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A Framework for Assessing the Value of RFID Implementation by Tier-One Suppliers to Major Retailers

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Abstract

Radio frequency identification (RFID) is a rapidly evolving technology for automatic identification and data capture of products. One of the barriers to the adoption of RFID by organizations is difficulty in assessing the potential return on investment (ROI). Much of the research and analyses to date of ROI in implementing RFID technology have focused on the benefits to the retailer. There is a lack of a good understanding of the impact of RFID at upper echelons of the supply chain. In this paper, we present a framework and models for assessing the value of RFID implementation by tier-one suppliers to major retailers. We also discuss our real-life application of this framework to one of Wal-Mart's top 100 suppliers.

Key words: RFID, business case, ROI model

1 Introduction

Radio frequency identification (RFID) is a rapidly evolving technology for automatic identification and data capture of products. RFID is poised to fundamentally change the way companies in a supply chain track, trace and manage assets. This will have a major impact on manufacturing, transportation, distribution and retail industries.

One of the barriers to the adoption of RFID by organizations is difficulty in assessing the potential return on investment (ROI). Much of the research and analyses (such as in [6] and [15]) of ROI in implementing RFID technology have focused on the benefits to the retailer. There is a lack of a good understanding of the impact of RFID at upper echelons of the supply chain. RFID technology can greatly impact the entire supply chain, affecting the retailers and the suppliers that manufacture and distribute goods for them.

The focus of this paper is on providing a comprehensive framework for assessing the benefits of RFID implementation to tier-one suppliers (including their manufacturing and distribution operations). For tier-one suppliers, RFID can offer five primary areas of benefit: lower operating costs, increased revenue, reduced inventory capital cost, lower overhead costs, and lead time reduction (Figure 1).

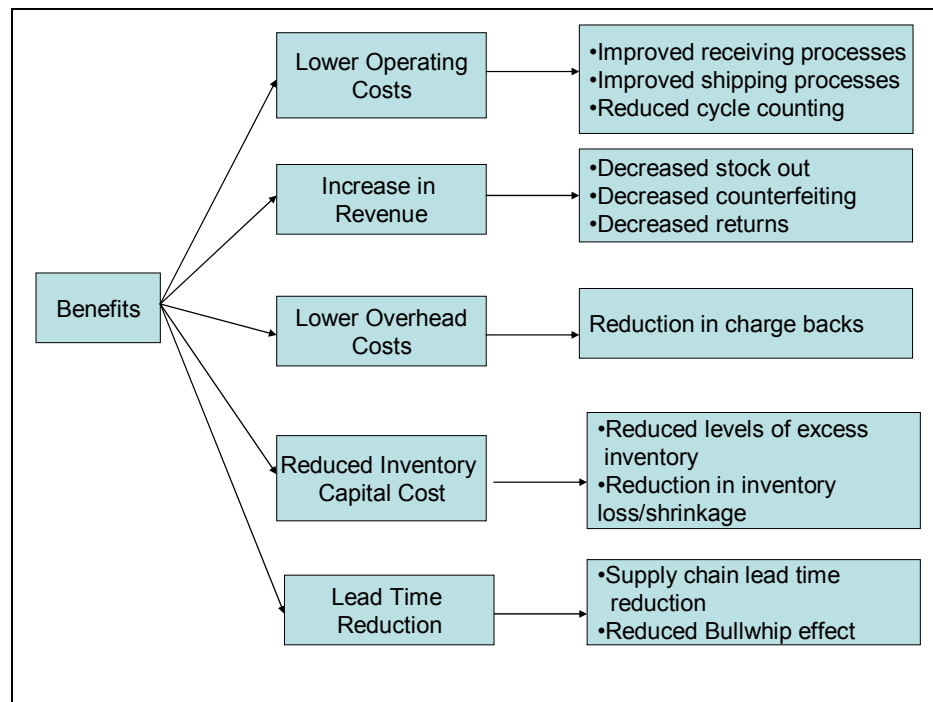


Figure 1: Primary Areas of Benefit to Tier-One Suppliers

RFID can enable increased efficiencies in operations which can result in lower operating costs. For example, the use of RFID within a supplier's distribution center enables a reduction in the number of incorrect manual counts, unreported stock loss, mislabeling, and inaccessible/misplaced inventory. By reducing the number of internal discrepancies, the receiving and shipping processes can be improved and the cycle counting process can be reduced or even eliminated.

An increase in revenue to the tier-one supplier can result through reduction in stock out, counterfeiting, and return incidents. At the retailer level, stocks outs occur due to cascading discrepancies upstream and unanticipated demand. RFID enables increased visibility and real-time information sharing in the supply chain and can thereby help reduce the number of stock outs that occur at the retail store due to inaccurate inventory data at the retailer level and further upstream. RFID can potentially detect irregular components entering the supply chain, catching and reducing the number of counterfeited items. Returned items can be traced by RFID and analyzed to prevent future incidents of returns in the future, saving the manufacturer the cost of potential returned items.

Overhead costs related to dispute resolution, specifically charge backs, is another area that RFID can impact and potentially improve. Charge backs create non-value added activities for both the supplier and the retailer. RFID can reduce the number and/or probability of charge back penalties through improved accuracy and visibility of inventory data throughout the supply chain processes.

A significant opportunity to reduce costs is in inventory capital. RFID allows inventory capital costs to be decreased by reducing the excess inventory or safety stock levels (while maintaining service levels) and also reducing inventory loss/shrinkage. Some causes of excess inventory and inventory loss/shrinkage that can be corrected by RFID are administrative errors, internal and external theft, and receiving errors.

RFID can improve lead time management at the supplier's factory and distribution center through enhanced visibility of levels of inventory and customer demands, improved internal operations, and reduction in the well-known Bullwhip effect [10]. Lead time reduction in turn helps reduce costs while improving the supplier's ability to meet demand.

