of shrinkage and delivery errors in Arena Software. Each replication has a Time-horizon TH

of 200 days. We assume 24 hours per day during the simulations. As mentioned above, the objective is to simulate each of the five RFID Information-sharing coordination over the 128 different supply chain. In this experiment, there are several stochastic factors such as mean capacity of end-user market due to its rate factor, collection leadtime, demand variability. These nondeterministics variables were presented in a similar study from Canella et al. (2016). The authors study these factors that influence reverse logistics on a close-loop supply chain. However, our study focus on decentralized entities, differente types of RFID technology and what are the supply chain system that is better for an RFID implementation.

The factors at two levels each (i.e., Low and High) used to create the design of experiment are described in the Table 5.7.

Table 5.7 Variable Factors and Levels

Category	Factor	Low	High
Demand	Mean and standard deviation of demand per day	20	35
Leadtime	Leadtime delivery (days)	8	14
	Leadtime collection (days)	4	7
	Leadtime production (days)	8	14
	Std Dev Leadtime collection (days)	1	2
Setup Cost	Setup cost manufacturer ($)	10	18
	Setup cost recycled-material supplier ($)	2	4
	Setup cost raw-material supplier ($)	5	10
Environment	Mean capacity end-user market	50	80
	Investment Collection Manufacturer ($)	0	4
	Investment Collection Green ($)	5	10

The variables that are fixed in all the 128 scenarios are described in the following Table 5.8.

Table 5.8 Fixed Factors and Values

Category	Variables	Value
Net inventory	Initial net inventory manufacturer	100
	Initial net inventory recycled-material supplier	100
	Initial net inventory raw-material supplier	100
Inventory position	Initial inventory position manufacturer	100
	Initial inventory position recycled-material supplier	100
	Initial inventory position raw-material supplier	100
Unit Cost	Unit procurement cost green ($)	100
	Unit procurement cost raw ($)	200
	Unit collection cost green ($)	100
	Unit production cost raw-material supplier ($)	200
Unit holding cost	Unit holding cost manufacturer ($)	0.15
	Unit holding cost recycled-material supplier ($)	0.10
	Unit holding cost raw-material supplier ($)	0.20
Unit shortage cost	Unit shortage cost manufacturer ($)	10
	Unit shortage cost recycled-material supplier ($)	5
	Unit shortage cost raw-material supplier ($)	7.50
RFID	RFID Read Rate Lower Bound Parameter for the Stochastic Uniform Distribution	85
	RFID Read Rate Upper Bound Parameter for the Stochastic Uniform Distribution	100

5.3.2 Results

This section presents the results from the simulation experiments. As stated on previous sections, we use average cost which is a common performance measure used in literature (Lee et. al, 2000).

5.3.2.1 Multiple Comparison Test

One of the objective of the thesis is to understand on what supply chain scenario it is beneficial to implement RFID. Further, more interesting is to understand what type of RFID information-sharing coordination is more suitable for a specific supply chain. We used Multiple Comparison Test (MCT) to statistically test our five RFID Configuration (NO, NI, PID, PIU and FI). MCT provided us over a 5% p-value which configurations were statistically significant. For our results, we were interested to identify the scenarios were there was only one statistically different mean compared to the rest. We choose the one that provided the lowest system cost. Below are the results from the MCT in Table 5.9. In addition, we extend the result and include outcomes were two means were statistically significant than the others and lowers. Table 5.10 shows the results. More than three means with lowest statistically system cost do not provide a specific managerial insight. Therefore, we limit this analysis to one and two means with statistically lower system cost. Results from all the MCT are shown in Table 5.11.

Table 5.9 Multiple Comparsion Test Results – One Statistically Different Mean

Analysis	NO	NI	PID	PIU	FI	Total Scenarios with One Mean Statistically Different
# of scenarios statistically lower that the 4 rest RFID Coordination	33	0	0	4	37	74

Table 5.10 Multiple Comparsion Test Results – Two Statistically Different Mean

RFID Coordination Means with Lowest System Cost	# of scenarios been the lowest that the rest
NO-PIU	4
NO-FI	6
PID-FI	1
PIU-FI	21
Total	32

Table 5.11 Multiple Comparison Test Result – All Means

# of Means Statistically Lower	# of Scenarios	% Weight
1	74	58%
2	32	25%
3	15	12%
4	7	5%
Total	128	100%

Just form these results we can make several insights. First, we see that there is no case in which NI was a significant mean with the lowest cost. This can serve as an intuition that even if operational benefits arises as previous research demonstrated over centralized scenarios, we need some type of information-sharing coordination among trading partners. Second, we see that PID have zero cases with the lowest system cost. This results that even though we have demand information that can be shared, the inventory control decisions are not efficient enough to achieve reduction on the overall cost. Third, there is almost a balance set of scenarios which it is better in term of cost to continue with NO RFID and another set to include Full-Integrated RFID Configurations.

Fourth, apart from the FI Configuration, PIU Configuration appeared 23% of the scenarios statistically significant (4 been the lowest mean, 4 cases with NO and 21 cases shared with FI). This is very significant finding since our modeling is an inventory control model. Therefore, when we include inventory information over the Inventory Position of to the Manufacturer and the Raw-Material Supplier, there is a complete visibility of the inventory on the system, been more proactive handling shortages.

For the next section, we want to investigate what type of supply chain scenarios provided good results over the 37 cases of FI and 33 cases NO through regression analysis. In addition, we will address the scenarios FI-PIU were statistically significant. These three analysis will provide us managerial insights over when to use each RFID Coordination.

5.3.2.2 Regression Analysis Test

From the 37 FI scenarios, we reached to 86% and 73% Multiple Square and R Square, respectively as shown in Table 5.12. This shows that the previous MCT analysis provided statistically scenarios were FI provided best results. It also provided insight that it might be helpful to consider interactions. From the ANOVA, it shows that it is statistically significant with F below 0% as shown in Table 5.13. The 12 factors from Table 5.7 are statistically significant below than 0% as shown in Table 5.14. Based on the coefficient, the three highest coefficient in terms of absolute value are Standard Deviation of the Collection Leadtime, Investment Collection from the Manufacturer, and the Investment Collection from Green. These are very important insight that shows that in any of these 37 scenarios, it is critical to control the collection leadtime to achieve lower cost. In addition, the incentive to the end-user market plays an important role been the manufacturer having more impact than the incentive from the recycled material supplier. Overall, we see that the main factors are the ones considered “green factors”. Therefore, this is a motivation for companies to undergo green initiatives with the right factors in-place and implementing FI. Managing these factors can enable system cost to decrease using technology such as RFID. Demand provided to be the most significant factor which is expected since demand drives the supply chain.

Table 5.12 Regression Statistics - FI

Statistic	Value
Multiple R	86%
R Square	73%
Adjusted R Square	73%
Standard Error	1,906
Observations	3,700

Table 5.13 ANOVA Statistics - FI

Statistic	df	SS	MS	F	Significance F
Regression	12	36,470,407,010.00	3,039,200,584.00	912.72	0
Residual	3,688	13,396,746,780.00	3,632,523.53		
Total	3,700	49,867,153,789.00			

Table 5.14 Regression Factors and Coefficients - FI

Factors	Coefficients	Standard Error	tStat	P-value
Intercept	(3,642)	457	(8)	2.14969E-15
Avg Dmd	-	-	65,535	-
Std Dev Dmd	388	5	76	-
LT Delivery	310	11	28	0.00%
LT Collection	(320)	23	(14)	0.00%
LT Production	178	12	15	0.00%
Setup Man	365	10	37	0.00%
Setup Green	210	36	6	0.00%
Setup Raw	94	14	7	0.00%
Cap EUM	(80)	3	(25)	0.00%
Inv Collection Man	(650)	18	(37)	0.00%
Inv Collection Green	(639)	15	(43)	0.00%
Std Dev Collection Green	686	67	10	0.00%

The No RFID provided good performance for the Multiple R and R Square 96% and 92% as shown in Table 5.15, respectively. Table 5.16 shows the ANOVA results. The results show good reference that our simulation has the adequate modeling and factors to study the supply chain. Table 5.17 presents an interesting outcome is that the Capacity of the end-user market and Investment Collection Manufacturer are not statistically significant. If we compared the Coefficients from the FI and NO, we can see that the NO coefficients cost are lower. Our intuition is that is not necessary to over invest when cost structures are lower. Leadtime delivery, Leadtime Production and Setup Cost Green are the three main factors affecting cost. We can infer that these supply chains configurations are based mostly on lower cost structure. Thus, the need for higher recycled material and higher investment in technology is not required.

Table 5.15 Regression Statistics - NO

Statistic	Value
Multiple R	96%
R Square	92%
Adjusted R Square	92%
Standard Error	461
Observations	3,300

Table 5.16 ANOVA Statistics - NO

Statistic	df	SS	MS	F	SignificanceF
Regression	12	8,458,086,736	704,840,561	3,616	0
Residual	3,288	699,238,075	212,664		
Total	3,300	9,157,324,811			

Table 5.17 Regression Factors and Coefficients - NO

Factors	Coefficients	Standard Error	tStat	P-value
Intercept	(722)	102	(7)	0%
Avg Dmd	-	-	65,535	-
Std Dev Dmd	277	2	160	-
LT Delivery	46	5	9	0%
LT Collection	(62)	6	(10)	0%
LT Production	52	3	19	0%
Setup Man	(2)	2	(1)	48%
Setup Green	52	8	6	0%
Setup Raw	25	4	6	0%
Cap EUM	1	1	1	31%
Inv Collection Man	4	5	1	39%
Inv Collection Green	17	3	5	0%
Std Dev Collection Green	(46)	17	(3)	1%

5.3.2.3 Analysis of Factorial and Interactions

We want to analyze more in depth the results. Thus, we run analysis of main and interactions effects to validate our regression analysis.

Analysis of Factorial and Interactions with RFID Full-Integrated

As we can see from Figure 5.1, average demand is the most important factor that increase the cost. This is expected since with more demand, more variable cost it is needed. The next main effect that impacts the system cost is the setup cost for the manufacturer. Over high setup cost for the manufacturer, the FI is the most suitable configuration to reduce cost. In this context, both investment collections are essential to reduce system cost as shown in Figure 5.1 and similar to results on previous section 5.3.2.2. It is important to have an agile supply chain to react with demand and leadtimes variations to attain higher return of the investment from reverse logistics.

If we continue the analysis, we can see that the most statistical significant factor is the manufacturing investment followed by the green investment as shown in Figure 5.2. This is a powerful insight in which confirm that RFID technology can enable enterprise system-wide initiatives to achieve lower cost. Important to notice that there are several interactions but the most important is the Avg Demand x Investment Manufacturing as shown in Figure 5.3 and Figure 5.4. This means that when the demand is higher, even if we invest in more expenses for investment manufacturing, the overall system cost is reduced.

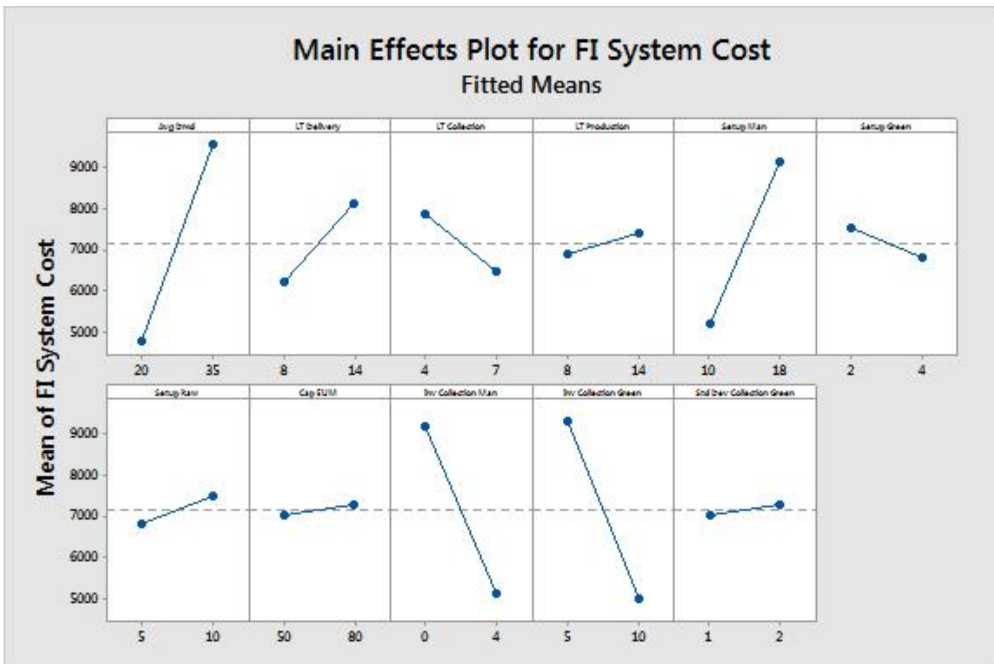

Figure 5.1 Main Effects Ploft for FI

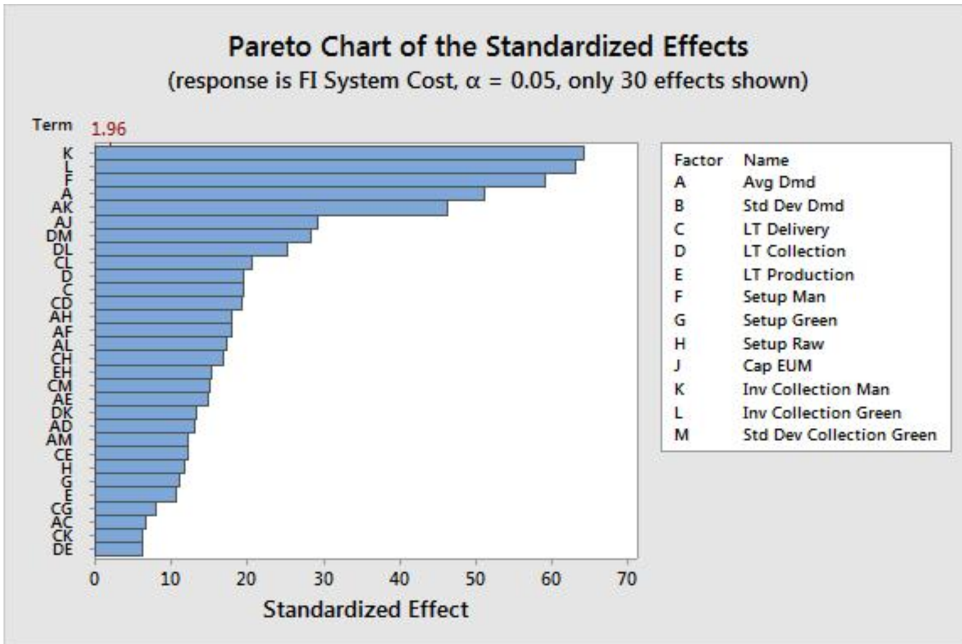

Figure 5.2 Pareto Chart of Standardized Effects for FI

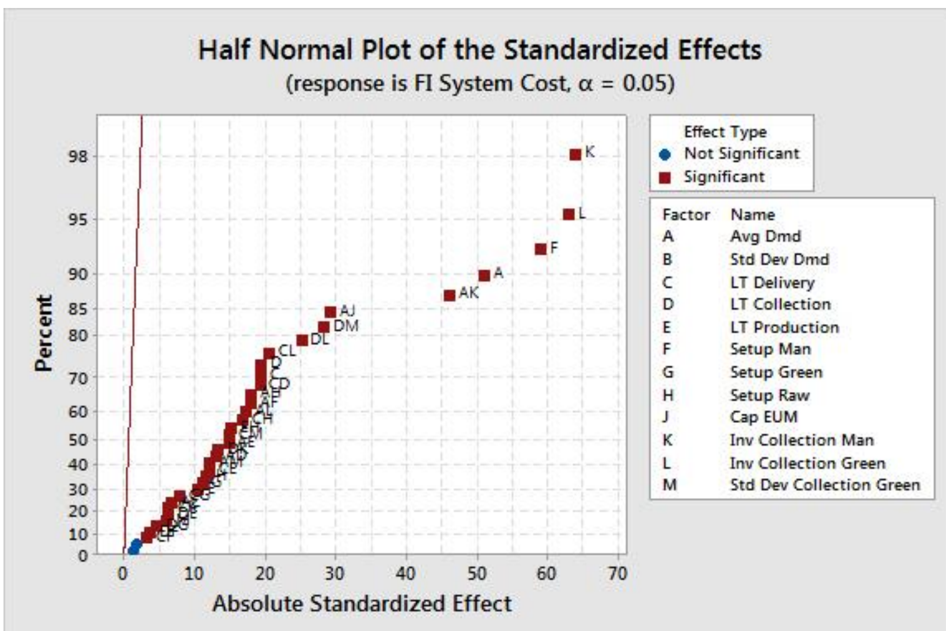

Figure 5.3 Half Normal Plof the Standardized Effects for FI

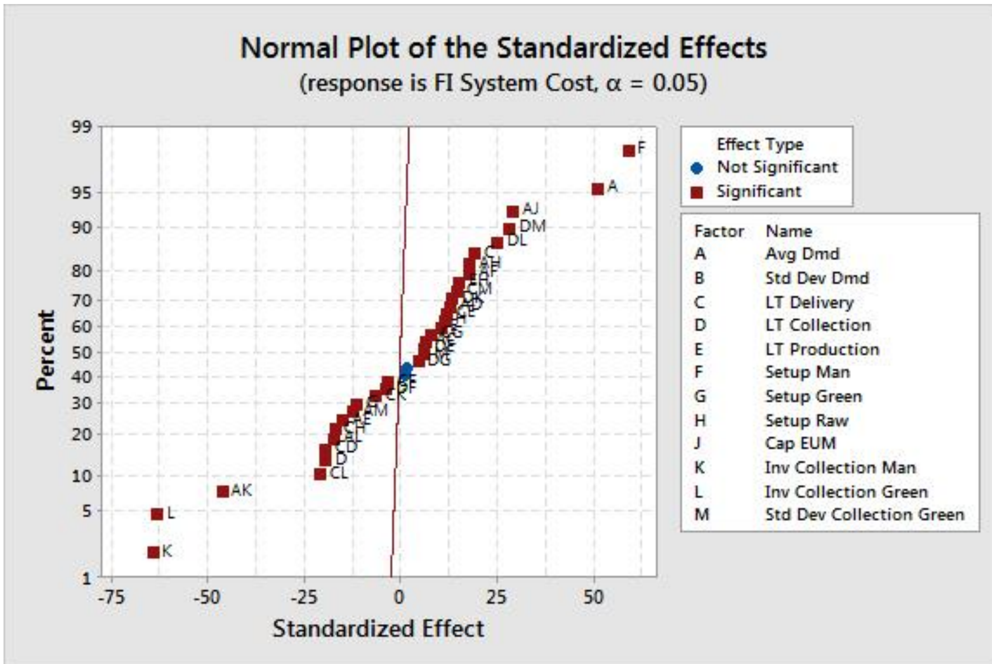

Figure 5.4 Normal Plot of the Standardized Effects for FI

<u>Analysis of Factorial and Interactions with No RFID</u>

Demand is the main factor impacting the system cost. Over this condition, the major cost are part of the variable cost of handling the demand. When the capital and setup cost is low, NO configuration is suitable to attain the lowest cost over the rest of the RFID configuration. As we can see in Figure 5.5, other factors do not provide a major impact to the system cost. Nevertheless, they still are significant factors such as leadtime collection and leadtime delivery as Figure 5.6 shows. Thus, under these systems its is reasonable to expect that leadtimes will be the important factors after the demand. High leadtime delivery provides a significant cost. Leadtime collection reflect the phenomenom of leadtime paradox in which high collection leadtime, lower cost. This phenomenon has been presented in previous research. Please refer to the literature review on Chapter 2.