The contribution of our research and this paper is that we have developed a systematic framework and a set of models for assessing the value of RFID implementation by tier-one suppliers to major retailers. Further we have verified and validated our framework and models for RFID impact assessment by applying it to one of Wal-Mart's top 100 suppliers. The models that we have developed for tier-one suppliers are readily adaptable to assess the value of RFID to upper echelons of the supply chain.

The rest of this paper is organized as follows. Section 2 presents a review of literature pertaining to RFID and supply chain dynamics. Section 3 provides an overview of our framework. Sections 4 – 8 discuss each of the benefit areas and associated models. Section 9 discusses the real-world industry application of our framework. The paper concludes with a summary in Section 10.

2 Literature Review

There is a large body of research literature pertaining to supply chain dynamics (see [19] for a good overview). In the context of our work, prior research on the effects of information accuracy, sharing, and visibility on supply chain performance are particularly relevant and are briefly reviewed below. Some recent research on RFID impact on supply chain management is also reviewed.

In [13], there is a discussion of how supply chain performance is dependent on information flow and connectivity between five business systems, namely marketing system, engineering system, manufacturing system, logistics system, and management system. Further, it provides a set of guiding principles for reducing demand uncertainty across the supply chain through improved information sharing and visibility.

[11] examines how RFID can improve supply chain performance, specifically through inventory reduction and service level improvement. Through use of discrete event simulation models and hypothetical data, they illustrate the potential impact of RFID-enabled inventory accuracy, shelf replenishment policies, and inventory visibility on the inventory profile, inventory shortage/overage, and costs. One of the key benefits of RFID that their simulations highlight is the ability to replenish the retail store shelves more often and at the right time, resulting in reduced inventory at the store as well as reduced probability of lost sales. By simulating the impact of visibility of inventory data between a retailer and its supplier, they show that a supplier can significantly reduce its inventory level in the distribution center while entirely eliminating backorders.

In [20], researchers have studied the impact that different levels of detailed information have on the quality of results while conducting a supply chain simulation. The implication of their findings to RFID application in supply chains is that the higher granularity of information sharing made possible by RFID across the supply chain will help improve the quality of supply chain management decisions. The impact of real time data is also discussed in [3].

A RFID based framework for "improving visibility of information in supply chains by reducing the delays in information flow" is provided in [7]. Computer simulations of the supply chain dynamics were run to determine the impact that differing conditions of information visibility have on cost. The results of the simulations show that with RFID-enabled information visibility, it was possible to achieve 40-70% reduction in inventory costs alone, along with reduction in lost sales due to absences of backlogs, improved customer service due to timely delivery of orders, and greater confidence in managing the supply chain due to accurate, real time knowledge of location of products moving in the supply chain. In [15], the situation of a retail store subject to inventory inaccuracies stemming from product misplacement type errors is considered. Using a Newsvendor model, the relative benefit of implementing RFID technology is studied.

In [2], a three echelon fast moving consumer goods supply chain is considered. Using survey-based quantitative and qualitative data on logistics processes, an assessment of the economical suitability of RFID and EPC was done. The researchers conclude that tagging at the pallet level is more economically justifiable than at the case level. The importance of adopting a process-based approach to modeling and assessing the impact of RFID is highlighted in [12].

[8] investigates the effect that information inaccuracy has on the inventory system's stock loss and stock out. Analytical and simulation models are used to illustrate that a small stock loss can lead to severe stock out situations. Their simulation study show that increasing the safety stock levels to compensate for uncertainty in inventory

accuracy is not an effective way to prevent stock out or stock loss. Instead they show that use of RFID can help a company “attain the lowest inventory for any given stock out.”

[5] addresses the issue of how the cost of item-level RFID in the retail supply chain should be allocated among supply chain partners such that supply chain profit is optimized. They consider the scenarios of both the case of a dominant manufacturer as well as the case of a dominant retailer, and analyze the results of an introduction of item-level RFID to such a supply chain depending on these market power characteristics.

The impact of RFID in contexts other than retail and manufacturing supply chains have also been studied by researchers. Findings in [1] point to potential performance improvements in the utility sector when RFID enables more integrated and more collaborative B-to-B e-commerce solutions. [4] reports on an analysis of the potential costs and benefits of using RFID technology for the management of ordnance inventory. Using survey data and a factorial model that combines a multi-criteria tool for the valuation of qualitative factors with a Monte-Carlo simulation, the researchers conclude that significant financial benefits are possible.

While these other researchers have examined specific RFID benefits to supply chain management, none has developed a comprehensive model to help assess RFID's ROI impact, particularly on suppliers. [9] highlights the need for model based analysis to help industry realize RFID's full potential. In this paper, we address precisely this research gap, and present a systematic framework for ROI assessment and associated models.

3 Our ROI Assessment Framework

The scope of this paper covers the assessment of RFID benefits on supply chain processes from the tier-one supplier (including its distribution center) to the retailer's distribution center. Even though our models have been developed in the context of tier-one suppliers, these models can be readily applied to manufacturers/suppliers at upper echelons of the supply chain since the upper echelons will have similar RFID benefit opportunities at inbound, production, and outbound supply chain processes. (In the remainder of the paper, we will therefore use the term “manufacturer” and “tier-one supplier” interchangeably.)