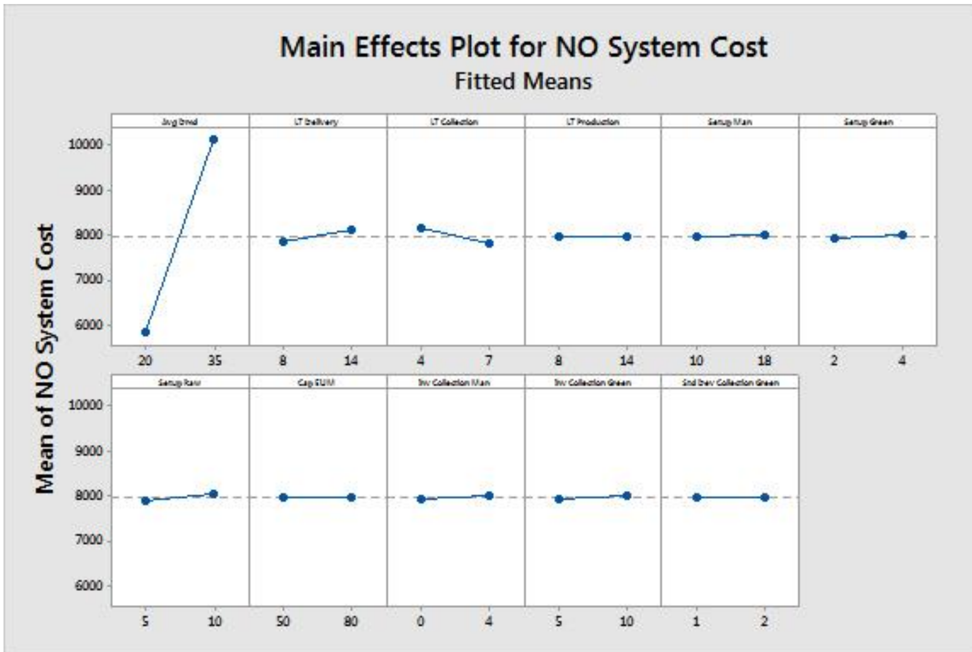

Figure 5.5 Main Effects Ploft for NO

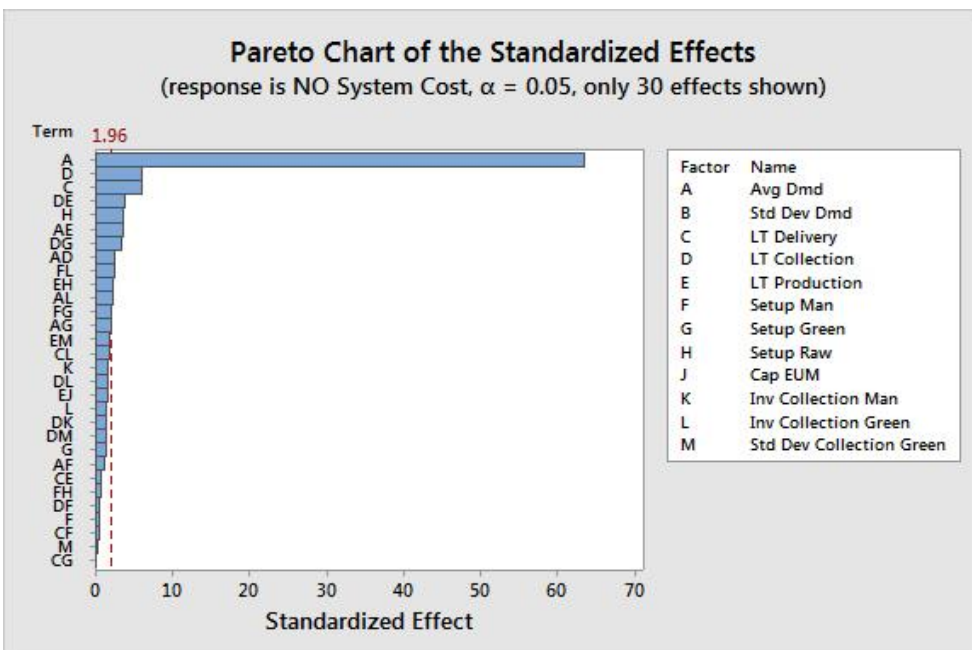

Figure 5.6 Pareto Chart of Standardized Effects for NO

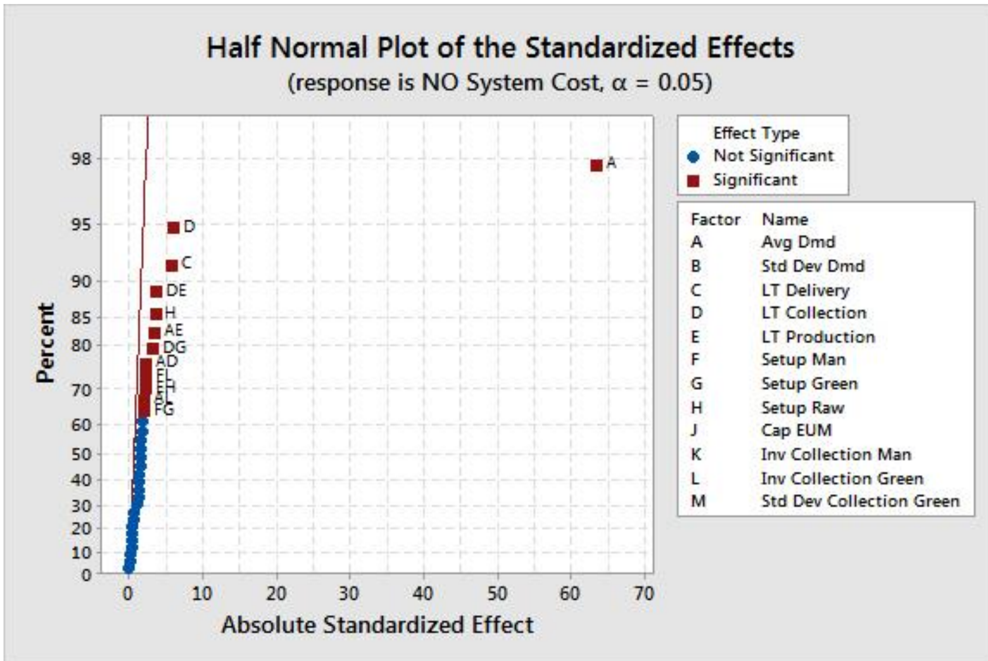

Figure 5.7 Half Normal Plof the Standardized Effects for NO

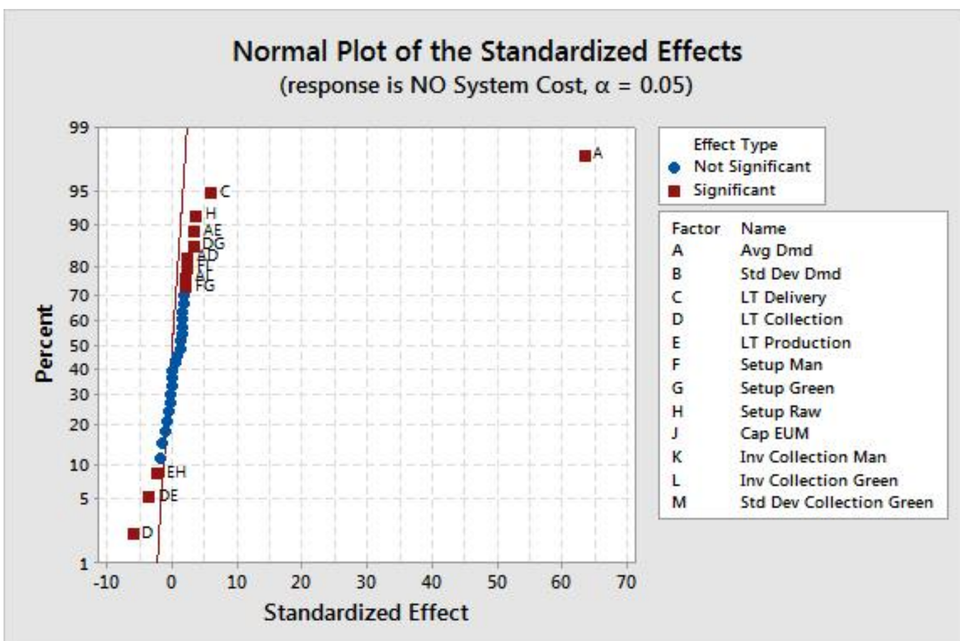

Figure 5.8 Normal Plot of the Standardized Effects for FI

5.4 Summary

This chapter presented the basic RFID information-sharing coordination. The chapter defined the five RFID coordination: No RFID (NO), RFID Non-Integrated (NI), RFID Partial-Integrated Downstream (PID), RFID Partial-Integrated Upstream (PIU), and RFID Full-Integrated (FI). A simulation analysis was performed over 128 supply chain scenarios testing 12 independent variables in which system cost was the depended variable. Multiple Comparison Test, Regression Analysis with ANOVA, and Interaction Analysis were conducted. From the results, we can describe the following insights:

- From the 128 supply chain scenarios, two coordination provided the best performance. FI provided 37 scenarios with the lowest system cost meanwhile NO provided 33 scenarios with the lowest system cost from the 128 scenarios. This provide a good managerial insight in which using basic RFID information-sharing coordination there are two coordination that can achieve the best performance over cost. One of them is FI in which both demand and inventory information is shared helping to attain the best performance. This allows the players to undergo green initiatives with the best results. In the other hand, there were supply chain scenarios were RFID was not required.
- NI had no scenario with the lowest system cost. This is an important managerial insight that shows that even though there can be operational benefits inside the centralized warehouse of each player, system cost benefits are not achieved if there is no sharing of information. Many papers and research focus on the centralized benefits of RFID. But few papers study the impact of RFID on decentralized systems. These results show that considering decentralized supply chains, it is needed information sharing to achieve higher results. The question is then, what type of information. Based on our results, this will depend on the information-sharing coordination. Below the analysis of PID and PIU.
- PID had no scenario with the lowest system cost. This reflects that this basic RFID coordination provides higher benefits for information sharing from inventory such as the one presented in the PIU case. Sharing only demand information from manufacture under this basic RFID coordination do not provide the best system cost performance. More models have to be explore to find the best inventory and production decisions to benefit from the demand information.

- From the PIU, we see that it achieved 4 scenarios with the lowest system cost and there were 21 cases with the FI coordination that PIU was the lowest. This shows that the basic RFID coordination provides better benefits if it is shared inventory information rather than demand information alone.
- We address the results from the FI that provided the highest performance. Companies with high cost structure benefits from reverse logistics initiatives. The more the collection investment from the manufacture and recycled material, better the overall system cost. However, to achieve its fullest potential, RFID Full Integration (FI) is necessary to provide the best information-sharing coordination among players. Three factors are important to monitor such as standard deviation of collection leadtime, investment collection of the manufacturer and the recycled material supplier. These three factors have the highest impact on the system cost.
- The system profile for FI based on the statistical analysis are the following. Main Effects are investment collection from manufacturer, investment collection from green supplier, setup cost manufacturer and average demand. The interaction effects with the highest impact on cost are average demand x investment collection manufacturer, average demand x cap end-user market, and leadtime collection x standard deviation collection.
- The managerial insights for FI are the following. RFID FI is preferred since it reduces cost over green investments. Enterprises that invest in environmental practices will have a higher cost (consistent with literature). It is recommended to use RFID FI to manage higher flow of returns (due to green investment) and the complexity involved. In addition, RFID FI mitigates cost over high setup cost. Enterprises with high manufacturer cost can use RFID FI to compensate with better coordination and reduce other cost such as ordering cost (due to higher returns). Also, RFID FI is recommended over fast consumer goods. Systems with high demand rotation can use RFID FI to have real-time information and enhanced reorder points to reduce cost.
- Finally, we address the results under NO was the best alternative. Companies does not need to undergo RFID implementation with system structure with lean cost structure in which the main variable cost is the cost associate with the demand

variable. Main factor to consider are delivery leadtime, leadtime production, and setup cost green.

- The system profile for NO based on the statistical analysis are the following. Main Effects are average demand, leadtime collection, leadtime delivery and setup cost raw. The interaction effects with the highest impact on cost are leadtime collection x leadtime Production and average demand x leadtime production.
- The managerial insights for NO are the following. NO is suitable for systems with low cost structure. If the enterprise is able to managed a low cost structure, then it is preferable to use NO. Average Demand is the primary impactor on cost. Given the efficient operations, average demand is the highest impactor for the overall system cost. In addition, leadtimes plays a key role over these systems. Given the low cost structure, the key factors to manage will be the different leadtimes and there interactions. Leadtime production join with high leadtime collection or high average demand can impact the overall system. Also, setup cost raw as the main cost impactor. The raw-material supplier needs to monitor the setup cost given the impact on cost.

We have defined managerial insights that can improve the system performance. However, as the results shows, there is still opportunity for improve the coordination since not all the instances, the RFIDs coordination were better than the NO RFID. In addition, over the basic RFID information-sharing coordination, inventory information has higher impact than demand information alone. The next chapter will present an improvement over the inventory policies and RFID coordination.

CHAPTER 6. ADVANCED RFID INFORMATION-SHARING COORDINATION

This chapter develops the new RFID information-sharing coordination. The chapter begins with an introduction in Section 6.1. In Section 6.2, our approach is presented. Numerical experiments are shown in Section 6.3, and summary in Section 6.4.

6.1 Introduction

The simple RFID information-sharing coordination from previous Chapter 5, utilized basic inventory policies from literature. Even though improvements were achieved, it is necessary better modeling to increase overall system performance. In addition, we found that inventory information provided better performance compared to demand information if shared alone. We need to continue exploring models that provide better performance with demand information.

Previous model used one inventory position to determine when to order. For this chapter, we are going to expand, from previous centralized reverse logistics models, the parallel inventory models which have two inventory positions to our decentralized green supply chain. From our results, splitting the inventory positions for raw and recycled material separately help reduced system cost as well as to increase demand and returns. This is part of the novelty of our research in which we propose a centralized model to be used over a decentralized supply chain with reverse logistics.

The objective of this chapter is to provide more guidelines on the different types of RFID coordination possible (now with an improved model) to achieve higher value on information sharing. The results quantitatively corroborate the notion of improvements with better coordination among the supply chain and that sharing information alone is not enough to attain the highest performance.

6.2 Approach

We delineate the five advanced RFID information-sharing coordination. Table 5.1 shows the summary of the advanced RFID information-sharing coordination.

Table 6.1 Summary of RFID Information-sharing coordination

RFID Configuration	Inventory Policy	Information Sharing	Entities Sharing	Type of Information	Inventory Decision Enhanced	Nomenclature
NO	Periodic	N.A.	None	None	None	None
NI	Continuous	No	None	None	None	None
PID	Continuous	Yes	Downstream	Demand	Reorder point of recycled-material supplier	$\bar{r}_g$
					Reorder point of raw-material supplier	$\bar{r}_r$
					Order Quantity of raw-material supplier	$\bar{Q}_r$
PIU	Continuous	Yes	Upstream	Inventory	Inventory position of manufacturer to produce	$\bar{X}_m^r$
					Inventory position of raw-material supplier	$\bar{X}_r$
FI	Continuous	Yes	Dowsntream & Upstream	Demand & Inventory	Reorder points, order quantities, and inventory positions	$\bar{r}_g$, $\bar{r}_r$, $\bar{Q}_r$, $\bar{X}_m^r$, $\bar{X}_r$

6.2.1 No RFID Coordination

There is no implementation of RFID tags and RFID readers in the warehouse of each of the players. Thus, the entities have to check their inventory under a periodic review inventory policy. This means that the players will not be able to check their on-hand inventory in real-time. Further, since there is no integration of the EPC Global Network, the players are not able to share information such as demand or inventory levels. Table 6.2 shows the inventory positions and inventory decision for the No RFID coordination. As a reference, this model is similar to Section 5.2.1 which serves as a baseline to compare the basic and advanced coordination.

Table 6.2 Inventory Position and Decision with No RFID Coordination

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m(t) := I_m(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_m} Q_m^r(t-i)$	$Q_m^g = \begin{cases} S_m - I_m(t) & \text{if } X_m(t) \le s_m \text{ and } I_g(t) \ge (S_m - I_m(t)) \\ 0 & \text{Otherwise} \end{cases}$ $Q_m^r = \begin{cases} S_m - I_m(t) & \text{if } X_m(t) \le s_m \text{ and } I_g(t) < (S_m - I_m(t)) \\ 0 & \text{Otherwise} \end{cases}$
Recycled-material supplier	$X_g(t) := I_g(t) + \sum_{i=1}^{LT_g} RC(t-i)$	$Q_g(t) = \begin{cases} R(E, CI) & \text{if } X_g(t) \le s_g \\ 0 & \text{Otherwise} \end{cases}$
Raw-material supplier	$X_r(t) := I_r(t) - B_r(t) + \sum_{i=1}^{LT_r} Q_r(t-i)$	$Q_r(t) = \begin{cases} S_r - I_r(t) & \text{if } X_r(t) \le s_r \\ 0 & \text{Otherwise} \end{cases}$

The manufacturer has only one inventory position X_m. If the inventory position X_m is less than or equal to the reorder point s_m , and there is enough on-hand inventory for the green supplier$I_g \geq (S_m - I_m)$, then the manufacturer orders to the green supplier $Q_m^g = (S_m - I_m)$. Otherwise, the manufacturer orders to the raw-material supplier $Q_m^r = (S_m - I_m)$. The recycled-material supplier collects returns R whenever its inventory position is less than or equal to its reorder point, $X_g \leq s_g$. The raw-material suppliers orders $Q_r = (S_r - I_r)$ whenever its inventory position is less than or equal to its reorder point, $X_r \leq s_r$.