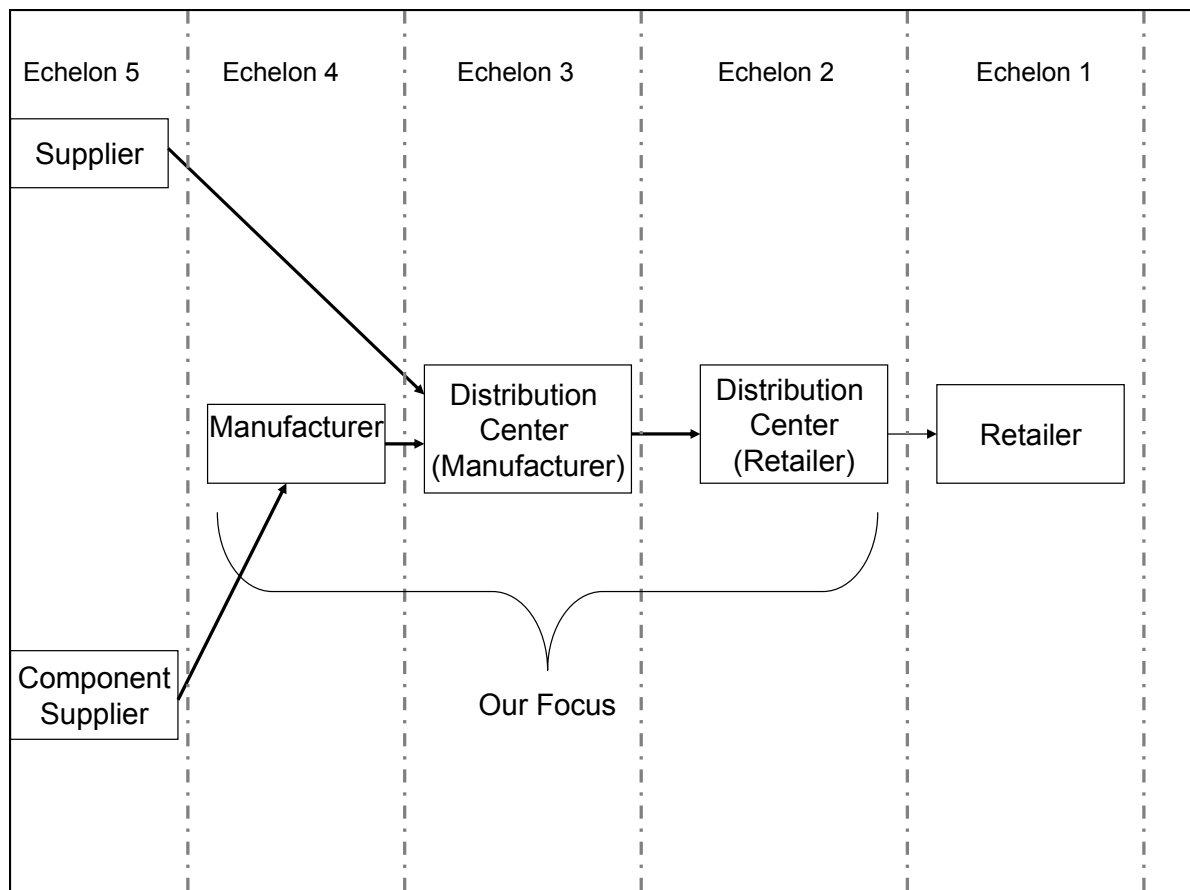


Figure 2: Echelons in Our Supply Chain Model

As shown in Figure 2, in our framework, the finished products supplied by the tier-one supplier to the retailer comprise of products that the tier-one supplier manufactures in its production facility (using components and materials from its suppliers) as well as products that are supplied in finished (fully assembled) form to the tier-one supplier. The latter category of products is received directly at the distribution center of the tier-one retailer (manufacturer), and does not have to go through its production facility. We assume that the RFID tags get applied at the pallet/case level at echelon five and are tracked from echelon five to one. Figure 3 illustrates the primary benefits accrued at the echelons linking the manufacturer to the retailer.

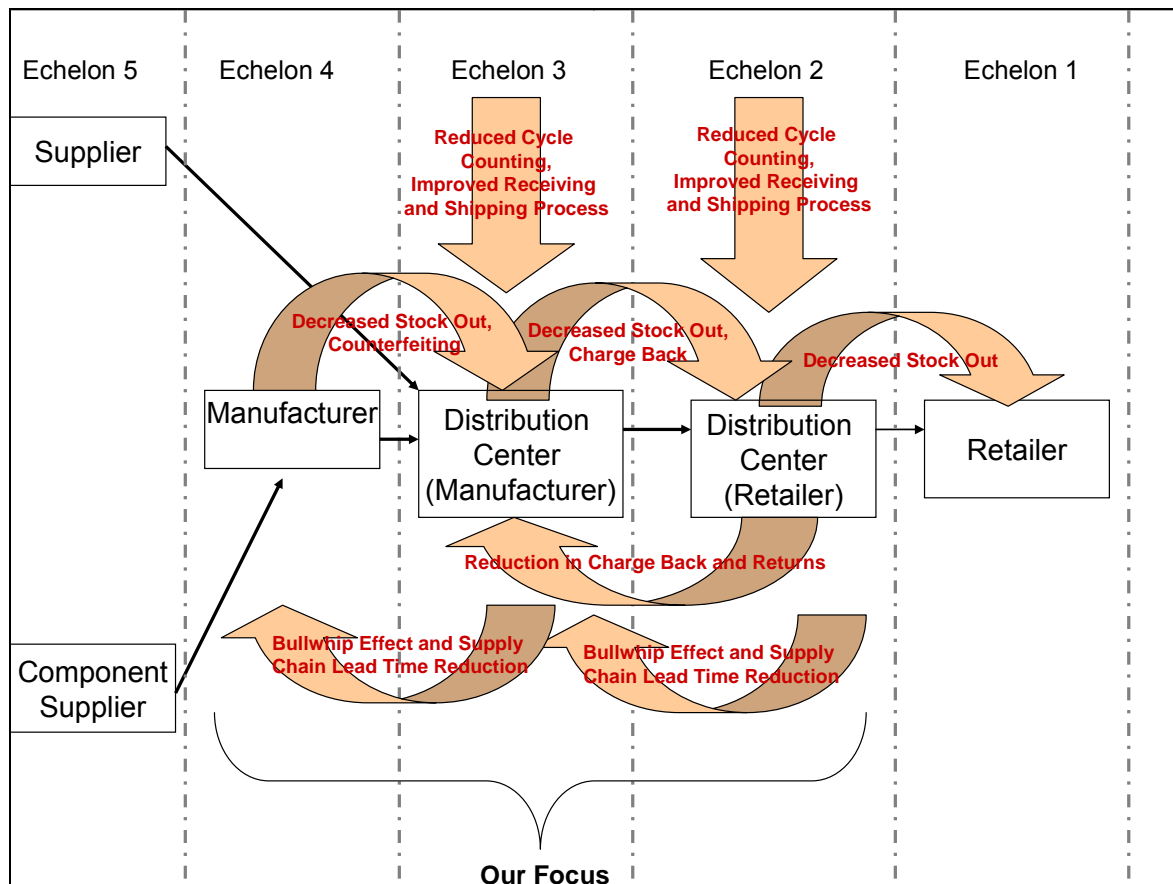


Figure 3: RFID Benefits at Echelons Interfacing Manufacturer and Retailer

Using this framework, we have developed an "RFID ROI Assessment Tool" that has been implemented in Microsoft Excel. This software tool is user-friendly and allows a manufacturer to calculate the potential benefits of RFID deployment, and perform scenario-based analysis on differing levels of RFID impact. Figure 4 is an example of one of the worksheets of the software tool, and depicts the summary of benefits.

In Sections 4 - 8 of the paper, we describe the assessment models underlying the five primary areas of RFID benefit outlined earlier (namely lower operating costs, increase in revenue, lower overhead costs, reduced inventory capital costs, and lead time reduction). Due to space constraints of this paper, only some of the models that are incorporated in the RFID ROI Assessment Tool are discussed in detail. Prior to the use of these models, it is expected that the manner in which RFID will reengineer supply chain processes is already known to the manufacturer. The benefits of the RFID implementation are assessed in the models by comparing performance metrics of RFID-enabled processes relative to those of the current processes.

	A	B	C	D	E	F	G	H
1	Summary of Benefits From Assessing the Value of RFID Implementation by Tier One Suppliers to Major Retailers of Consumer Packaged Goods							
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Figure 4: Summary Worksheet from RFID ROI Assessment Tool

4 Lower Operating Cost

At both manufacturing and distribution facilities (specifically, warehouses), there is a significant number of opportunities to improve operational efficiencies through the use of RFID, resulting in increased throughput, decreased inventory levels, increased visibility of incoming containers, and improved rush/expedited order management, among many other benefits.

4.1 Main Warehouse Operations

Improved Receiving Processes for Inbound Units: During the unloading process, RFID can enable increased receiving efficiency through auto-counting and precise instructions for put-away. Throughout the put away process, paper work reduction, less fork truck driving, and more accurate bin inventory are some of the gains in efficiency due to RFID. Finally, at the end of the receiving process, auto-reconciliation can replace the manual paper work and manual computing.

Improved Shipping Processes for Outbound Units: Similar to the receiving process, there are efficiencies that can be gained from the shipping process after implementing RFID. During the picking process, RFID can enable a reduction in paper work, optimally choose picking routes, and reduce bin location exception management. Other improvements to the shipping process occur during reconciliation such as electronic count certification process and net weight reconciliation by scales.

Table 1: Movement Types

	Unloading	Receiving	Put Away	Picking	Loading
Inbound moves	x	x	x		
Cross docking moves	x	x	-	x	x
Outbound moves				x	x

Improved Cross Docking Processes: Cross docking operations may be assimilated to a regular outbound operation by this model shown in Table 1. Cross docking time is equivalent to the sum of unloading, receiving, and loading time for inbound and outbound units. Cross docking events will move (decrease) events from regular inbound, saving put away moves as a result of enabling or increasing this type of moves.

The variables and notation used in the warehouse process efficiency calculations models are described below.

t	= Echelon number, for $t = 1, \dots, 5$
k	= Truck load type for $k = 1 \dots q$
$U_{t,k}$	= Unloading time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$R_{t,k}$	= Receiving time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$PA_{t,k}$	= Put away time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$J_{t,k}$	= Picking time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$L_{t,k}$	= Loading time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$ITL_{t,k}$	= Annual number of inbound truckloads at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$OTL_{t,k}$	= Annual number of outbound truckloads at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$CI_{t,k}$	= Average crew size to work on an inbound truckload at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$CO_{t,k}$	= Average crew size to work on an outbound truckload at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$IEU_{t,k}$	= Increased efficiency percentage after implementation of RFID for the unloading time at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$IER_{t,k}$	= Increased efficiency percentage after implementation of RFID for the receiving time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$IEPA_{t,k}$	= Increased efficiency percentage after implementation of RFID for the put away time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$IEJ_{t,k}$	= Increased efficiency percentage after implementation of RFID for the picking time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$IEL_{t,k}$	= Increased efficiency percentage after implementation of RFID for the loading time/unit at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$CD_{t,k}$	= Increased percentage of regular inbound units switched to cross docking at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$IU_{t,k}$	= Inbound units (annual) at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$ (Including cross-docking units)
$OU_{t,k}$	= Outbound units (annual) at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$XU_{t,k}$	= Inbound units for cross docking
$FTTI_{t,k}$	= Fixed time per incoming truckload at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$FTTO_{t,k}$	= Fixed time per outgoing truckload at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
AH_t	= Annual operating available hours at echelon $t = 1, \dots, 5$
ID_t	= Number of inbound dedicated dock doors at echelon $t = 1, \dots, 5$
OD_t	= Number of outbound dedicated dock doors at echelon $t = 1, \dots, 5$
EAH_t	= Effective annual available hours per full time equivalent (FTE) at echelon $t = 1, \dots, 5$
ACS_t	= Average number of crews working at echelon $t = 1, \dots, 5$

The expressions used in the warehouse process efficiency calculations models are described below.