6.2.2 RFID Non-Integrated Coordination

The players in the supply chain have RFID implemented in their warehouse. Each player has the RFID tags in their inventories and RFID readers. This implementation enables the players to change from a periodic review to a continuous review. The change in policy signifies real-time monitoring allowing to be better prepared to satisfy demand over changes in the reverse channel (e.g., stochastic returns and collection leadtimes). Even though the players have installed RFID in their warehouses, they have not performed any integration to exchange information through the EPC Global Network. Therefore, no coordination is made to enhance inventory policies.

Table 6.3 Inventory Position and Decision with RFID Non-Integration

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m^g(t) := MR * I_m(t) + \sum_{i=1}^{LTm} Q_m^g(t-i) + \sum_{i=1}^{LTg} Q_m^r(t-i)$ $X_m^r(t) := MR * I_m(t) + \sum_{i=1}^{LTm} Q_m^g(t-i) + \sum_{i=1}^{LTm} Q_m^r(t-i)$	$Q_m^g(t) = \begin{cases} Q_m(t) & if\ X_m^g(t) \le r_{mg} \\ 0 & Otherwise \end{cases}$ $Q_m^r(t) = \begin{cases} Q_m(t) & if\ X_m^r(t) \le r_{mr} \\ 0 & Otherwise \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LTg} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & if\ X_g(t) \le r_g \\ 0 & Otherwise \end{cases}$
Raw-material supplier	$X_r(t) := MR * I_r(t) - B_r(t) + \sum_{i=1}^{LTr} Q_r(t-i)$	$Q_r(t) = \begin{cases} Q_r(t) & if\ X_r(t) \le r_r \\ 0 & Otherwise \end{cases}$

From previous inventory policies on reverse logistics, authors introduced two inventory-positions models to analyze separately the procurement decisions on when to request production (e.g., raw-materials) or when to request returns (e.g., recycled materials). From these models, the separate or parallel decisions in the inventory models of reverse logistics provided better performance than regular one inventory-position models (Kiesmüller, 2003; Teunter et al., 2004). However, this parallel decision was modeled in a centralized version in which the manufacturer has the complete visibility of the warehouse, thus visibility from the serviceable inventory as well as returns inventory. In previous Chapter 5, we defined the inventory decisions on a decentralized supply chain with reverse logistics operations. Now, we extend this work and define different kind of coordination with two inventory positions.

The manufacture has two-inventory position, one to trigger orders to the recycled-material supplier X_m^g and one to trigger orders to the raw-material supplier X_m^r. The different is that to request green, we take outstanding raw-materials orders up-to the collection leadtime LT_g. Whereas, to trigger orders to the raw-material supplier, we take outstanding raw-materials orders up-to the delivery leadtime to the manufacturer LT_m. Further, there are two reorder points. If the inventory position to produce is less than or equal to the reorder point to produce $X_m^r \leq r_{mr}$, then order to the raw-material supplier. This r_{mr} is equal to the s in the No RFID case, $r_{ms} = s$. Similar, if the inventory position to recycle is less than or equal to the reorder point to recycled $X_m^g \leq r_{mg}$, then order to the recycled-material supplier. The recycled-material supplier has a similar inventory position and policy than the NO RFID, just in a continuous review. The raw-material supplier has a similar inventory position and policy than the No RFID case, but the order quantity is optimal such as Q_r given the continuous review policy.

6.2.3 RFID Partial-Integrated Downstream Coordination

The players in the RFID Partial-Integrated Downstream (PID) coordination have installed the RFID components in their warehouse and are able to monitor their inventory in real-time. In addition, the players have performed partial integration in the sense that now the downstream player (i.e., manufacturer) will provide value-information to the suppliers. The manufacturer will exchange demand information to the suppliers through the EPC Global Network. From this, the recycled-material supplier is able to enhance its reorder point. The raw-material supplier is able to enhance its reorder point as well as its order quantity.

Table 6.4 Inventory Position and Decision with RFID Partial-Integrated Downstream

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m^g(t) := MR * I_m(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_g} Q_m^r(t-i)$ $X_m^r(t) := MR * I_m(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_m} Q_m^r(t-i)$	$Q_m^g(t) = \begin{cases} Q_m(t) & if\ X_m^g(t) \leq r_{mg} \\ 0 & Otherwise \end{cases}$ $Q_m^r(t) = \begin{cases} Q_m(t) & if\ X_m^r(t) \leq r_{mr} \\ 0 & Otherwise \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LT_g} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & if\ X_g(t) \leq \overline{r}_g \\ 0 & Otherwise \end{cases}$
Raw-material supplier	$\overline{X}_r(t) := MR * I_r(t) - B_r(t) + \sum_{i=1}^{LTr} Q_r(t-i)$	$\overline{Q}_r(t) = \begin{cases} \overline{Q}_r(t) & if\ X_r(t) \leq \overline{r}_r \\ 0 & Otherwise \end{cases}$

Since the manufacturer is the one that is providing the information, the enhancements in the inventory will be in the suppliers. Now, the recycled-material supplier calculates an enhanced reorder point $\bar{r}_g$ given that the reorder point depends on demand information. Therefore, the recycled-material supplier instead of using historic orders from the manufacturer, it will use real demand information. Similar, the raw-material supplier calculates an enhanced reorder point $\bar{r}_r$ and it calculates an enhanced optimal order quantity $\bar{Q}_r$ since this information depends on the demand.

6.2.4 RFID Partial-Integrated Upstream Coordination

The players are able to have a continuous review inventory policy and exchange information through the EPC Global Network. In this case, the suppliers are the ones who share information such as inventory levels. The manufacturer is able to read the on-hand inventory from both suppliers. In addition, the raw-material supplier is also able to count the recycled-material on-hand inventory to calculate an enhance inventory position.

Table 6.5 Inventory Position and Decisio with RFID Partial-Integrated Upstream

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m^g(t) := MR * I_m(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i)$ $+ \sum_{i=1}^{LT_g} Q_m^r(t-i)$ $\overline{X}_m^r(t) := MR * I_m(t) + MR * I_g(t)$ $+ \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_m} Q_m^r(t-i)$	$Q_m^g(t) = \begin{cases} Q_m(t) & if\ X_m^g(t) \leq r_{mg} \\ 0 & Otherwise \end{cases}$ $Q_m^r(t) = \begin{cases} Q_m(t) & if\ \overline{X}_m^r(t) \leq r_{mr} \\ 0 & Otherwise \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LT_g} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & if\ X_g(t) \leq r_g \\ 0 & Otherwise \end{cases}$
Raw-material supplier	$\overline{X}_r(t) := MR * I_r(t) + MR * I_g(t)$ $- B_r(t) + \sum_{i=1}^{LT_r} Q_r(t-i)$	$Q_r(t) = \begin{cases} Q_r(t) & if\ \overline{X}_r(t) \leq r_r \\ 0 & Otherwise \end{cases}$

The manufacturer, in order to request production to the raw-material supplier when it is just strictly necessary, will count the on-hand inventory of the recycled-material supplier I_g in its inventory position to produce $\bar{X}_m^r$. Further, the raw-material supplier acts as an alternative supplier in the case there is not enough returns on the green supplier's inventory. Therefore, the productions depend on the on-hand inventory of the recycled-material supplier. The raw-material supplier will then include on-hand inventory of the recycled-material supplier in its inventory position $\bar{X}_r$.

6.2.5 RFID Full-Integrated Coordination

In this case, all the entities have installed RFID elements in their warehouses and also all the entities are sharing information. This coordination is the highest level of integration. The manufacturer share demand information to the suppliers and supplier share their on-hand inventory.

Table 6.6 Inventory Position and Decision with RFID Full-Integrated

Player	Inventory Position	Inventory Decision
Manufacturer	$X_m^g(t) := MR * I_m(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_g} Q_m^r(t-i)$ $\overline{X}_m^r(t) := MR * I_m(t) + MR * I_g(t) + \sum_{i=1}^{LT_m} Q_m^g(t-i) + \sum_{i=1}^{LT_m} Q_m^r(t-i)$	$Q_m^g(t) = \begin{cases} Q_m(t) & if\ X_m^g(t) \le r_{mg} \\ 0 & Otherwise \end{cases}$ $Q_m^r(t) = \begin{cases} Q_m(t) & if\ \overline{X}_m^r(t) \le r_{mr} \\ 0 & Otherwise \end{cases}$
Recycled-material supplier	$X_g(t) := MR * I_g(t) - B_g(t) + \sum_{i=1}^{LT_g} RC(t-i)$	$Q_g(t) = \begin{cases} RC(E, CI) & if\ X_g(t) \le \overline{r}_g \\ 0 & Otherwise \end{cases}$
Raw-material supplier	$\overline{X}_r(t) := MR * I_r(t) + MR * I_g(t) - B_r(t) + \sum_{i=1}^{LTr} Q_r(t-i)$	$\overline{Q}_r(t) = \begin{cases} \overline{Q}_r(t) & if\ \overline{X}_r(t) \le \overline{r}_r \\ 0 & Otherwise \end{cases}$

In this integration, the manufacturer has an enhanced inventory position to produce $\bar{X}_m^r$. The recycled-material supplier has an enhanced reorder point $\bar{r}_g$. And the raw-material supplier has an enhanced inventory position $\bar{X}_r$, a reorder point $\bar{r}_r$, and a optimal quantity $\bar{Q}_r$.

6.3 Numerical Experiments

We define the simulation, design of experiments and results from the advanced RFID coordination study in the following sections.

6.3.1 Simulation Approach and Design of Experiment

The simulation methodology is similar as in Chapter 5. The simulation model from Chapter 5 had one process code to simulate the manufacturing inventory positions and decisions. However, the model for the advanced have two separate and independent process codes to simulate manufacturing inventory positions and decisions for the recycled materials and for the raw materials. This independent process code was built over the four RFID coordination NI, PID, PIU and FI.

6.3.2 Results

6.3.2.1 Multiple Comparison Test

Table 6.7 to 6.9 shows the results from the Multiple Comparison Test (MCT) over the advanced RFID Information-sharing coordination.

Table 6.7 Multiple Comparsion Test Results – One Statistically Different Mean

Analysis	NO	NI	PID	PIU	FI	Total Scenarios with One Mean Statistically Different
# of scenarios statistically lower that the 4 rest RFID Coordination	9	0	55	0	0	64

Table 6.8 Multiple Comparsion Test Results – Two Statistically Different Mean

RFID Coordination Means with Lowest System Cost	# of scenarios been the lowest that the rest
NI-PID	8
PID-FI	40
Total	48

Table 6.9 Multiple Comparison Test Result – All Means

# of Means Statistically Lower	# of Scenarios	% Weight
1	64	50%
2	48	38%
3	16	13%
4	0	0%
Total	128	100%

From the results, there are two coordination that provided the lowest mean returns. PID provided the best results with 55 scenarios with the lowest mean. As described in the results from Chapter 5, PID did not had any scenario with the lowest system cost. Now, the advanced RFID coordination enable to receive higher benefits from the demand information. In addition, 9 scenarios from NO achieved the lowest cost.

These result provides an interesting managerial insight. The companies that can implement the parallel inventory positions presented in Section 6.2, are able to achieve lower system cost if the manufacturer is capable of sharing demand information. This means that it is not necessary under these scenarios to implement the full integrations with the recycled-material and raw-material supplier. This is a good insight for practitioner since implementing more players is practice could be more difficult in terms of organizational and IT structure.

We can also see from Table 6.8 that NI-PID has 8 scenarios and PID-FI has 40 scenarios with the lowest system cost. NI is now a better coordination with parallel inventory positions. Also, FI appeared as an additional alternative for 40 cases.

6.3.2.2 Regression Analysis Test

The results presented on Table 6.10 shows higher Multiple R, R Square and adjusted R Square above 94%. This shows that our model, in this case PID, is providing the adequate factors and elements to drive to our recommendations. Similar case, ANOVA shows that there are significant factors impacting the supply chain. From Table 6.11, we see that the main factors impacting the overall system cost. Two are related with demand such as the average demand and standard deviation of the demand; also, related with environment factors are the standard deviation collection leadtime and the average leadtime collection. It is recommendable to implement PID in these system conditions since they are highly sensitive to demand and in the PID configuration the main information that is shared is demand. In addition, this provides additional motivation to implement reverse logistics using PID since even over high collection leadtime and high standard deviation leadtime, the PID configuration is able to provide the lowest system cost.

We saw leadtime delivery and setup cost of manufacturer with negative coefficient. The R Square analysis provided a higher value of above 94%. Also, the factors with the highest impact are the ones below. As we saw in Chapter 2, in literature it was been presented the leadtime paradox which have lower results with higher leadtime. In addition, these results are over the total system cost, not particularly for the manufacturer cost that in the results should have an impact to the cost. Overall, this set of results are the combinations of all the dynamics that are happening in the system.

Table 6.10 Regression Statistics - PID

Statistic	Value
Multiple R	97%
R Square	94%
Adjusted R Square	94%
Standard Error	420.67
Observations	5,500

Table 6.11 ANOVA Statistics - PID

Statistic	df	SS	MS	F	Significance F
Regression	12	15,470,803,024.96	1,289,233,585.39	7,947.49	0
Residual	5,488	971,189,580.21	176,966.03		
Total	5,500	16,441,992,605.96			

Table 6.12 Regression Factors and Coefficients - PID

Factors	Coefficients	Standard Error	tStat	P-value
Intercept	(1,824)	82.94	-21.99	8.64E-103
Avg Dmd	-	0.00	65,535.00	-
Std Dev Dmd	232	0.81	285.94	-
LT Delivery	(17)	2.02	-8.63	0.00
LT Collection	149	4.13	35.95	0.00
LT Production	11	1.93	5.56	0.00
Setup Man	(7)	1.42	-5.10	0.00
Setup Green	(4)	5.89	-0.67	0.50
Setup Raw	3	2.33	1.22	0.22
Cap EUM	2	0.38	6.34	0.00
Inv Collection Man	8	2.90	2.69	0.01
Inv Collection Green	1	2.28	0.66	0.51
Std Dev Collection Green	551	24.57	22.40	0.00

We continue exploring the 40 scenarios were PID and FI provided the best performance results as noted in Table 6.7. From the Regression analysis, we obtained Multiple R, R Square and adjusted R Square above 96%. This suggest that the model is providing the factors that explain our observable variable which is the system cost. The ANOVA demonstrations that there are significant variables impacting the results. From the regression analysis, it demonstrates that the factor with highest impact is the Standard deviation leadtime from collection. If we compare the regression coefficient from Table 6.11 versus Table 6.14, we see that the Coefficient in Table 6.14 are higher. We can infer that in system where there is more stochastic variability, it is advisable to use PID as well as FI. Also, the other factors with high Coefficient is standard deviation. Again, PID and FI are suitable RFID configurations when there is high variability on the stochastic factors such as standard deviation of demand and standard deviation leadtime from collection.

Table 6.13 Regression Statistics – PID-FI

Statistic	Value
Multiple R	98%
R Square	96%
Adjusted R Square	96%
Standard Error	335
Observations	4,000

Table 6.14 ANOVA Statistics – PID-FI

Statistic	df	SS	MS	F	Significance F
Regression	12	9,878,377,969	823,198,164	7,991	0
Residual	3,988	448,185,844	112,384		
Total	4,000	10,326,563,813			

Table 6.15 Regression Factors and Coefficients – PID-FI

Factors	Coefficients	Standard Error	tStat	P-value
Intercepción	(666)	82.69	-8.05	0%
Avg Dmd	-	0	65,535.00	-
Std Dev Dmd	211	0.86	244.97	-
LT Delivery	(17)	2.13	-8.13	0%
LT Collection	21	3.75	5.70	0%
LT Production	3	1.85	1.83	7%
Setup Man	3	1.43	1.98	5%
Setup Green	1	5.75	0.24	81%
Setup Raw	(5)	2.28	-2.15	3%
Cap EUM	2	0.37	6.17	0%
Inv Collection Man	12	2.94	4.10	0%
Inv Collection Green	(2)	2.22	-0.80	42%
Std Dev Collection Green	809	37.75	21.43	0%

6.3.2.3 Analysis of Factorial and Interactions

Now, we are going to validate the main and interactions effects to gain more insights from the results.

Analysis of Factorial and Interactions with RFID Partially-Integrated Downstream

From Figure 6.1, we can see that average of demand and standard deviation of leadtime collection. Also, average leadtime collection is another main effect with an impact on system cost. We can see that under system with high collection leadtime and high stochastic variability on the collection leadtime, it is suitable to implement RFID configurations with demand sharing such as PID. From Figure 6.3 and 6.4, we see that there are two important interactions effects which are Avg Demand x Leadtime Collection and Leadtime Production x Setup Cost Manufacturer. The later interaction provides an important insight in which with high leadtime production and with high setup cost manufacturer, it is advisable to implement PID to overcome high system cost.