$XU'_{t,k}$	= New # of units for cross docking (revised after RFID implementation)
$U'_{t,k}$	= unloading time after implementation of RFID
$U'_{t,k}$	= $U_{t,k} * (1 - IEU_{t,k})$ at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$R'_{t,k}$	= receiving time after implementation of RFID
$R'_{t,k}$	= $R_{t,k} * (1 - IER_{t,k})$ at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$PA'_{t,k}$	= put away time after implementation of RFID
$PA'_{t,k}$	= $PA_{t,k} * (1 - IEPA_{t,k})$ at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$J'_{t,k}$	= picking time after implementation of RFID
$J'_{t,k}$	= $J_{t,k} * (1 - IEJ_{t,k})$ at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
$L'_{t,k}$	= loading time after implementation of RFID
$L'_{t,k}$	= $L_{t,k} * (1 - IEL_{t,k})$ at echelon $t = 1, \dots, 5$ for truck load type $k = 1, \dots, q$
DCI_t	= Dock capacity inbound (Hours)
DCI_t	= $\sum AH_t * ID_t$ at echelon $t = 1, \dots, 5$
DCO_t	= Dock capacity outbound (Hours)
DCO_t	= $\sum AH_t * OD_t$ at echelon $t = 1, \dots, 5$
DC_t	= Total dock capacity of inbound and outbound (Hours)
DC_t	= $\sum DCI_t + DCO_t$ at echelon $t = 1, \dots, 5$
LC_t	= Labor capacity
LC_t	= $\sum EAH_t * ACS_t$ at echelon $t = 1, \dots, 5$

4.1.1 Effort Analysis for Current Process

The effort analysis to determine the labor hours and floor hours for inbound and outbound operations at echelon $t = 1, \dots, 5$ for truck load $k = 1, \dots, q$ for the current process can be done as follows.

$$FHIC_{t,k} = \text{Floor hours for inbound operations at current state}$$

$$FHIC_{t,k} = FTTI_{t,k} * ITL_{t,k} + IU_{t,k} * (U_{t,k} + R_{t,k} + PA_{t,k}) - X * PA_{t,k}$$

FHOC_{t,k} = Floor hours for outbound operations at current state

$$FHOC_{t,k} = FTTO_{t,k} * OTL_{t,k} + OU_{t,k} * (J_{t,k} + L_{t,k})$$

LHIC_{t,k} = Labor hours for inbound processes at current state

$$LHIC_{t,k} = (IU_{t,k} * (U_{t,k} + R_{t,k} + PA_{t,k}) - X * PA_{t,k}) * CI_{t,k}$$

LHOC_{t,k} = Labor hours for outbound processes at current state

$$LHOC_{t,k} = (OU_{t,k} * (J_{t,k} + L_{t,k})) * CO_{t,k}$$

4.1.2 Effort Analysis for RFID Enabled Technology

The effort analysis to determine the labor hours and floor hours for inbound and outbound truckloads at echelon $t = 1, \dots, 5$ for truck load $k = 1, \dots, q$ for an RFID enabled process can be done as follows. Note that in the RFID enabled situation, the unloading, receiving, put away, picking, loading, and cross docking processes would be improved, using variables U', R', PA', J', L', XU' .

FHIR_{t,k} = Floor hours for inbound operations after RFID implementation

$$FHIR_{t,k} = FTTI_{t,k} * ITL_{t,k} + IU_{t,k} * (U'_{t,k} + R'_{t,k} + P'A_{t,k}) - XU' * PA'_{t,k}$$

FHOR_{t,k} = Floor hours for outbound operations after RFID implementation

$$FHOR_{t,k} = FTTO_{t,k} * OTL_{t,k} + OU_{t,k} * (J'_{t,k} + L'_{t,k})$$

LHIR_{t,k} = Labor hours for inbound processes after RFID implementation

$$LHIR_{t,k} = (IU_{t,k} * (U'_{t,k} + R'_{t,k} + PA'_{t,k}) - XU' * PA'_{t,k}) * CI_{t,k}$$

LHOR_{t,k} = Labor hours for outbound processes after RFID implementation

$$LHOR_{t,k} = (OU_{t,k} * (J'_{t,k} + L'_{t,k})) * CO_{t,k}$$

4.1.3 Current Capacity Utilization Analysis

The utilization analysis for the current state to determine the dock capacity utilization and labor capacity utilization for the current process can be done as follows.

DCUC_t = Dock capacity utilization for inbound and outbound units at current state

$$DCUC_t = \sum (FHIC_t + FHOC_t) / DC_t \text{ at echelon } t = 1, \dots, 5$$

LCUC_t = Labor capacity utilization at current state

$$LCUC_t = (LHIC_t + LHOC_t) / LC_t \text{ at echelon } t = 1, \dots, 5$$

4.1.4 RFID-enabled Capacity Utilization Analysis

The utilization analysis for RFID enabled and cross docking parameters to determine the dock capacity utilization and labor capacity utilization can be done as follows. Dock capacity utilization and labor capacity utilization can be calculated using Equations 1 and 2, whereas the dock capacity availability gain and labor capacity availability gain can be calculated using Equations 3 and 4.