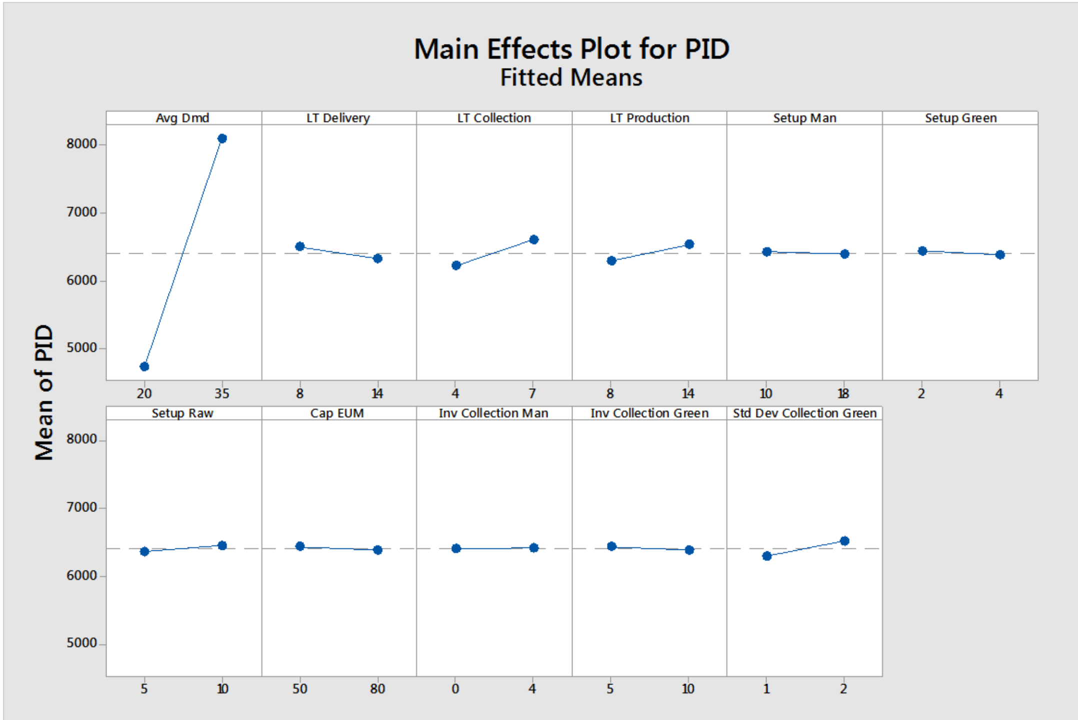

Figure 6.1 Main Effects Ploft for PID

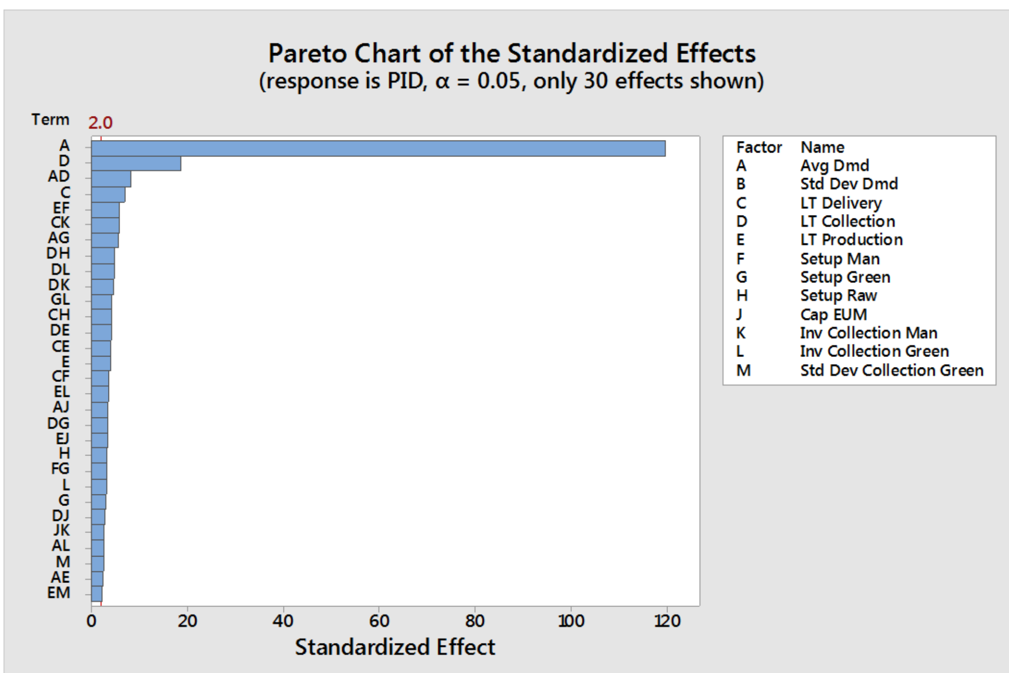

Figure 6.2 Pareto Chart of Standardized Effects for PID

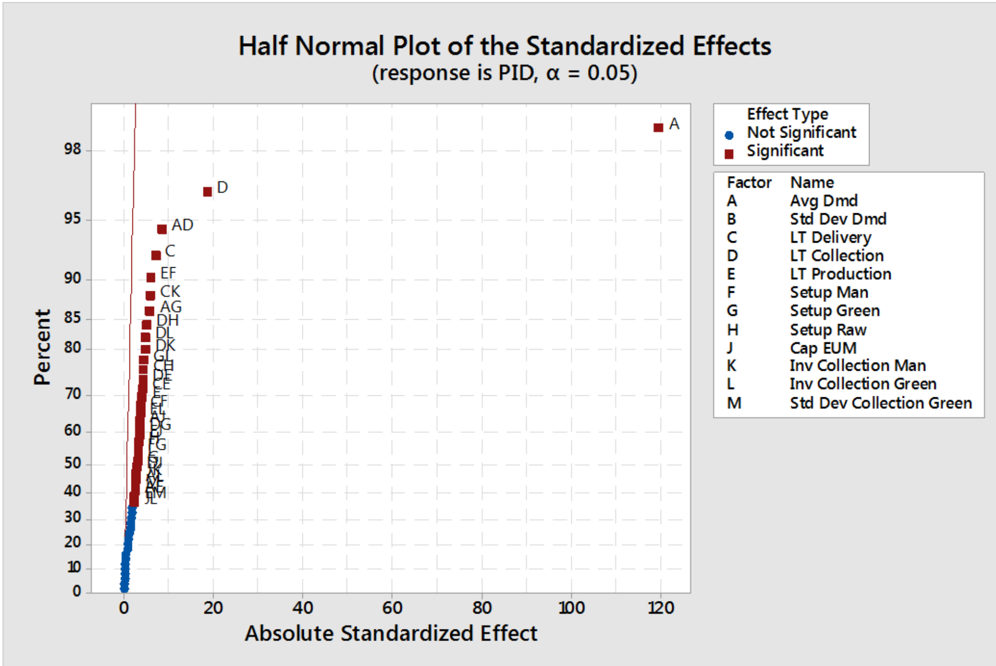

Figure 6.3 Half Normal Plof the Standardized Effects for PID

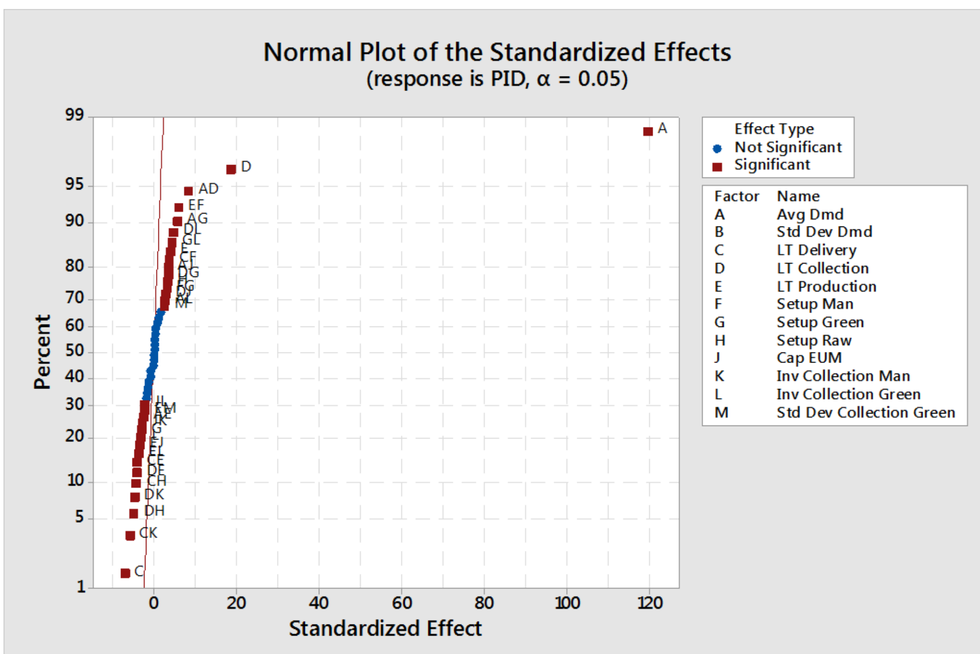

Figure 6.4 Normal Plot of the Standardized Effects for PID

Analysis of Factorial and Interactions with RFID Full-Integrated

As we can see from Figure 6.5, FI configuration is better to be implemented with industries with high average demand and standard deviation collection leadtime. If we compare Figure 6.1 versus Figure 6.5, we see that the standard deviation collection leadtime is higher on the scenarios were FI had better performance. This is an important insight that reflects the power of RFID integration. Under higher stochastic variability, it is better to implement Full Integration to have all information such as demand and inventory. In addition, interaction effects analysis provides another useful contribution in which Leadtime Delivery x Leadtime Production are key impactors on the system cost. This means that FI systems are better configurations were the raw-material supplier has a higher leadtime production and the manufacturer has higher leadtime delivery.

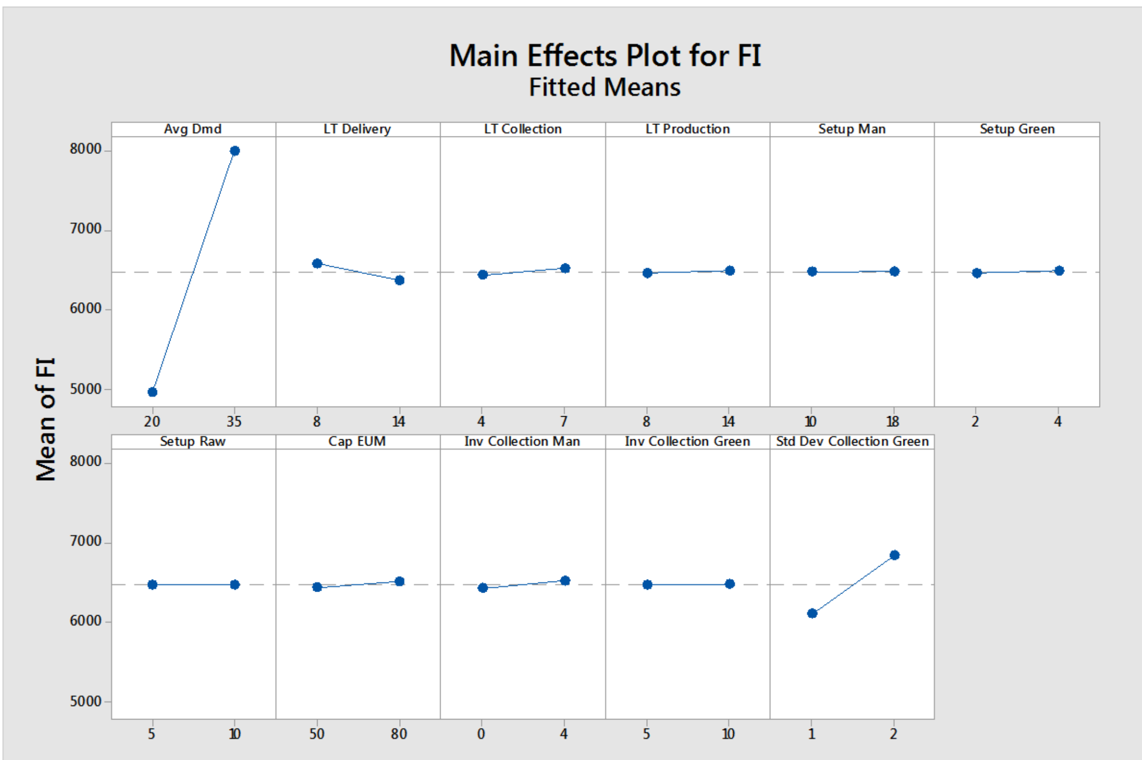

Figure 6.5 Main Effects Ploft for PID-FI

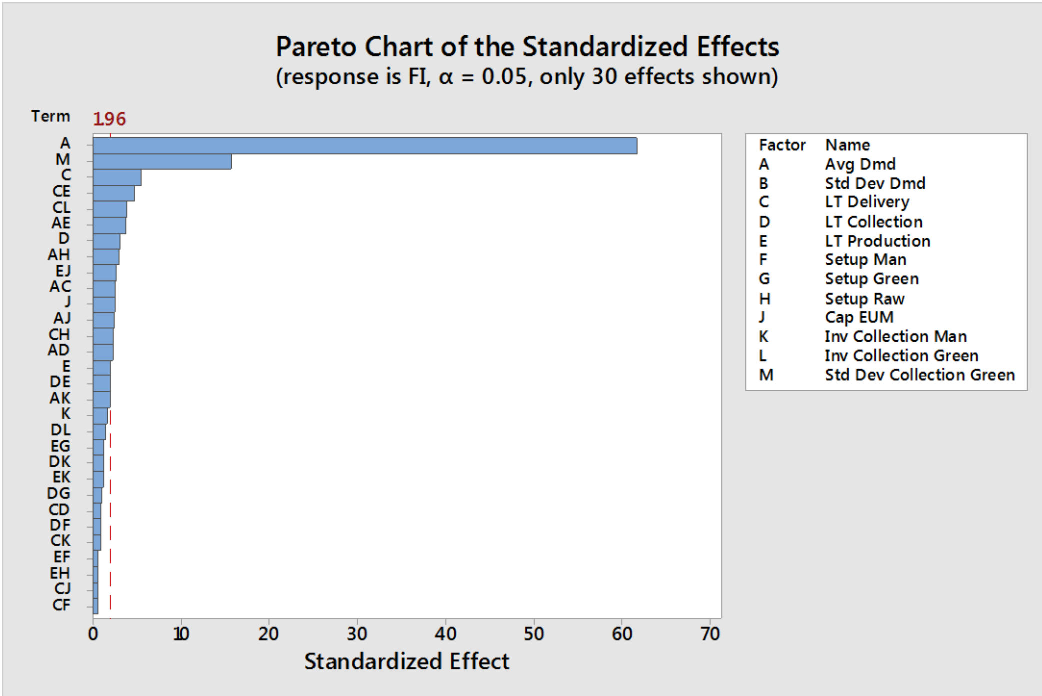

Figure 6.6 Pareto Chart of Standardized Effects for PID-FI

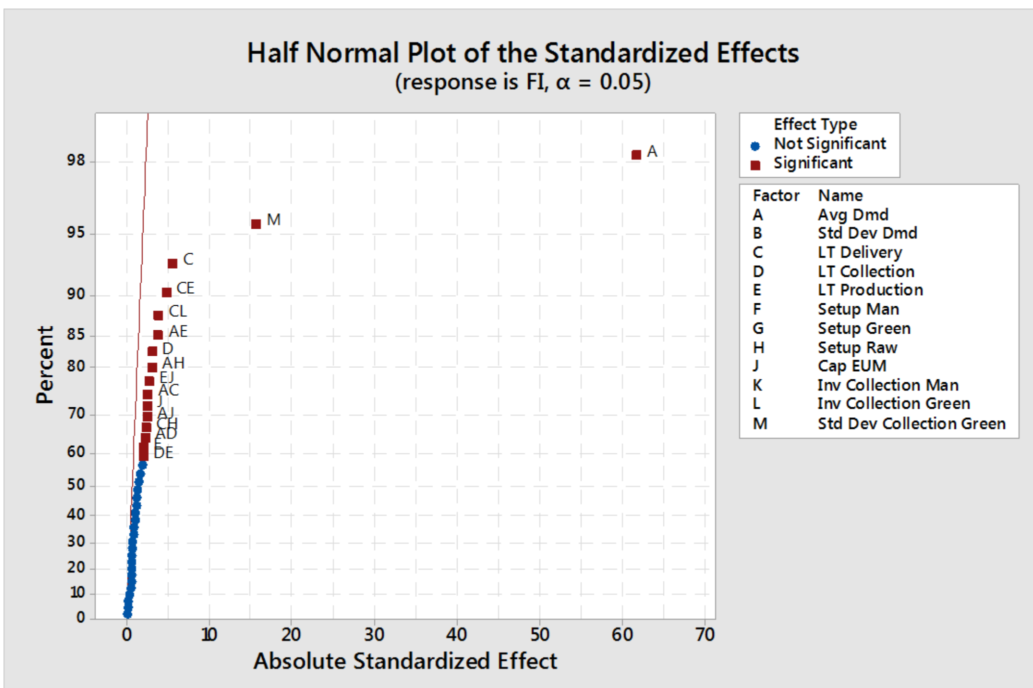

Figure 6.7 Half Normal Plof the Standardized Effects for PID-FI

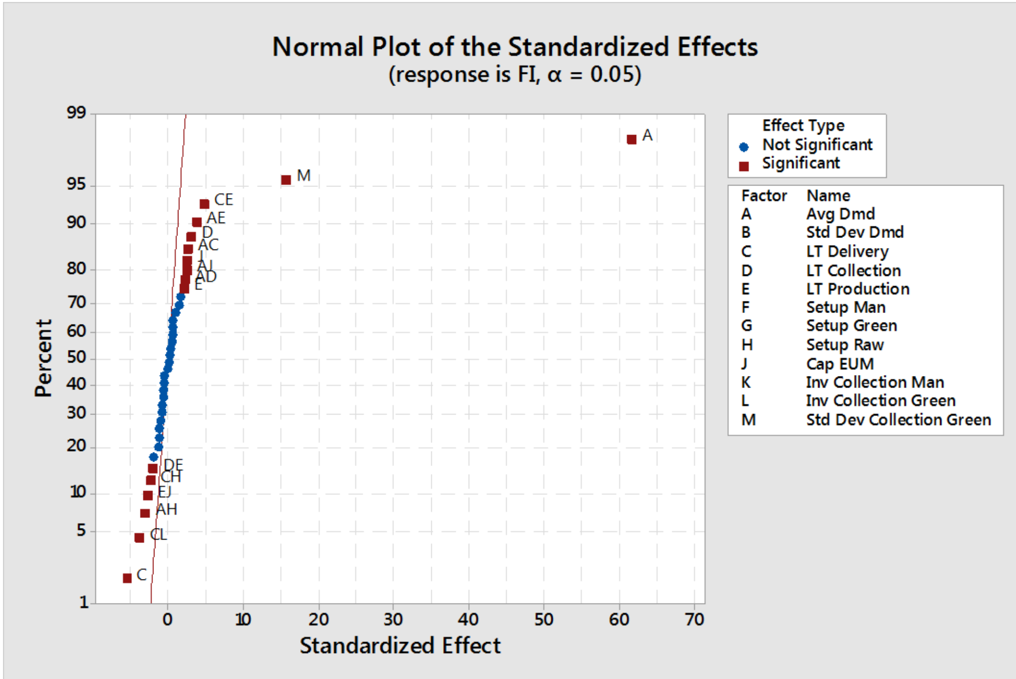

Figure 6.8 Normal Plot of the Standardized Effects for PID-FI

6.3.2.4 Basic versus Advanced RFID Coordination

Now that we have presented both results for Basic and Advanced in Chapter 5 and Chapter 6, respectively, we will compare the overall results from each modeling. We compare each RFID coordination. For this, we used Hypothesis Test comparing the two samples with different variance with alpha levels of 0.05. Table 6.15 shows the results. As we can see from the results, all P-values showed lower than 5% reflecting that there is a difference between the means between Basic vs Advanced RFID Coordination. This is one of the findings that provides novelty to our work in which there are no reach papers that we are aware of that analyze a decentralized supply chain with reverse logistics scenarios that compares not only the impact of RFID technology but how the RFID coordination among the partners can change their performance. It is not enough to share information, but it is important how this data is exchange and used. As we saw, changing the inventory decisions, changed the overall performance on the supply chain. We can tell based on these results that technology alone cannot provide the highest impact. As we saw in Chapter 5, there were 33 scenarios with NO as the best scenario, but with Chapter 6 in Advanced, there were only 9 cases.

Table 6.16 Basic vs Advanced RFID Coordination

RFID Configuration	Mean	Variance	N	T-Value	P-Value	DF
NI Basic	10,627	12,163,038	12,800	103.79	0%	20,151.00
NI Advanced	6,957	3,841,949	12,800			
PID Basic	8,691	5,424,414	12,800	94.68	0%	23,466.00
PID Advanced	6,275	2,911,612	12,800			
PIU Basic	8,358	31,641,739	12,800	2.13	2%	17,452.00
PIU Advanced	8,242	5,955,859	12,800			
FI Basic	7,075	13,391,838	12,800	11.80	0%	19,357.00
FI Advanced	6,644	3,691,723	12,800			

6.4 Summary

Chapter 6 presented an alternative RFID Coordination approach to the one presented in Chapter 5. Chapter 5 used traditional production and inventory decision showed in literature and practitioners. This provided several scenarios in which RFID Coordination had better performance than NO case. However, there were 33 scenarios in which NO case still was better than the RFID Coordination. In Chapter 6 we proposed a novel solution integrating from centralized reverse logistics the concept of two inventory positions. Using two inventory positions, one for the raw-material supplier and one for the recycled-material supplier, provided parallel inventory decisions that helped the system to be more reactive and sensitive to changes on stochastic factors and changes in the supply chain. This is part of the novelty of our research that uses centralized theory into our decentralized supply chain with reverse logistics operations. Below the major insights found in this Chapter 6.

- From the 128 supply, PID provided the best results with 55 of the cases with the lowest system cost. This finding provides alternatives to the companies. If the companies can obtain reliable demand information and at the same time implement the two inventory positions, then they can implement PID just sharing demand information through the supply chain. This is an alternative from the Basic RFID in which most of the cases, the supply chain needed to implement FI which can mean higher implementation cost since inventory from the upstream and demand from the downstream needed to be shared.

- FI provided also best performance alongside with PID in 40 scenarios. FI similar to basic continue to be a relevant alternative to reach to the lowest system cost.
- Important to notice that NO provided just 9 scenarios as the lowest compared to 33 in the Basic RFID analysis from Chapter 5. This means that the Advanced RFID Configuration provided better performance that the Basic RFID Configuration.
- PID cases provided the best alternative in 55 scenarios. We performed regression analysis to understand the impact of the independent factor. It is suitable to implement PID were we have a supply chain system with higher average of demand and standard deviation of demand. We can see that the industries such as fast consuming goods can beneficiate from this implementation. In addition, two green factors provided to be significant under these scenarios. The average leadtime of the collection investment with its standar deviation impacts dramatically the overall system cost. For these reasons, PID is the best RFID configuration which have high demand, high demand variability, high collection leadtime and high variability. This can be useful insights for companies with consumer product in which the reverse logistics is not mature enough and high variability is presented.
- The system profile for PID based on the statistical analysis are the following. The main effects are average demand, leadtime collection and leadtime delivery. The interaction effects that have the highest impact on cost are average demand x leadtime collection, leadtime production x setup cost manufacturer, and leadtime delivery x investment collection manufacturer.
- The managerial insights for PID are the following. RFID PID with parallel IP provides more sensitivity to demand. With the advanced model, RFID PID is capable of coordinate better the system. Parallel inventory positions with demand sharing enables the system to reduce overall system cost and take advantage of higher demand visibility. Another key insight, RFID PID is as a solution to avoid RFID FI investment. The use of parallel inventory position with RFID enable the system to use demand and achieve the best performance. Other players are not required to implement RFID, reducing implementation cost. Also, leadtime are key factors to control. Leadtimes are the factors that can impact the overall cost system.
- We study the 40 scenarios were FI provided the best performance. System in which the standard deviation of the collection leadtime is very high, it is necessary to

implement FI. In addition, the system has higher standard deviation of the leadtime delivery. Under higher stochastic variability, the analysis shows that higher RFID coordination enables to provide the lower system cost.

- The system profile for FI based on the statistical analysis are the following. The main effects are average demand, standard deviation collection leadtime, and leadtime delivery. The interactions effects are leadtime delivery x leadtime production, leadtime delivery x investment collection green, and average demand x leadtime production.
- The managerial insights for FI are the following. RFID FI is suitable for high variability on reverse operations. Over system with high variability, it is not enough to share demand information. Full-Integration is necessary to reduce overall cost. In addition, RFID FI achieves higher demand rotation. Similar to PID, RFID FI enables the system to attain higher demand with the lowest system cost. Also, leadtime delivery is a key factors that can impact the overall cost system.
- We compared the Basic vs Advanced RFID coordination. We performed the hypothesis test to check if the overall means from Basic vs Advanced provided a different between NI, PID, PIU and FI. It was shown that there is enough statistical evidence that corroborate that Basic vs Advanced means are different. Therefore, we see and can infer that Advanced modeling.
- Companies that wants to implement green supply chain system can use RFID technology. But as the results shows, Advanced RFID information-sharing coordination will provided better benefits. In addition, particular insight over stochastic factors such as collection leadtime and standard deviation of demand will motivate to integrate PID or system with higher variability FI.

CHAPTER 7. CONCLUSIONS

This thesis provided new modeling to effectively manage supply chain with reverse logistics operations through the use of Radio Frequency Identification (RFID) information-sharing coordination. In this chapter, we present the summary of the thesis and the future research direction.

Chapter 1 provided the general background for the research in terms of motivations, benefits and challenges of environmental supply chains. Further, we introduced Radio Frequency Identification technologies as a prominent mechanism to improve performance in these supply chains.

Chapter 2 defined the common literature review to develop the thesis. We presented the motivations and challenges of environmental supply chain adoptions. Later, the chapter emphasizes the importance of investigating RFID coordination methods that enable integration among parterns rather than just looking at the operational improvements.

Chapter 3 presented the general supply chain structure. The interaction among the players, the leadtimes, and flow of material are defined in this chapter. In addition, we detailed the common environmental and economic performance measures for the thesis. Also, the inventory definitions were defined. A complete set of cost measures, inventories, and ordering decisions are described.

Chapter 4 we explain that before there is a coordination, it is important to define the technology configurations. We presented additional references about players sharing information and also different RFID configuration in practice and literature.

We then proposed our five RFID technology configurations that considers who are the players, who installed the RFID technology, who shares the information and what type of information. This RFID configuration will help as the base to define the RFID coordination with the inventory policies from Chapter 5 and 6.

Chapter 5 devised the first RFID information-sharing coordination from basic RFID configuration and inventory policy alignments. Simulations experiment and statistical results helped compare the different coordination.

Chapter 6 showed more alignment from the advanced (parallel) RFID information-sharing coordination. This new modeling provides higher performance among players. The players were able to have more flexibility in their inventory decisions given by the parallel inventory enhancement. Further, the chapter compared basic versus advanced RFID information-sharing coordination and results shows that the advanced coordination is much better than the basic RFID coordination.

The future direction of the thesis is to exploring the adaptive algorithm. We desire to study more theoretical formulations that enable more agile and flexible supply chain. In addition, we want to analyze more the impact of different parameters through experimental studies. Preliminary experiments are presented in the following Chapter 8.

In addition, we want to explore the case where the returns materials are more expensive than raw materials. This is an interesting topic with more barriers in order to economically justify the environmental initiatives.

CHAPTER 8. FUTURE WORK

From previous chapter, we defined the RFID information-sharing coordination under specific supply chain scenarios. However, there can be changes in the supply chain where adaptive protocols are needed. This chapter explore for future research three adaptive algorithms. First, we study learning algorithms that enable identify dynamically optimal RFID information-sharing coordination. Second, we propose a self-adaptive protocol that helps the system adapt its RFID information-sharing coordination over dynamic supply chain environments. And third, multi-agent reinforcement learning delineates the RFID information-sharing coordination individually by player.

This chapter initiate with an introduction of the three problems in Section 7.1 we are exploring. In Section 7.2, the relevant works of the problems are presented. Section 7.3 details our proposals. Then, in Section 7.4 numerical results are presented and Section 7.5 shows the summary.

8.1 Introduction

The players have to decide what type of RFID coordination they want to pursue depending on initial resources and budget constraints with the guidelines provided on Chapter 4 to 6. However, based on this initial decision, the players do not know what type of RFID information-sharing coordination is more suitable for the supply chain if it has dramatic change in the structure and factors.

To address this problem, we use the concept of reinforcement learning. The supply chain dynamically will learn what the best policy is. The term policy refers to the changes in the RFID information-sharing coordination in order to reach to the optimal RFID configuration. This approach will enable any supply chain in a given moment to learn and to apply the optimal RFID information sharing policy.

In practice, it is assumed that the manager has complete information of the supply chain structure, cost information, and parameters to run the learning algorithm. After the learning algorithm is run with this available information, then the supply chain manager will have an optimal RFID policy which provides guidelines of the RFID implementation.

The managers have already decided the RFID information-sharing coordination based on the managerial guidelines from Chapter 4-6, either with previous knowledge from experts or from the reinforcement learning approach stated above. However, the economic benefits from the RFID coordination can be hurt when drastic changes occur to the supply chain. In today's market place, volatile business characteristics are the constant where external forces like competition, consumer purchase behavior, oil fluctuation, supply chain disruptions, and government regulations are powerful forces impacting the supply chain (Christopher, 2000; Yusuf et al., 2004). Therefore, our next challenge to address is what self-adaptive RFID information sharing protocol can be implemented to adjust to these dynamic business characteristics and remain economical and environmental responsible over volatile markets.

We proposed a self-adaptive RFID information sharing protocol to manage volatile changes in the supply chain environment. First, the autonomic control loop from control theory helped us define important phases in the self-adaptive algorithm such as collect, analyze, decide, and act. In the collect phase, the system measures cost performance and supply chain characteristics. Then, the analyze phase enables the system to assign performance and policy points. For example, the current RFID integration receives positive or negative points based on the previous cost performance. In addition, if the supply chain characteristics change (e.g., higher collection leadtime) and there is a rule that triggers the preference for a new RFID integration, the preferred RFID integration will be assigned a positive point. These rules can be obtained from either experts or simulation experiments. We explore a heuristic algorithm in which the system will evaluate its current state and choose the future state based on the total points. The algorithm chooses the RFID coordination for the future state that has the highest total points from the performance and policy points assigned in the analyze phase. This will enable the supply chain system remain cost efficient over changes in the supply chain selecting the most efficient RFID coordination in the act phase.

From previous adaptive algorithm, all the players choose the same RFID information-sharing coordination. The assumption is that a central agent is coordinating all of the players to achieve a system wide performance. Then, cooperation mechanisim can be execute with the overall system savings. However, there can be cases where the players desire to implement RFID coordination individually. In this case, the players are implementing RFID technology only if there is an economic improvement for the individual player. The third adaptive problem will address reinforcement learning algorithms in a multi-agent setting. The goal will be to have proper reinforcement learning algorithm to learn the RFID information-sharing coordination in the supply chain that provide a win-win situation for all players.

8.2 Related Work

In this section we cover three different stream of research: reinforcement learning, self-adaptive and control theory and multi-agent reinforcement learning. This reference will serve as a background of the exploratory and preliminary results.

The first literature that we are going to investigate is on the reinforcement learning algorithm. There have been some works in terms of reinforcement learning applied to supply chains. Kaihara (2003) presented a virtual market programming with multi-agent over a supply chain. This virtual market helped solve the production allocation based on the interaction among the players over dynamic environments.

Kim (2005) investigates two-echelon supply chain composed of one manufacturer and multiple retailers. The authors do not rely on statistical distribution to model the demand. Rather, the authors used reinforcement learning algorithm called action-value method to adaptively change the control parameters of the inventory policies whenever there is a change in demand pattern. The authors assumed to have perfect information in the entire supply chain.

Piramuthu (2005) propose an automated supply chain configuration mechanism with the use of machine learning. This approach helps the supply chain re-configure itself based on ordering policies over dynamic scenarios. The results shows that dynamic over static mechanisms provided higher order fulfillment and higher profit.

Ivanov et al. (2010) study the scenario of multi-structural dynamics in the supply chain. These dynamics in such as in functional, organizational, informational, and financial provides complexities to the supply chain. Moreover, this structure change dynamically more frequently with the insertion of electronic communication such as internet. The author proposed an agile supply chain management that enables execution of planning and operational control over dynamic multi-structural framework. This is achieved with the use of control theory, operations research, and agent-based modeling.

These previous papers are examples of the value of analyzing dynamics policies over the supply chain. Few researches address the notion of technology as an enabler of higher integration. However, none of them study how to change the information technologies coordination given a specific supply chain. This chapter investigates the use of reinforcement learning to determine the efficient policy to determine the RFID information-sharing coordination over green supply chains.

The second literature review presented is self-adaptive and control theory. As Oreizy et al. (1999) define, “self-adaptive software modifies its own behavior in response to changes in its operating environment”. This concept of self-adaptive algorithms has grown in popularity over the past few years in academia and industry. Due to this new venue of research, many fields are contributing to the topic such as control theory, artificial intelligence, mobile and autonomous robots, multi-agent systems, fault-tolerant computing, distributed systems, self-managing systems, biology, machine learning, sensor networks, and others Brun et al. (2009). Below are relevant papers addressing self-adaptive algorithms for our research.

Cheng et al. (2009) presented a comprehensive research roadmap on software engineering for self-adaptive systems. The authors presented four main areas of research: modeling, requirements, engineering, and assurance. Andersson et al. (2009) described the modeling dimensions of self-adaptive system. The modeling dimension can be classified in goals of adaptation, causes of the change, mechanisms to enable self-adaptive systems, and impact of the adaptation. Silva-Souza et al. (2011) studied the importance of requirements of adaptive systems. The authors presented an awareness requirement model with the purpose of explicitly defining what situations the systems need to adapt. These requirements help the programmer or manager define in what scenario is require the adaption. For example, does the adaptation need to occur during a small change? Or does the system have to adapt in a particular and critical behavior? Whittle et al. (2009) developed a language to address the uncertainty in system requirements. The language called RELAX helps identify critical requirements but at the same time relax other non-critical requirements in a given time. Brun et al. (2009) study the engineering of self-adaptive systems an argued that feedback loops needed to be engineering as a first order level in the model. Hebig et al. (2010) present as well the necessity to have control loops as a first class element in the modeling. As the authors mentioned, previous methods of self-adaptive system just highlight the use of feedback loops, but few of them provide a detail mechanisms of how a feedback loop is composed of and helped the system to monitor, analyze, decide, and act. IBM’s autonomic model MAPE-K and Shaw’s feedback control are two good examples of self-adaptive systems in which feedback loops are described in a first order model (Diao et al., 2005; Diao et al., 2005; Brun et al., 2009; Muller et al., 2008).

As the authors mentioned above, the area of self-adaptive system is increasing and new models require to be formulated. In addition, few models clearly define the engineering of the feedback loop in a self-adaptive algorithm as a first order level. This section aims to provide a practical example where control theory with the use of feedback loops are clearly modeled and defined. Further, most of the self-adaptive theory relies on the software and computer domain. Our goal is to use this self-adaptive concept to our green supply chain problem. From our knowledge, most of the supply chain flexibility relies on agile and adaptive supply chain concept (Choi et al., 2001; Christopher and Towill, 2001; Christopher and Towill, 2002). However, few papers address a formal and quantitative self-adaptive protocol. We aim to provide a constructive example on how self-adaptive models from software engineering can be implemented in the environmental supply chain concepts with the use of control theory.

Finally, the last literature is Multi-Agent Reinforcement Learning. As Busoniu et al. (2006) presented, there are different type of MARL algorithms depending on their type. For example, there can be cooperative, competitive, and mix MARL. In this research, we address the cooperative algorithm since we want to achieve collaboration between the agents in order to attain the highest social welfare. Most of the cooperative MARL cases try to maximize the total discounted rewards received from the policies. However, each entity has to make a specific action in order to increase the discounted rewards and there should be some kind of coordination between the agents.

Kaelbling et al. (1996) presented one of the earliest surveys on Reinforcement Learning (RL). The authors defined RL "the problem faced by an agent that learns behavior through trial-and-error interactions with a dynamic environment". Models covered are trading off exploration and exploitation, Markovian decision theory, learning from delayed reinforcement, and others. Giannoccaro and Pontrandolfo (2002) studied the use of

Markovian Decision process and reinforcement learning algorithms to coordinate the inventory decision policies from a supply chain with different players as suppliers, manufacturers, and distributors. Busoniu et al. (2006) presented a new survey based on the different application of multi-agent system and reinforcement learning. The author's objective is to integrate the theory, issues to be addressed and future research directions. Chaharsooghi et al. (2008) study the use of reinforcement learning algorithm in order coordinate ordering policies in a supply chain with multiple levels. The RL algorithm objective is to minimize inventory holding cost in the supply chain.

For this new research question, the problem will be addressed with reinforcement learning algorithms in a multi-agent setting. The goal will be to have proper reinforcement learning algorithm to learn the RFID information-sharing coordination in the supply chain based that enable cost reduction for all the players.

8.3 Approach

Based on the above literature, we present three type of preliminary approaches: Dynamic RFID Information-sharing coordination, Self-Adaptive RFID Information-sharing coordionation and Multi-agent RFID Information-sharing coordination.

We begin with Dynamic RFID Information-sharing coordination. The problem that we face is of a supply chain that at the initial time, it has to choose a specific RFID information-sharing coordination. However, the supply chain does not know what is the optimal RFID information-sharing coordination that is capable to maximize its economic performance. For this chapter, we use the method of reinforcement learning, especially Q-learning algorithm proposed by Watkins (1989). The agent applies an action given a particular state. The agent then evaluates the results of this action based on the immediate reward. In addition, the agent analyzes the delayed rewards, which are the rewards from the future state based on the action chosen. The agent performs this action repeatedly over all the states possible, and learns which action provides the highest reward, based on immediate and delayed reward.

Definition 8.1 (Q-Learning algorithm): let us consider the supply chain as an agent. This agent is testing different discrete, finite set called state based on a set of actions. The state is a controlled Markov process in which the agent is the controller. For our case, the states are the different types of RFID information-sharing coordination available, and the action is the RFID information-sharing coordination chosen from a given state. This means at the step n the agent identify what is the current state $x_n (\in X)$ and then an action is made $a_n (\in \Omega)$. The agent receives a reward r_n in which this reward depends only on the state and action.

The goal of the agent is then to find the optimal policy in which maximizes total discounted expected reward. Discounted rewards, is the reward perceived in the actions of step $n + 1$. As Watkins and Dayan (1992), the algorithm is as follow:

- Define the current state x_n
- Choose and perform an action a_n
- Detect the future state y_n
- Award an immediate reward r_n
- Adjust the Q_{n-1} values in terms of the learning factor α_n such as:

$$Q_n(x,a) = \begin{cases} (1-\alpha_n)Q_{n-1}(x,a) + \alpha_n[r_n + \gamma V_{n-1}(y_n)] & if\ x = x_n and\ a = a_n \\ Q_{n-1}(x,a) & otherwise \end{cases}, \quad \text{Eq. 7.1}$$

where $V_{n-1}(y) \equiv \max b\ \{Q_{n-1}(y,b)\}$.