DCUR_t = Dock capacity utilization for inbound and outbound units after RFID implementation

$$DCUR_t = \sum (FHIR_t + FHOR_t) / DC_t \text{ at echelon } t = 1, \dots, 5 \quad (1)$$

LCUR_t = Labor capacity utilization after RFID implementation

$$LCUR_t = (LHIR_t + LHOR_t) / LC_t \text{ at echelon } t = 1, \dots, 5 \quad (2)$$

DCAG_t = Dock capacity availability gain for inbound and outbound units

$$DCAG_t = DCUC_t - DCUR_t \text{ at echelon } t = 1, \dots, 5 \quad (3)$$

LCAG_t = Labor capacity availability gain

$$LCAG_t = LCUC_t - LCUR_t \text{ at echelon } t = 1, \dots, 5 \quad (4)$$

4.2 Increased Efficiencies in Cycle Counting

One the largest benefit of RFID is its ability to improve inventory accuracy. Improving inventory accuracy can enable a reduction in excess, obsolete, or unsaleable inventory, reduction in cycle counts, and decrease in potential incomplete orders. Increasing efficiency in cycle counting will save time from the actual cycle count and from the cycle count discrepancy resolution process within the supplier's and retailer's warehouses. There can be up to a 25 percent reduction in retail labor expenses due to improved cycle counting [14].

The variables used in the cycle counting calculation are described below.

- i = SKU number, for $i=1, \dots, n$
 t = Echelon number, for $t=1, \dots, 5$
 $T_{i,t}$ = Time (in hours) it takes to complete one regular cycle count of SKU $i=1, \dots, n$ at echelon t for $t=1, \dots, 5$
 $F_{i,t}$ = Time (in hours) it takes to resolve one discrepancy cycle count of SKU $i=1, \dots, n$ at echelon t for $t=1, \dots, 5$
 $W_{i,t}$ = Hourly cost associated with the cycle counter employee of SKU $i=1, \dots, n$ at echelon t
 $N_{i,t}$ = Number of discrepancies cycle counts conducted (annual) at current state of SKU $i=1, \dots, n$ at echelon t for $t=1, \dots, 5$
 $N'_{i,t}$ = Number of discrepancies cycle counts conducted (annual) after the implementation of RFID of SKU $i=1, \dots, n$ at echelon t for $t=1, \dots, 5$

To determine the cost of inventory inaccuracy use Equation 5.

$$\text{Efficiency Cost of Inventory Inaccuracy:} = \sum (N_t - N'_t) * (F_t - T_t) * W_t \text{ for } t=1, \dots, 5 \quad (5)$$

5 Increase in Revenue

There are several ways in which RFID can help increase revenue. We discuss two of these ways in this section.

5.1 Reduction in Stock Out

At the store level, one of the most detrimental losses to both retailer and supplier organizations is stock outs for the potential associated loss of sale. Stock outs are due to multiple sources of error within an organization such as the distribution center's poor product availability, inaccuracy in inventory information from its retail and suppliers stores, and poor store replenishment policies. The probability of a stock out can be reduced through the use of RFID at the appropriate places within a distribution center and retail store.

Stock outs can occur because of three main reasons: Delivery lead time variation, consumer demand variation, and inventory level accuracy. RFID can improve only the lead time variation and the inventory level accuracy. RFID does not affect consumer demand variation.

The variables used in the stock out models are defined below.

- i = SKU number, for $i=1, \dots, n$
 t = Echelon number, for $t=1, \dots, 5$
 $LT_{i,t}$ = Replenishment lead time of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $LTV_{i,t}$ = Variance of replenishment lead time of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $DV_{i,t}$ = Variance of demand of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $ILA_{i,t}$ = Inventory level accuracy of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $SOLTV_{i,t}$ = Quantity of stock outs contributed by lead time variance of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $SODV_{i,t}$ = Quantity of stock outs contributed by demand variance of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $SOILA_{i,t}$ = Quantity of stock outs contributed by inventory level accuracy of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $LTVI_{i,t}$ = Percent of improvement in variability of replenishment lead time after implementation of RFID of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $ILAI_{i,t}$ = Percent of improvement in variability of inventory level accuracy after implementation of RFID of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $D_{i,t}$ = Demand in units of SKU $i=1, \dots, n$ at echelon $t=1, \dots, 5$
 $DS_{i,t}$ = Selling price of SKU number, for $i=1, \dots, n$ at echelon $t=1, \dots, 5$

A stock out occurs when the actual demand exceeds the actual on-hand inventory. In practical terms, many retailers estimate the stock out by multiplying the estimated daily demand for an SKU by the number of days the item is out of stock and finally replenished. Thus, stock out probability (SO) is the probability that the actual demand exceeds the actual inventory level times the demand, and is a function of the variability of delivery lead time, demand, inventory accuracy.

$$SO_{i,t} = p(D_{i,t} > IL_{i,t}) * (D_{i,t} - IL_{i,t}) \Rightarrow f(LTV_{i,t}, DV_{i,t}, ILA_{i,t})$$

The potential for out of stock sales can be projected to determine the realizable sales. Assuming the manufacturer operates its supply chain in an on-demand philosophy; stock outs and delays at any level can result in a stock out at the store level and cause a loss sale. The formula for the realizable sales can be calculated by determining the realizable sales using Equation 6.

$$\begin{aligned} SOC_{i,t} &= \text{Stock out at the current level} \\ SOC_{i,t} &= SOLTV_{i,t} + SODV_{i,t} + SOILA_{i,t} \text{ of SKU } i=1, \dots, n \text{ at echelon } t=1, \dots, 5 \end{aligned}$$

$$SOR_{i,t} = \text{Stock out after the implementation of RFID}$$

$$SOR_{i,t} = (1 - LTV_{i,t})SOLTV_{i,t} + SODV_{i,t} + (1 - ILAI_{i,t})SOILA_{i,t} \text{ of SKU } i=1, \dots, n \text{ at echelon } t = 1, \dots, 5$$

$$RS_t = \text{Realizable Sales at Echelon } t$$

$$RS_t = \sum DS_i * (SOC_{i,t} - SOR_{i,t}) \text{ of SKU } i=1, \dots, n \text{ at echelon } t \quad (6)$$

5.2 Decreasing Counterfeiting Incidents in the Supply Chain

Counterfeiting occurs when illegal copies of a particular product enters the supply chain which can result in loss of profits to the original manufacturer. Counterfeiting is a growing problem and can be potentially very dangerous to the consumer, especially in the pharmaceutical arena. [17] reports that “manufacturers and [original manufacturers] lose up to \$500 billion in sales each year due to the counterfeiting of a wide variety of products, including apparel, cosmetics, liquor, perfumes and pharmaceuticals.” RFID can potentially detect irregular components entering the supply chain, thereby catching and reducing the number of counterfeited items.