From the algorithm, there are two parameters that we study. First, given an action a_n at time, this action will be then the future state x_n. Now, the agent have to decide what is the next action a_{n+1}. For this, there is a probability p such that 0 < p < 1. Higher p refers to exploration in which the agent chooses the next action randomly. This is intended to learn from the most possible state-actions scenarios (exploration). However, lower p tends to choose based on the optimal or higher $Q_{n+1}(x,a)$. This case the algorithm will tend to search for the Q-value with the highest rewards (exploitation).

The second parameter is the delayed (discounted) reward γ such that $0 < \gamma < 1$. Higher delayed reward provides more weight the future reward from $Q_{n+1}(x, a)$. By the contrary, lower delayed reward will mostly focus on the immediate reward from the action a_n.

We continue with Self-Adaptive RFID Information-sharing coordination. We developed our self-adaptive algorithm with the use of control theory. For self-adaptive algorithms, it is important to define the dimensions of the system that we are studying. As Cheng et al. (2009) mentioned, the dimensions can be described as modeling, requirements, engineering, and assurance.

Definition 8.2 (Modeling Dimension): modeling dimensions help us define precisely the goals of the system, the changes that occur in the system, the mechanism that the system uses to adapt to these changes, and the desire effect of this adaptation.

<u>Goals</u>

The goals are the objective that the system wants to achieve. For our research, the goal of the system is to remain economically and environmentally viable over changes in the supply chain by the adaptability of RFID coordination. The evolution of the goal is considered static since they will not change over time. The flexibility of the goal is rigid in the sense the system must always seek to have the lower cost and higher returns as possible. The duration of the goal is persistent, this means that the same objective is valid for every period t. The goal is multiple since it considers two objectives: economic and environmental goals. Further, we model these goals as independent.

Table 8.1 Goals Dimensions

Goal Dimension	Value
Evolution	Static
Flexibility	Rigid
Duration	Persistent
Multiplicity	Multiple goals
Dependency	Independent

Change

The change dimensions refer to the supply chain characteristics that varies over time due to internal (e.g., setup cost) or external (e.g., government regulations) forces. This will be the causes of adaptation. The source of the change is internal. Specially, we analyze the changes of production leadtime, collection leadtime, delivery leadtime, capacity of the end-user market, and demand. The frequency of these changes can occur either rare or frequent. In our study, we specify that the system have a change in its characteristics at $t = 1000$. The supply chain system cannot anticipate these changes, therefore is unforeseen.

Table 8.2 Change Dimensions

Change Dimension	Value
Source	Production leadtime, collection leadtime, capacity of the end-user market, and demand
Frequency	Change at $t = 1000$
Anticipation	Unforeseen

Mechanisms

These dimensions define how the system is going to adapt based on the changes presented in the system. For our research, the mechanisms are the five RFID information-sharing coordination. Our type of mechanisms is structural since the RFID technology-supply chain integration is going to adapt. We are modeling the mechanism the most autonomous possible. It is desire to have an adaptive system that identifies and reacts based on some rules. The rules are the part of the algorithm that needs some assistant either from experts or by simulation experiments. Our research defines rules based on our simulation experiments. The adaptation is decentralized since it is distributed across the supply chain. The scope of the system is localized for each entity. Based on the adaptation, each entity will need to adjust its RFID technology-supply chain integration. For the research, we set no leadtime for the adaptation. This means the adaptation occurs instantaneously. The timeliness is guaranteed in the sense that the self-adaptation is reached and completed. The mechanism will react as an even-trigger (i.e., whenever there is a change in the supply chain characteristics).

Table 8.3 Mechanisms Dimensions

Mechanisms Dimension	Value
Type	Structure
Autonomy	Autonomous with knowledge-base from simulation experiments
Organization	Decentralized
Scope	Local
Duration	Instantaneously
Timeliness	Guaranteed
Triggering	Event-Triggering

<u>Effects</u>

The main impacts on the effectiveness on the self-adaptive protocol are on cost and environment improvements. For us, both are critical since companies objectives are to decrease cost and increase environment benefits. The predictability depends on the knowledge base from the simulation experiments, therefore is non-deterministic. Currently, we are not addressing any monetary or system efforts to adjust the RFID integrations. Therefore, the overhead is insignificant. The self-adaptive algorithm is to be considered semi-resilient since it depends on the severity of the changes involved in the supply chain (e.g., natural disaster).

Table 8.4 Effects Dimensions

Effects Dimension	Value
Criticality	Critical
Predictability	Non-deterministic
Overhead	Insignificant
Resilience	Semi-resilient

Definition 8.3 (Requirements Dimension): Requirements dimensions refer to the specification of what needs to be monitor and under what conditions needs the adaptation to occur. We consider important factors that can impact the performance of this green

supply chain. They are production leadtime, collection leadtime, delivery leadtime, capacity of the end-user market, and demand as described in Chapter 3. We can also consider monitoring other factors such as setup cost, holding cost, collection investment, etc. However, we are going to relax these factors in the self-adaptive algorithm. Further, the goal of the system is to remain economically and environmentally viable over volatile changes in the system. Therefore, we monitor total system cost and total returns ordered.

Definition 8.3 (Modeling Dimension): As part of the Engineering dimesion, as Brun et al. (2009) mention, control theory and specially the use of feedback loops are principal elements to engineer self-adaptive systems. Most of the work has been in software system. Our research explorer the use of feedback loops from software system to supply chain applications. In addition, we introduce a Heuristic model to make the proper decision.

This is one of the first proposals that we are aware of that uses Control Theory for self-adaptive algorithms in a green supply chain setting. Below is our self-adaptive algorithm.

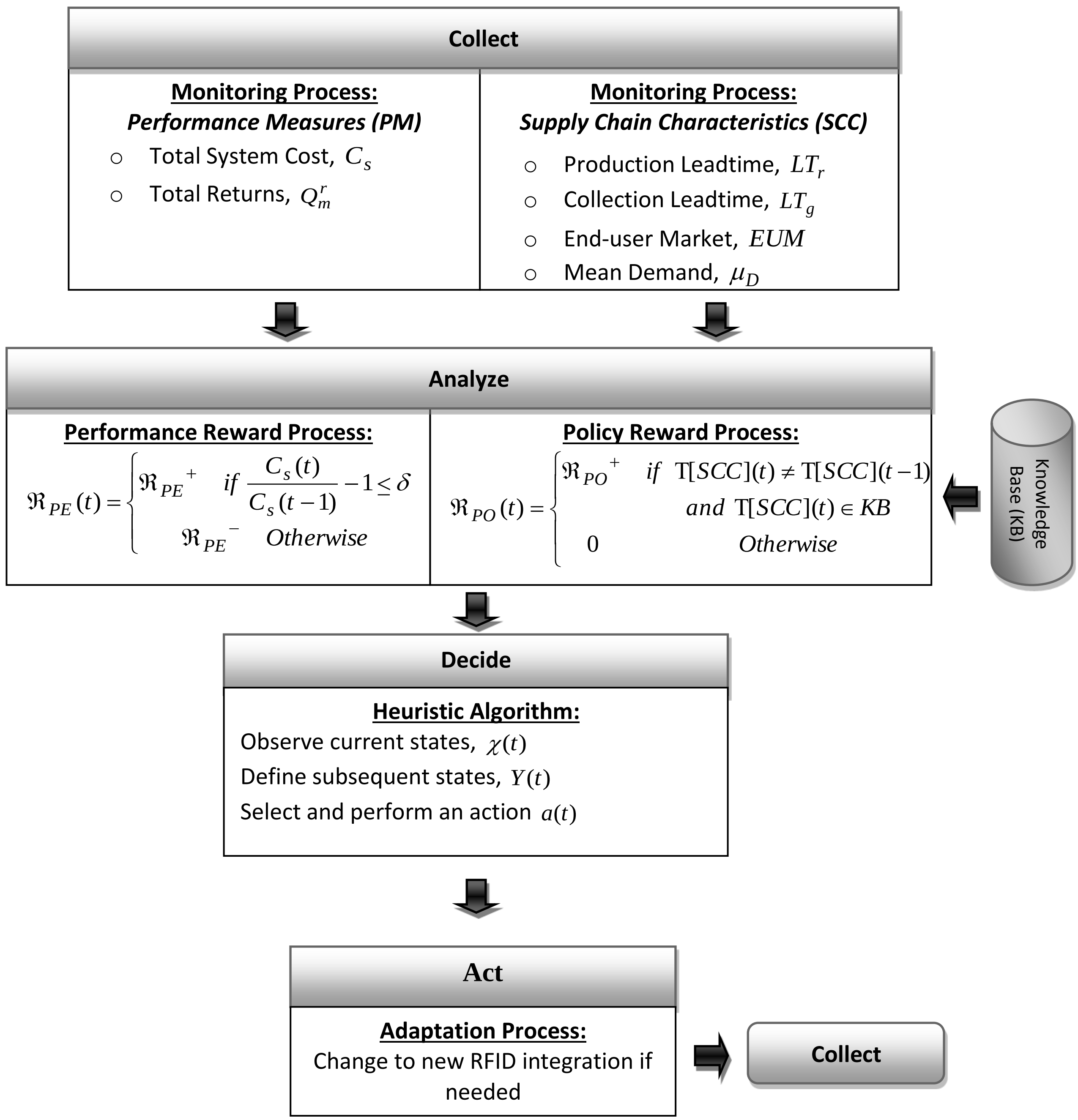

Figure 8.1 Self-Adaptive Algorithm

Collect

The collect phase includes two monitoring processes. There is monitoring process of the performance measures which include the total system cost C_s and the total returns ordered Q_m^r. In addition, there is the monitoring process of the supply chain characteristics. The system monitors different critical factors for the supply chain, in our experiment production leadtime LT_r, collection leadtime LT_g, delivery leadtime LT_m, end-user market EUM, and mean demand μ_D. These two monitoring processes will allow the supply chain to check their performance measures and see if there are any drastic changes to the system.

Analyze

The analyze phase have two processes: the performance reward process and the policy reward process. In the former, the total system cost is evaluate every time t. After $t+1$, we compared the total system cost from time t to $t+1$. If the total system cost decreased over a certain threshold δ, then a positive performance reward $\Re_{PE}{}^{+}$ is given to the current RFID integration. If the total system cost increased over the threshold δ, a negative reward $\Re_{PE}{}^{-}$ is given to the current RFID integration.

The policy reward process compares the data collected from the monitoring process supply chain characteristics, in our research the 5-tuples $\text{T}[SCC]$ and compared it to the Knowledge Base (KB) from the simulation experiments. If there is a change in the supply chain characteristics $\text{T}[SCC](t) \neq \text{T}[SCC](t-1)$ and there is a rule that applies to this change $\text{T}[SCC](t) \in KB$, then a positive policy reward $\Re_{PO}{}^{+}$ is given to the desire RFID integration. Otherwise, no policy reward is given.

Decide

The states χ are the five possible RFID integrations, $\chi \in X$ such that $X \in \{NO, NI, PID, PIU, FI\}$. The current state $\chi(t)$ is the current RFID integration that the supply chain is using. Then, the heuristic process will choose the future state that has the highest total reward $\Re_{\chi}(a) = \Re_{PE}{}^{+} + \Re_{PE}{}^{-} + \Re_{PO}{}^{+}$.

Act

Based on the decision from the previous phase, the supply chain will act and adapt to the integration selected in the decide phase.

Definition 8.4 (Assurance Dimension): And finally, assurance dimesions is the validation of the system and constant monitoring and evaluation of the performances measures.

Now, we proceed the explorartion of Multi-Agent RFID Information-sharing coordionation. Multi-agent Reinforcement Learning can be modeled with Stochastic Games (SG) also known as Markov Games. We can define SG as a tuple *{X, U1, …Un, f, p1, …, pn}*. The variable *n* represents the number of agents in the system. *X* is the discrete environment in the system. *Ui*, is the set of action that an agent *i* can perform. The combination of all the *Ui* from the *n* agents will give us the joint set of actions *U = U1 x U2 x … x Un. f* is the transition probability given an environment *X* at time *t*, performing an action *U*, to be in a new environment *X* at time *t+1, f: X x U x X → [0,1]*. And finally the reward function of the agents which is defined as *pi: X x U x X →, i = 1, …, n.* The state transitions will depend in the results from joint actions of the *n* agents, *T* , . This means that the rewards will depend as well from the joint actions taken from the *n* agents. The overall objective is to maximize the long run return. This can be done through the optimal-action value function (Q-function). Q-function can compute the expected return given a state-action pair based on a given policy *h*. A policy *h* describes the behavior of the agent in order to choose an action based on the state *X*.

8.4 Numerical Experiments

Preliminary Experiment 8-1

We begin the experiments analyzing the reinforcement learning algorithm with the use of Q-learning. Below are the details of the experiment and results.

Design of Experiments

We performed a simulation experiment. The experiment runs 10,000 days with 10 replications. The supply chain structure, parameters and variables are similar to the ones in Chapter 5 and Chapter 6. Related with the reinforcement learning algorithm, the parameters of the Q-Learning algorithm are 0.80 for exploration and 0.80 for delayed reward. We test the Q-Learning algorithm over all the RFID information sharing strategies as mentioned in Definition 6.1.

Numerical Results and Discussions

As we see from Table 8.5, independently from what is the initial state, the optimal policy is to move to the RFID information-sharing coordination with demand information shared. This is supported by the results obtained in the previous chapter. This proposal provides an opportunity to determine what is the optimal RFID policy that is better for a given supply chain (i.e., given each particular run from the simulation experiment). This enables supply chain managers to determine optimal solutions even if they do not know *a priori* the best strategy. Now, we compare the economic performance of the Q-learning policies with the static policies.

Table 8.5 Q-Learning Results

Run	Q11	Q12	Q13	Q14	Q15	Q21	Q22	Q23	Q24	Q25	Q31	Q32	Q33	Q34	Q35	Q41	Q42	Q43	Q44	Q45	Q51	Q52	Q53	Q54	Q55
1	0.45	0.56	0.44	0.71	1.00	0.35	0.14	0.50	0.71	1.00	0.65	0.54	0.73	0.64	1.00	0.81	0.91	1.00	0.96	1.00	0.94	1.00	1.00	1.00	1.00
2	0.49	0.57	0.39	0.74	1.00	0.52	0.64	0.57	0.58	1.00	0.80	0.76	0.87	0.69	1.00	0.93	0.97	0.91	0.92	1.00	0.96	1.00	1.00	1.00	1.00
3	0.45	0.61	0.80	0.76	1.00	0.68	0.59	0.41	0.56	1.00	0.82	0.61	0.52	0.55	1.00	0.82	0.84	0.89	0.87	1.00	0.96	0.96	1.00	1.00	1.00
4	0.36	0.52	0.62	0.67	1.00	0.42	0.46	0.47	0.60	1.00	0.80	1.00	0.52	0.53	1.00	0.86	0.85	0.91	0.89	1.00	0.91	1.00	1.00	1.00	1.00
5	0.25	0.33	0.36	0.48	1.00	0.48	0.52	0.58	0.69	1.00	0.75	0.90	0.83	0.68	1.00	0.93	0.91	0.89	0.96	1.00	1.00	1.00	1.00	1.00	1.00
6	0.61	0.55	0.57	0.53	1.00	0.74	0.41	0.55	0.48	1.00	0.86	0.55	0.66	0.58	1.00	0.81	0.96	0.68	0.91	1.00	1.00	1.00	1.00	1.00	1.00
7	0.38	0.34	0.55	0.65	1.00	0.83	0.52	0.43	0.78	1.00	0.75	0.70	0.60	0.58	1.00	0.91	1.00	0.75	0.91	1.00	0.96	0.96	1.00	1.00	1.00
8	0.33	0.59	0.49	0.70	1.00	0.67	0.57	0.49	0.61	1.00	0.62	0.66	0.79	0.69	1.00	1.00	0.87	0.73	0.91	1.00	1.00	1.00	1.00	1.00	1.00
9	0.33	0.59	0.55	0.82	1.00	0.57	0.39	0.69	0.50	1.00	0.72	0.84	0.59	0.66	1.00	0.84	0.77	0.78	0.87	1.00	1.00	0.96	0.96	1.00	1.00
10	0.31	0.44	0.47	0.62	1.00	0.65	0.60	0.52	0.60	1.00	0.64	0.77	0.53	0.73	1.00	0.78	0.91	0.95	0.89	1.00	1.00	1.00	1.00	1.00	1.00
11	0.32	0.40	0.47	0.73	1.00	0.41	0.44	0.51	0.59	1.00	0.37	0.47	0.59	0.58	1.00	0.99	0.81	0.71	0.82	1.00	1.00	1.00	1.00	1.00	1.00
12	0.28	0.52	0.59	0.75	1.00	0.44	0.15	0.82	0.62	1.00	0.66	0.71	0.73	0.73	1.00	0.70	0.81	0.85	0.96	1.00	1.00	1.00	1.00	1.00	1.00
13	0.34	0.50	0.59	0.70	1.00	0.54	0.54	0.60	0.68	1.00	0.82	0.70	0.55	0.62	1.00	0.87	0.91	0.82	0.91	1.00	0.96	1.00	1.00	1.00	1.00
14	0.37	0.36	0.41	0.71	1.00	0.70	0.60	0.47	0.57	1.00	0.47	0.60	0.52	0.60	1.00	0.93	0.96	0.90	0.84	1.00	0.83	0.91	0.96	1.00	1.00
15	0.48	0.47	0.52	0.47	1.00	0.41	0.75	0.45	0.67	1.00	0.58	0.70	0.62	0.60	1.00	0.85	0.83	0.97	1.00	1.00	1.00	1.00	1.00	1.00	1.00
16	0.55	0.44	0.50	0.55	1.00	0.68	0.57	0.38	0.55	1.00	0.62	0.73	0.54	0.68	1.00	0.76	0.96	0.84	0.89	1.00	0.96	0.96	1.00	1.00	1.00
17	0.39	0.36	0.62	0.62	1.00	0.53	0.52	0.73	0.57	1.00	0.58	0.71	0.55	0.57	1.00	0.77	0.71	0.76	0.87	1.00	0.89	0.96	1.00	1.00	1.00
18	0.50	0.47	0.77	0.83	1.00	0.54	0.52	0.50	0.62	1.00	0.87	0.78	0.65	0.69	1.00	0.89	0.80	0.82	0.96	1.00	0.94	0.96	1.00	1.00	1.00
19	0.44	0.55	0.53	0.64	1.00	0.75	0.59	0.49	0.64	1.00	0.92	0.56	0.46	0.62	1.00	0.80	0.83	0.90	0.96	1.00	0.89	0.96	1.00	1.00	1.00
20	0.43	0.47	0.61	0.70	1.00	0.68	0.50	0.34	0.59	1.00	0.66	0.66	0.51	0.62	1.00	0.71	0.88	0.84	0.96	1.00	0.95	0.93	0.96	1.00	1.00
21	0.35	0.44	0.49	0.62	1.00	0.60	0.60	0.71	0.66	1.00	0.69	0.82	0.60	0.58	1.00	0.92	0.94	0.84	0.80	1.00	0.96	1.00	1.00	1.00	1.00
22	0.30	0.59	0.49	0.61	1.00	0.41	0.42	0.38	0.44	1.00	0.55	0.55	0.56	0.63	1.00	0.92	0.93	0.80	0.89	1.00	0.89	0.96	1.00	1.00	1.00
23	0.42	0.44	0.60	0.53	1.00	0.52	0.44	0.43	0.69	1.00	0.65	0.73	0.75	0.71	1.00	0.90	1.00	0.86	0.69	1.00	0.96	0.96	1.00	1.00	1.00
24	0.37	0.46	0.69	0.51	1.00	0.61	0.58	0.56	0.60	1.00	0.75	0.57	0.59	0.67	1.00	0.96	0.87	0.81	0.91	1.00	0.95	0.96	1.00	1.00	1.00
25	0.33	0.37	0.44	0.72	1.00	0.44	0.64	0.74	0.78	1.00	0.88	0.55	0.65	0.57	1.00	0.74	0.74	0.82	0.78	1.00	0.89	0.93	0.96	1.00	1.00
26	0.25	0.50	0.54	0.78	1.00	0.26	0.23	0.52	0.60	1.00	0.79	0.67	0.66	0.74	1.00	0.80	0.74	0.89	1.00	1.00	1.00	1.00	1.00	1.00	1.00
27	0.22	0.56	0.44	0.53	1.00	0.57	0.51	0.59	0.71	1.00	0.60	0.45	0.73	0.63	1.00	0.93	0.80	0.87	0.87	1.00	0.96	0.91	1.00	1.00	1.00
28	0.28	0.57	0.31	0.60	1.00	0.51	0.72	0.40	0.58	1.00	0.56	0.77	0.74	0.68	1.00	0.99	0.88	0.84	0.91	1.00	1.00	1.00	1.00	1.00	1.00
29	0.23	0.55	0.28	0.74	1.00	0.48	0.57	0.53	0.62	1.00	0.66	0.72	0.72	0.60	1.00	0.92	0.73	0.91	0.87	1.00	1.00	1.00	1.00	1.00	1.00
30	0.45	0.75	0.54	0.64	1.00	0.54	0.43	0.57	0.61	1.00	0.79	0.71	0.75	0.59	1.00	0.96	0.88	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00
31	0.27	0.48	0.66	0.69	1.00	0.49	0.37	0.38	0.71	1.00	0.78	0.85	0.86	0.62	1.00	1.00	0.74	0.87	0.96	1.00	0.96	1.00	1.00	1.00	1.00
32	0.55	0.58	0.45	0.74	1.00	0.41	0.34	0.49	0.51	1.00	0.65	0.68	0.74	0.61	1.00	0.91	0.91	0.58	0.78	1.00	0.96	0.96	1.00	1.00	1.00

Table 8.6 Dynamic Policy with NO RFID as the Initial Strategy

Run	Strategy for Static: NO	Strategy for Q-Learning: Follow Q Policy	Δ %
	Total System Cost (Static)	Total System Cost (Dynamic)	
1	11,507,737	8,547,052	-26%
2	17,276,250	13,399,479	-22%
3	11,470,785	8,602,007	-25%
4	17,100,652	13,459,810	-21%
5	11,299,699	8,554,310	-24%
6	17,431,901	13,537,443	-22%
7	11,241,629	8,586,888	-24%
8	17,242,544	13,597,188	-21%
9	11,499,889	8,602,437	-25%
10	17,286,601	13,311,767	-23%
11	11,527,041	8,677,681	-25%
12	17,192,678	13,399,295	-22%
13	11,425,676	8,579,858	-25%
14	17,473,216	13,369,509	-23%
15	11,358,262	8,620,954	-24%
16	17,360,960	13,431,119	-23%
17	11,359,407	8,596,562	-24%
18	17,260,791	13,491,630	-22%
19	11,315,234	8,691,499	-23%
20	17,061,084	13,601,108	-20%
21	11,184,956	8,666,892	-23%
22	17,456,964	13,661,173	-22%
23	11,093,462	8,688,365	-22%
24	17,282,548	13,661,009	-21%
25	11,401,171	8,660,054	-24%
26	17,232,705	13,407,510	-22%
27	11,375,748	8,702,199	-24%
28	17,123,906	13,477,167	-21%
29	11,321,035	8,631,930	-24%
30	17,525,615	13,559,230	-23%
31	11,215,353	8,705,291	-22%
32	17,425,062	13,676,120	-22%

From the results, 100% of the runs the dynamics strategy performed better than the static strategy. This means that the Q-Learning algorithm successfully provide the optimal value in all the cases.

Table 8.7 Dynamic Policy with RFID NI as the Initial Strategy

Run	Strategy for Static: NI	Strategy for Q-Learning: Follow Q Policy	Δ %
	Total System Cost (Static)	Total System Cost (Dynamic)	
1	9,359,118	8,547,052	-9%
2	14,198,383	13,399,479	-6%
3	9,475,064	8,602,007	-9%
4	14,389,783	13,459,810	-6%
5	9,581,044	8,554,310	-11%
6	14,461,048	13,537,443	-6%
7	9,614,174	8,586,888	-11%
8	14,574,860	13,597,188	-7%
9	8,858,950	8,602,437	-3%
10	13,226,305	13,311,767	1%
11	8,872,462	8,677,681	-2%
12	13,347,353	13,399,295	0%
13	8,903,435	8,579,858	-4%
14	13,542,772	13,369,509	-1%
15	8,980,932	8,620,954	-4%
16	13,552,750	13,431,119	-1%
17	9,459,254	8,596,562	-9%
18	14,278,993	13,491,630	-6%
19	9,621,931	8,691,499	-10%
20	14,420,931	13,601,108	-6%
21	9,567,847	8,666,892	-9%
22	14,475,208	13,661,173	-6%
23	9,660,949	8,688,365	-10%
24	14,681,928	13,661,009	-7%
25	8,845,476	8,660,054	-2%
26	13,301,897	13,407,510	1%
27	8,909,434	8,702,199	-2%
28	13,319,003	13,477,167	1%
29	8,926,418	8,631,930	-3%
30	13,548,891	13,559,230	0%
31	9,018,091	8,705,291	-3%
32	13,625,524	13,676,120	0%

In this case, with the initial state as NI, 81% of the runs the dynamic strategy performed better than the static strategy.

Table 8.8 Dynamic Policy with RFID PID as the Initial Strategy

Run	Strategy for Static: PID	Strategy for Q-Learning: Follow Q Policy	Δ %
	Total System Cost (Static)	Total System Cost (Dynamic)	
1	9,211,967	8,547,052	-7%
2	13,649,314	13,399,479	-2%
3	9,281,577	8,602,007	-7%
4	13,698,839	13,459,810	-2%
5	9,206,662	8,554,310	-7%
6	13,668,747	13,537,443	-1%
7	9,278,122	8,586,888	-7%
8	13,750,738	13,597,188	-1%
9	8,741,244	8,602,437	-2%
10	12,870,546	13,311,767	3%
11	8,747,536	8,677,681	-1%
12	12,938,278	13,399,295	4%
13	8,695,494	8,579,858	-1%
14	12,890,764	13,369,509	4%
15	8,745,398	8,620,954	-1%
16	12,996,218	13,431,119	3%
17	9,290,868	8,596,562	-7%
18	13,777,118	13,491,630	-2%
19	9,342,945	8,691,499	-7%
20	13,817,144	13,601,108	-2%
21	9,320,954	8,666,892	-7%
22	13,773,264	13,661,173	-1%
23	9,369,724	8,688,365	-7%
24	13,899,507	13,661,009	-2%
25	8,753,154	8,660,054	-1%
26	12,984,809	13,407,510	3%
27	8,786,693	8,702,199	-1%
28	13,009,231	13,477,167	4%
29	8,755,100	8,631,930	-1%
30	13,048,183	13,559,230	4%
31	8,819,332	8,705,291	-1%
32	13,079,860	13,676,120	5%

The table 8.9 shows that when the initial strategy is PID, there are 75% cases in which the dynamic strategy is better than the static strategy. We can see that PID is a good RFID strategy since it provides 25% of the cases better results than RFID Full-Integrated.

Table 8.9 Dynamic Policy with RFID PIU as the Initial Strategy

Run	Strategy for Static: PIU	Strategy for Q-Learning: Follow Q Policy	Δ %
	Total System Cost (Static)	Total System Cost (Dynamic)	
1	10,465,807	8,547,052	-18%
2	15,497,314	13,399,479	-14%
3	11,308,361	8,602,007	-24%
4	16,445,665	13,459,810	-18%
5	10,509,355	8,554,310	-19%
6	15,681,596	13,537,443	-14%
7	11,304,108	8,586,888	-24%
8	16,562,282	13,597,188	-18%
9	10,398,959	8,602,437	-17%
10	15,336,229	13,311,767	-13%
11	11,301,842	8,677,681	-23%
12	16,194,518	13,399,295	-17%
13	10,422,604	8,579,858	-18%
14	15,554,859	13,369,509	-14%
15	11,284,884	8,620,954	-24%
16	16,399,567	13,431,119	-18%
17	10,525,079	8,596,562	-18%
18	15,616,118	13,491,630	-14%
19	11,389,415	8,691,499	-24%
20	16,510,531	13,601,108	-18%
21	10,498,481	8,666,892	-17%
22	15,836,099	13,661,173	-14%
23	11,382,637	8,688,365	-24%
24	16,707,881	13,661,009	-18%
25	10,457,967	8,660,054	-17%
26	15,383,685	13,407,510	-13%
27	11,391,263	8,702,199	-24%
28	16,280,609	13,477,167	-17%
29	10,526,173	8,631,930	-18%
30	15,620,794	13,559,230	-13%
31	11,426,915	8,705,291	-24%
32	16,502,958	13,676,120	-17%

If the system initiates with PIU, then 100% of the cases the dynamic strategy performed better than static. The Q-Learning algorithm found the optimal strategy in all the runs.

Preliminary Experiment 8-2

Design of Experiments

Now, we explorer the impact of two important parameters in Q-Learning: exploration and delayed reward parameters. For this, we present the average of the 32 runs. Table 8.10 shows the Average Q-Matrix with p = 0.20 and γ = 0.80.

Results and Discussions

Table 8.10 Exploration (0.20) and Delayed Reward (0.80) Experiments

Avg. Q-Matrix	NO	NI	PID	PIU	FI
NO	1.0410	1.0161	1.0050	1.0122	7.9588
NI	1.0770	1.1383	1.3220	1.0164	2.1615
PID	1.0045	1.2093	1.0413	1.1672	4.3645
PIU	1.0180	1.0372	1.1253	1.0708	9.4159
FI	1.5136	2.0768	2.0096	1.8840	157.6164
Total Average	1.1308	1.2955	1.3007	1.2301	36.3034

Table 8.11 Static vs Dynamic RFID Strategies (p = 0.20 and γ = 0.80)

Analysis	RFID Strategies from Best to Worst Economic Performance				
Static	FI	PID	NI	PIU	NO
Dynamic	FI	PID	NI	PIU	NO
Match Optimality	Yes	Yes	Yes	Yes	Yes
Total Average Q-Value	36.3034	1.3007	1.2955	1.2301	1.1308

From Table 8.10, we see that FI provides the highest average Q-value from the Q-matrix. These reaffirm the results that higher integration under the RFID Full-Integrated coordination as well as the PID provides the highest economic benefit for the system even in dynamic environments. In addition, the order of Q-values from high to low is congruent to the results obtained in the static scenarios as we see in Table 8.11. In addition, this result proves that the Q-Learning algorithm is an efficient method to determine the optimal RFID information-sharing strategy. Related with the parameters, since p = 0.20, we are doing exploitation. From the results, exploitation provides congruent results to the findings from static scenario due to the tendency to maximize Q-values. Also, γ = 0.80 means that there is a high weight on delayed rewards. High delayed reward factor provide good results since the tendency is to move towards the best integration possible in the long-run.

Preliminary Experiment 8-3

Design of Experiments

For this experiment, we present the average of the 32 runs. We use p = 0.80 and γ = 0.80. Table 8.12 shows the Average Q-Matrix with p = 0.80 and γ = 0.80.

Results and Discussions

Table 8.12 Exploration (0.80) and Delayed Reward (0.80) Experiments

Avg. Q-Matrix	NO	NI	PID	PIU	FI
NO	1.2545	1.1669	1.1247	1.1459	2.2023
NI	1.1039	1.5949	1.1619	1.1377	1.4989
PID	1.1622	1.2343	1.9229	1.2102	1.4191
PIU	1.2165	1.1422	1.2187	1.2112	1.5657
FI	1.7481	1.6508	1.5708	1.3822	2.1149
Total Average	1.2970	1.3578	1.3998	1.2174	1.7602

Table 8.13 Static vs Dynamic RFID Strategies (p = 0.80 and γ = 0.80)

Analysis	RFID Strategies from Best to Worst Economic Performance				
Static	FI	PID	NI	PIU	NO
Dynamic	FI	PID	NI	NO	PIU
Match Optimality	Yes	Yes	Yes	No	No
Total Average Q-Value	1.7602	1.3998	1.3578	1.2970	1.2174

Table 8.12 shows the results with tendency for more exploration (p = 0.80). Overall, the Top 3 best strategies still are the same congruent with the Static Scenario: FI, PID, NI. However, there are cases in which the FI does not have the highest Q-value. This can be confirmed in Table 8.13. Since we are exploring more the options, then there is a tendency to test more Q-values but in contrast bypassing the optimal value. High delayed reward (p = 0.80) still provide good results.

Preliminary Experiment 8-4

Design of Experiments

For this experiment, we present the average of the 32 runs. We use p = 0.20 and γ = 0.20. Table 8.14 shows the Average Q-Matrix with p = 0.20 and γ = 0.20.

Results and Discussions

Table 8.14 Exploration (0.20) and Delayed Reward (0.20) Experiments

Avg. Q-Matrix	NO	NI	PID	PIU	FI
NO	1.0034	1.0033	1.0013	1.0016	1.2504
NI	1.0019	1.0149	1.0109	1.0023	1.0610
PID	1.0008	1.0082	1.0036	1.0078	1.0629
PIU	1.0030	1.0061	1.0035	1.0110	1.1071
FI	1.0609	1.0802	1.0507	1.0761	2.8865
Total Average	1.0140	1.0225	1.0140	1.0198	1.4736

Table 8.15 Static vs Dynamic RFID Strategies (p = 0.20 and γ = 0.20)

Analysis	RFID Strategies from Best to Worst Economic Performance				
Static	FI	PID	NI	PIU	NO
Dynamic	FI	NI	PIU	PID	NO
Match Optimality	Yes	No	No	No	No
Total Average Q-Value	1.7602	1.3998	1.3578	1.2970	1.2174

In this experiment, the order of the best RFID coordination is different from the Static scenario. With a lower delayed reward γ = 0.20, the Q-value distance itself from the optimal Q-value. This result is important because it provides the notion of "preparedness". Since higher γ provides delayed reward for future actions, then it means that Full-Integrated and Partial-Integrated Downstream are more prepare to continue increasing performance even under dynamic changes in the system. If we consider just immediate reward, we might choose other coordination that are not the optimal for the long-run.

Preliminary Experiment 8-5

Design of Experiments

For this experiment, we present the average of the 32 runs. We use p = 0.80 and γ = 0.20. Table 8.16 shows the Average Q-Matrix with p = 0.80 and γ = 0.20.

Results and Discussions

Table 8.16 Exploration (0.80) and Delayed Reward (0.20) Experiments

Avg. Q-Matrix	NO	NI	PID	PIU	FI
NO	1.0304	1.0296	1.0199	1.0269	1.2479
NI	1.0167	1.0612	1.0322	1.0232	1.0584
PID	1.0256	1.0447	1.0764	1.0378	1.0502
PIU	1.0309	1.0248	1.0391	1.0401	1.0649
FI	1.1104	1.1107	1.0999	1.0673	1.1703
Total Average	1.0428	1.0542	1.0535	1.0391	1.1183

Table 8.17 Static vs Dynamic RFID Strategies (p = 0.80 and γ = 0.20)

Analysis	RFID Strategies from Best to Worst Economic Performance				
Static	FI	PID	NI	PIU	NO
Dynamic	FI	NI	PID	NO	PIU
Match Optimality	Yes	No	No	No	No
Total Average Q-Value	1.1183	1.0542	1.0535	1.0428	1.0391

This experiment provides the worst performance. Exploration (p = 0.80) and low delayed reward (γ = 0.20) combined, provide the worst case since it distance itself from the optimal values from the Static Experiment.

Preliminary Experiment 8-6

Now, we address the concept of self-adaptive protocols from control theory. In previous sections, we developed an algorithm that enables the system to adapt over changes in the supply chain characteristics. Now, in this section we provide the outcomes of the self-adaptive algorithm. First, we have to develop our knowledge base for our self-adaptive algorithm, especially for the analyze decision in the policy reward process. For this, we search for the minimum value in all the runs from our simulations experiments and identify which integrations was it. Figure 6.1 shows us the results.

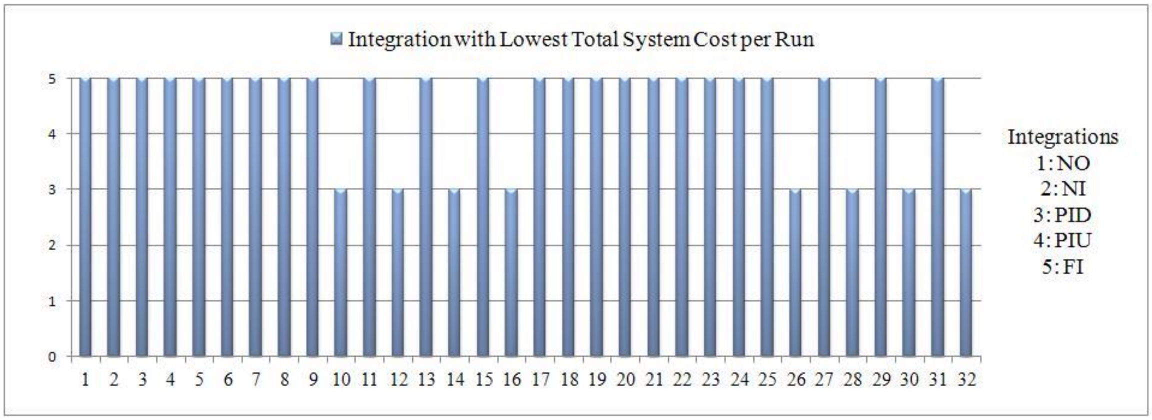

Figure 8.2 Integrations with the Lowest Total System Cost per Run

Figure 8.2 shows that 75% FI and 25% PID provided the lowest total cost from the 32 runs. We have defined the best strategies over the specific runs. Now, we have to define over the 25% PID cases, what were the supply chain characteristics and find if there is a pattern or a rule.