The variables used in the counterfeiting models are described below.

- i = SKU number, for $i=1, \dots, n$
- t = Echelon number, for $t=1, \dots, 5$
- $CF_{i,t}$ = Cost of SKU $i=1, \dots, n$ and echelon $t=1, \dots, 5$
- $US_{i,t}$ = Average Number of units of SKU $i=1, \dots, n$ and echelon $t=1, \dots, 5$
- $bcf_{i,t}$ = Percent of counterfeiting currently – Percent of counterfeiting after implementation of RFID of SKU $i=1, \dots, n$ and echelon number, for $t=1, \dots, 5$

The formula to calculate added revenue due to reduced counterfeiting incidents can be calculated using equation 7.

$$\text{Added Revenue due to Reduced Counterfeiting Incidents}$$

$$= \sum \sum CF_{i,t} * US_{i,t} * bcf_{i,t} \text{ of SKU } i=1, \dots, n \text{ at echelon number } t = 1, \dots, 5 \quad (7)$$

6 Overhead Costs, Dispute Resolution

Inefficiencies and inaccuracies in supply chain processes create a variety of non-value-added back-office processes. RFID can enable a reduction in such non-value-added activities and can thereby help reduce organizational overhead costs as explained below.

6.1 Reduction in Charge Back

RFID can improve receiving and verifications processes from supplier to retailer in order to reduce the occurrence and severity of charge backs caused by inaccurate inventory data information. According to the field study conducted, some of the top charge back reasons at a major retail store were: lack of synchronization between invoicing and retailer receiving process, quality issues, and retail stores claiming shortage in count versus bill of lading amount. RFID-enabled receiving and verification processes can significantly reduce the number of chargebacks and the associated costs of non-value-added activities. The savings in charge-backs alone can provide the payback for deploying RFID.

Some of the micro-level issues contributing to excess inventory are administrative errors, cargo transfer errors, internal theft, poor dock-to-stock time, put-away errors, and receiving errors[16]. By automating the delivery of products at the retail level, shrinkage caused by issues contributing to excess inventory can be reduced, thereby reducing the number of charge back penalties due to inaccurate quantities shipped and/or received [11].

RFID can help correct the lack of synchronization between the suppliers invoicing process and the retail stores receiving process which will reduce charge back fees related to “no merchandise received for invoice sent by the supplier”. RFID can enable productivity improvements in the receiving and product check in. Therefore, the receiving process can be handled automatically eliminating the chargeback administrative overhead related to the discrepancy between the suppliers invoicing process and the retailers receiving process. Charge backs and dispute resolution usually delay the related order payment settlement, generating a financial cost for the supplier.

RFID can also improve processes for accurate identification and count of products at key points in the supply chain process. Therefore, with the accurate verification of product delivery done electronically (thereby eliminating the errors due to manual counts), the responsibility for missing products can be properly identified and charged accordingly.

The variables used in the charge back calculation are described below.

- z = Type of charge back for $z=1, \dots, m$
- CB_z = Number of charge backs (annual) for type of charge back for $z=1, \dots, m$

LB_z = Cost of labor for resolving charge back for type of charge back for $z=1, \dots, m$
 EB_z = Cost of direct penalty associated with charge back for $z=1, \dots, m$
 FB_z = Financial cost of outstanding receivables associated with charge back for $z=1, \dots, m$

Given all of the main contributors and/or benefits that result due to implementing RFID, the potential reduction in net charge back can be determined from the net charge back cost and the impact of improvement. The formula for the potential reduction in net charge back can be calculated by determining the sources of charge back penalties and using Equation 8.

There are two major types of charge backs. The first type is related to discrepancies on quantities and quality of products involving a stop or delay of payment. The second type is penalties as a result of not meeting established performance levels (e.g., delivery time, loading time, or minimum inventory levels).

To determine the realizable savings for charge backs $z = 1, \dots, m$, Equation 8 can be applied.

$$\text{Realizable Savings from Charge Backs} = \sum CB_{z=1, \dots, m} * LB_{z=1, \dots, m} + \sum CB_{z=1, \dots, m} * EB_{z=1, \dots, m} + \sum CB_{z=1, \dots, m} * FB_{z=1, \dots, m} \quad (8)$$

6.2 Increased Accuracy to Identifying and Locating Defective Items (Recalls)

RFID can potentially effect three cost contributions incurred by defective items or recalls. The increased efficiencies enabled by RFID can reduce the cost of handling defective items. The cost of identifying defect reasons can also be reduced through improved traceability that RFID allows. Lastly, RFID can reduce the cost of defective items reaching consumers, through improved speed and accuracy of recall response.

6.3 Other Overhead Cost, Avoid Capital Investment in Facilities

As discussed in Section 7, inventory levels can be reduced through the use of RFID. The free warehouse space may reduce/delay the capital investments required for future warehouse capacity expansion.

7 Inventory Capital Cost

Depending on the supplier, substantial working capital may be tied up in inventory, thereby making it an area of great opportunity to reduce costs. Inventory capital cost reduction opportunities can be divided into two main types: excess inventory and inventory loss.