From data mining techniques, we used association rule and found that when mean demand is high and there is a slow leadtime delivery, it is preferred to use PID. Otherwise, use FI. Below is the definition of the rule obtained from our simulation experiment.

$$Knowledge\ Base\ (KB) = \begin{cases} Use\ PID & if\ \ \mu_D \Rightarrow high\ and\ LT_m \Rightarrow high \\ Use\ FI & Otherwise \end{cases}$$

Now that we have our knowledge base (KB) from the simulation experiment, we are going to perform four tests to see if the system improves its performance with the use of the self-adaptive algorithm. We performed four test in which at $t = 0$ there is an initial supply chain characteristic (i.e., $\mathrm{T}[SCC](t = 0))$. Then, at $t = 365$, the system will suffer a change on the supply chain characteristics. In the cases without self-adaptive (SA) algorithm, the system will change at time $t = 365$, but there is no algorithm to dynamically adapt to these supply chain changes. In the case with SA, the system will change at time $t = 365$ and the SA algorithm will be active. The performance reward process is evaluated every time 365 days, and the policy reward process is activated if a change in the system is made. This means the algorithm will collect, analyze, decide, and act in order to remain economically and environmental viable. Figure 8.3 and Figure 8.4 show the results in terms of the environmental and economic performance, respectively.

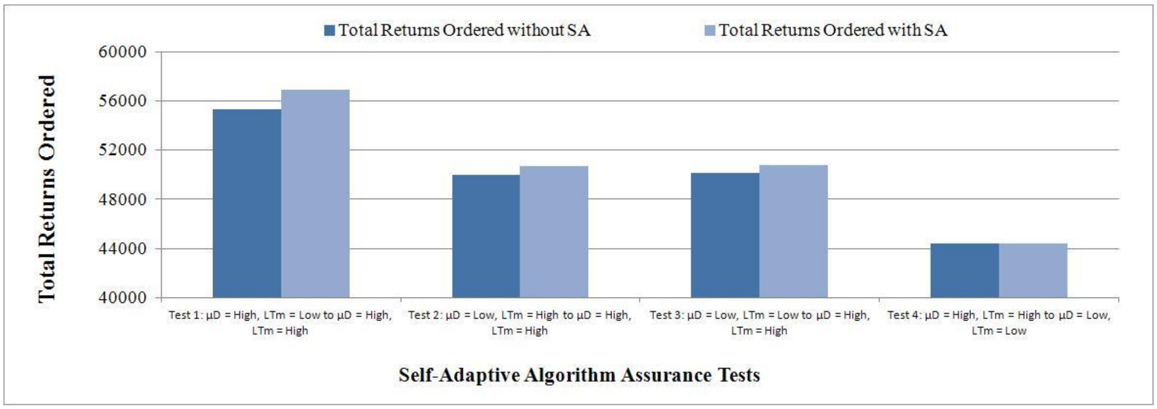

Figure 8.3 Environmental Self-Adaptive Algorithm Assurance Tests

As Figure 8.3 shows, the self-adaptive algorithm has the capability to improve environmental performance over systems with no self-adaptive algorithms. If drastic changes occur to the supply chain characteristics, the system will be able to collect, analyze, decide, and act appropriately to adapt to a new integration.

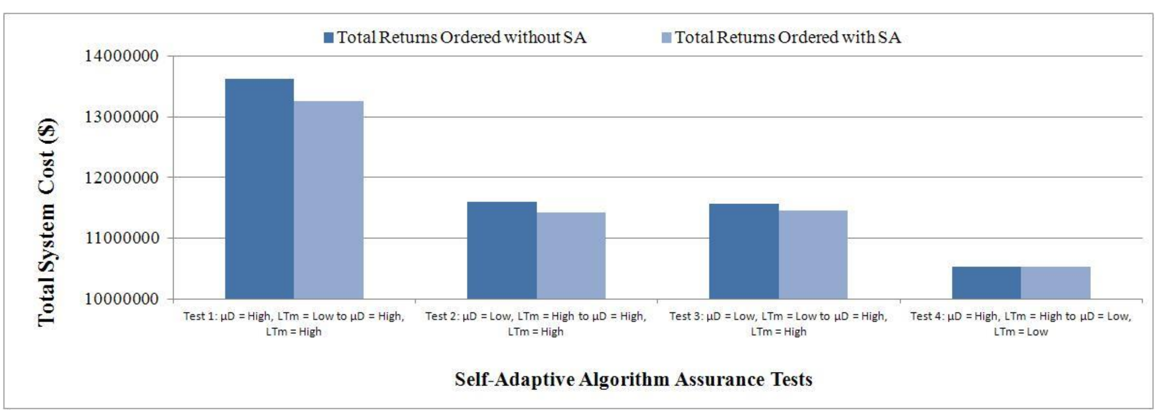

Figure 8.4 Economic Self-Adaptive Algorithm Assurance Tests

Figure 8.4 shows us than on every test performed, the supply chain with the self-adaptive algorithm performed better or at least similar than the supply chain without the self-adaptive algorithm. For example, 2.70%, 1.55%, 0.90%, and 0.00% where the changes from the SA than without SA case. These tests demonstrate that the SA algorithm proposed is capable of detecting the necessary measurements and factors. In addition, the SA algorithm assigned performance and policy rewards to the entire time horizon. Further, based on the total reward given, the algorithm adjusts its current integration state and adapt to the desire integration which has the highest total reward.

Preliminary Experiment 8-7

This section presents the results from the multi-agent reinforcement learning algorithm. For the sample space, each player can choose NO RFID (Action 1), RFID Nonintegrated (Action 2), and RFID Full-Integrated (Action 3). Below are the combinations that provide economic improvements for all players in each run. We present the combinations of actions such that $Amgr$, where the first index refers to the action taken from the manufacturer, the second index refers to the action taken from the recycled-material supplier, and the third index refers to the action taken from the raw-material supplier. In run #1 for example, there are three possible combinations in which the players can achieve economic improvements. The combinations are A132, A332, and A221.

Table 8.18 Multi-Agent Reinforcement Learning Results

Run	Actions which allow cooperation (cost reduction for all players)		
1	A132	A332	A221
2	A132	A332	A121
3	A132	A332	A232
4	A132	A332	A312
5	A132	A332	A121
6	A132	A332	
7	A132	A332	A222
8	A132	A332	A121
9	A132	A332	A112
10	A132	A332	A111
11	A132	A332	A321
12	A132	A332	A231
13	A132	A332	A322
14	A132	A332	A112
15	A132	A332	A111
16	A132	A332	A331
17	A132	A332	A222
18	A132	A332	A222
19	A132	A332	A112
20	A132	A332	A322
21	A132	A332	A211
22	A132	A332	A121
23	A132	A332	A121
24	A132	A332	A221
25	A132	A332	A231
26	A132	A332	A331
27	A132	A332	A232
28	A132	A332	A331
29	A132	A332	A331
30	A132	A332	A322
31	A132	A332	A212
32	A132	A332	A331

From Table 8.18, we can see the actions that enable collaboration in a decentralized scenario with multiple agents. Actions A132 and A332 are consistently providing benefits for the three entities.

8.5 Summary

Supply chain managements nowadays is been presented with new business scenarios where the structure of the supply chain have to change in order to remain profitable. This is the case due to many changes in the economic landscape such as competition, customer behavior, oil price, and even natural disasters. With the inclusion of reverse logistics, this complexity aggravates even more. For this reason, managers has to now under their current state or scenario as shown in Chapter 4-6, what are the possible alternative and which one of them provide their highest return on the investment if there is a huge change in the supply chain. More importantly, how can the companies manage the performance of the system. We have provided an analysis of the dynamic policies that can be implemented to change the RFID information-sharing coordination through reinforcement learning (i.e., Q-learning). The results shows that RFID Full-Integrated is the primary option independently of what initial state the supply chain is given our design of experiment. Furthermore, for new settings, this learning model has proven in the experiment to attain the optimal value.

In addition, we study in average the impact of exploration and delayed reward. From the results, exploitation and high delayed reward provided the closes results to the optimal value compared with the Static scenario. Exploration compared with exploration defined a higher Q-value for the optimal or preferred RFID information sharing strategies. With the experiment, we confirm the trade-off of exploration. Further, higher delayed reward provide the notion of preparedness in the sense that RFID Full-Integrated and RFID Partial-Integrated Downstream are able to attend higher results over the long-run compared to other scenarios that provide high weight on immediate rewards.

Apart from the reinforcement learning, we study how the supply chain can adapt its RFID coordination if there is a drastic change in the supply chain. Nowadays, supply chain is affected by various factors such as demand fluctuation, competition, and even natural disasters. For these reasons, we developed a self-adaptive algorithm with the use of feedback loops. The system is able to collect performance measures and supply chain characteristics, analyze current RFID integrations and performance, decide the appropriate RFID integration, and adapt if it is necessary. We tested our algorithm on several scenarios an whenever there was a change, the system with the self-adaptive algorithm performed better or at least equal than the system without the algorithm. This means that the system is more reliable and flexible over volatile changes in the supply chain.

Finally, we explore the scenario where choose individually their RFID coordination. To achieve this, multi-agent reinforcement learning provided us the optimal combinations that allow an increase in the economic performance measures for all the entities. This study provides an overview of the decision where each entity has its own RFID information sharing strategy. This experiment increases the notion of collaboration and provides new venues for future research.

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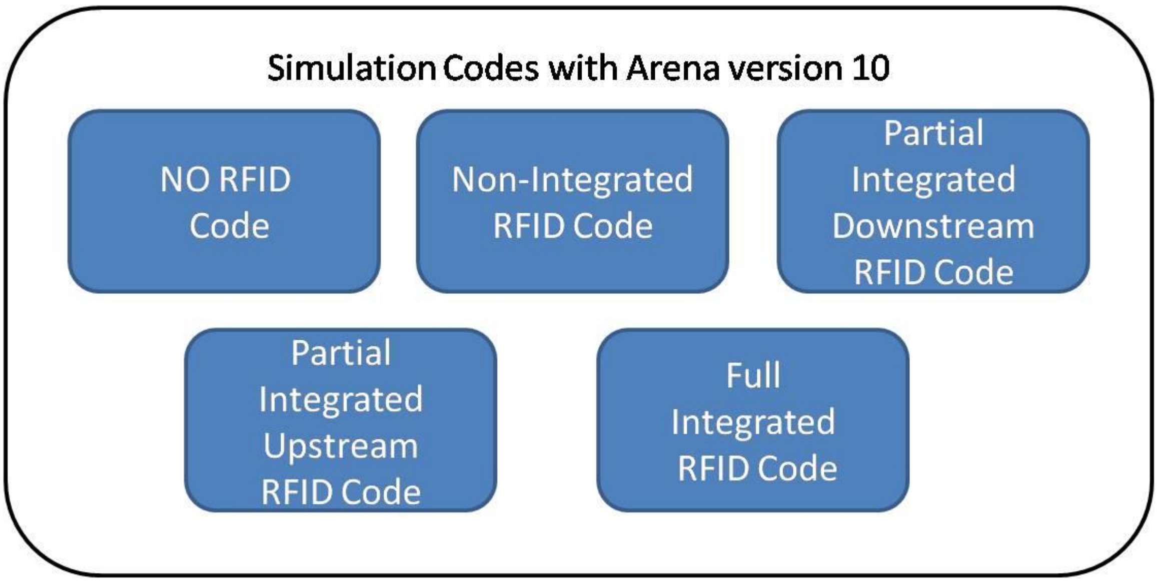
APPENDIX

APPENDIX

Simulation Modeling

We compare five different RFID configuration-coordination scenarios. For each coordination, a simulation experiment is conducted. We use Arena Software version 10. The figure below shows an illustration of the higher modeling of our simulation codes.



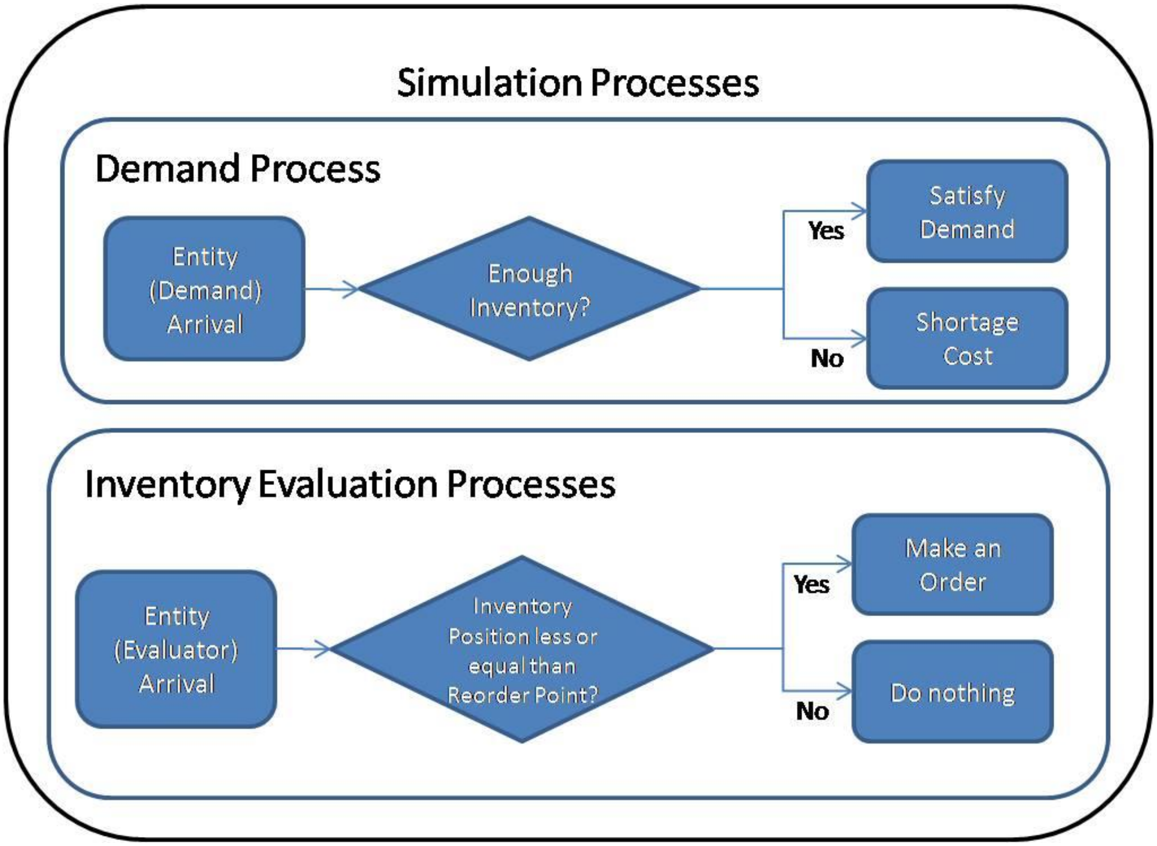
Appendix Figure 1 Simulation Codes

For each simulation code, we have the following Arena Software structure in terms of processes and elements. First, we have a demand process. The demand process begins with an arrival of demand every interrarrival time. Then, the assign block from Arena enable us to determine if there is enough serviceable inventory to satisfy demand. If there is enough serviceable inventory, then demand is served and serviceable inventory is reduced. Otherwise, there would be a shortage cost for the manufacturer.

The second process is the manufacturer's inventory evaluation. The process begins with entities entering the process every time evaluation interval. The assign options with Arena enable us to model the inventory evaluation from the manufacturer where the inventory position X is compared with the reorder point. If the inventory position is below or equal to the reorder point, then a Q order is placed to the suppliers. Here, we check if there is enough inventory on the recycled-material supplier side. If there are enough returns, then the manufacturer orders to the recycled-material suppliers; otherwise, the manufacturer orders to the raw-material supplier. Leadtime delivery is modeled and manufacturer receives inventory.

The third process is the recycled-material's inventory evaluation. Similar to the manufacturer, the process begins with entities arriving at every time evaluation interval. The inventory position is evaluated with the reorder point. If the inventory position is below or equal to the reorder point, a collection order is executed based on the returns formulation from section 3.1.1.2. Recall that here the recycled-material will obtain its material from the end-user market which is stochastic.

Finally, the fourth process is the raw-material supplier's inventory evaluation. The entities arrive and perform an evaluation every time interval. A production order is placed if the inventory position is below or equals its reorder point. The raw-material supplier seeks for its material from the environment. The figure below shows an example of the modeling structure for the four processes.

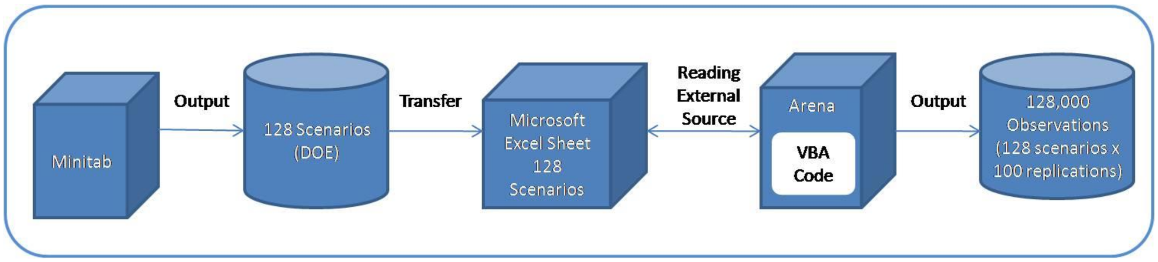


Appendix Figure 2 Simulation Processes – Basic

Appendix Table 1 Simulation Elements

Element	Number of Items
Entities	7
Attributes	11
Variables	82
Expression	30
Output	26

In order to include the 128 scenarios from the Design of Experiment into the Arena Code, we programmed a Visual Basic Code capable of reading the 128 scenarios from an excel file and replicate the run 100 times for each of the simulation code. For the entire experiment, we have 12,800 observations per code x 5 simulation code = 64,000 observations. Figure below shows a representation of the Minitab, Visual Basic Code, and Arena Software.



Appendix Figure 3 Minitab, VBA Code, and Arena Relations

VITA

VITA

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