7.1 Reduction in Levels of Excess Inventory

Inventory levels are driven by several factors: product availability which is mostly affected by the:

- Lead time from production to delivery
- Uncertainty of the delivery lead time
- Consumer demand
- Uncertainty of the consumer demand
- Penalty for excess inventory
- Loss revenue for unfulfilled demand.

The penalty for excess inventory is driven by the cost of capital of holding inventory, administrative cost of carrying inventory (warehousing space, insurance, and warehouse management), and obsolescence cost driven by the probability of product becoming unsellable. The factors through which RFID may enable improvements are in the lead time reduction (efficiency gains) and delivery time uncertainty (accuracy and timely information).

7.1.1 Reductions in Levels of Excess Inventory Calculations

The variables used in the reduced levels of excess inventory models are defined below.

i = SKU number, for $i=1, \dots, n$
 t = Echelon number, for $t = 1, \dots, 5$

- $LT0_{i,t}$ = Current lead time to move inventory from echelon $(t + 1)$ start process to echelon (t) ready to sell point for SKU number $i=1, \dots, n$
 $LTV0_{i,t}$ = Current variance of lead time $LTO_{i,t}$
 $LT1_{i,t}$ = Lead time after RFID implementation to move inventory from echelon $(t + 1)$ start process to echelon (t) ready to sell point for SKU number $i=1, \dots, n$
 $LTV1_{i,t}$ = Variance of lead time $LTO_{i,t}$ after RFID implementation
 $D_{i,t}$ = Demand of SKU number $i=1, \dots, n$ at $t = 1, \dots, 5$
 $DV_{i,t}$ = Variation of demand of SKU number $i=1, \dots, n$ at $t = 1, \dots, 5$
 RF = Risk factor to balance cost/benefit effects of inventory availability

The risk factor is a “safety net” mechanism to optimize the availability of the inventory level. Two factors are in competition to define the size of this factor: unfilled demand loss (UDL) and the penalty for excess inventory (PEI), as seen in Figure 5. The characteristics and relevance of these factors depend on the product type and markets. For example, an item with high gross profit margin rate and low item cost may use a large risk factor. On the other hand, a product with low margin rates and high item cost may use a low risk factor. Depending on which economic elements are more relevant, the factor will move in the range between one and four. This range was selected based on coverage probability resulting from multiples of the variance in a normal distribution as illustrated below.

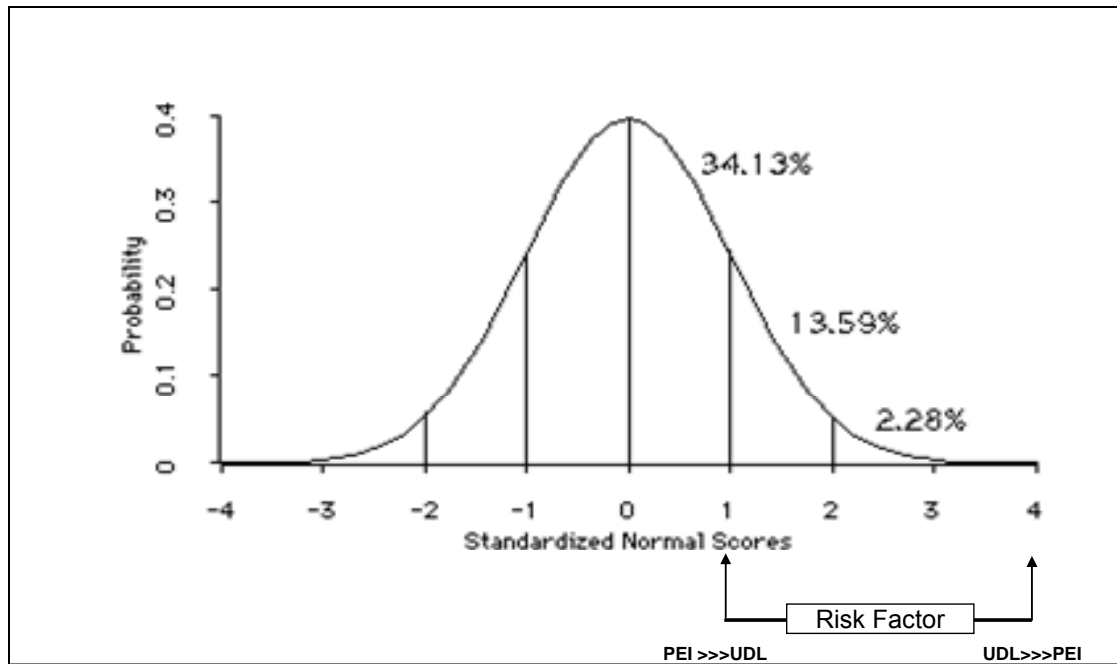


Figure 5: Risk Factor Relationship Between UDL and PEI

The expressions used in the benefit calculations are described below.

$$\text{Inventory Level} = IL_{i,t} = (LT_{i,t} + LTV_{i,t} * RF) (D_{i,t} + DV_{i,t} * RF)$$

As discussed before, RFID is not expected to affect the demand related factors, therefore for the purposes of our discussion, all demand related elements will be consider constant ($C_{i,t}$).

$$\begin{aligned} C_{i,t} &= D_{i,t} + DV_{i,t} * RF \\ IL0_{i,t} &= C_{i,t} * (LT0_{i,t} + RF * LTV0_{i,t}) \\ IL1_{i,t} &= C_{i,t} * (LT1_{i,t} + RF * LTV1_{i,t}) \end{aligned}$$

The formula to calculate the change in levels of excess inventory can be calculated using Equation 9.

$$\Delta IL_{i,t} = C * (LT0_{i,t} - LT1_{i,t}) + C * RF * (LTV0_{i,t} - LTV1_{i,t}) \quad (9)$$

The reduction in levels of excess inventory model can be assessed through a sensitivity analysis as illustrated in Figure 6. Assume that demand = 90, $C = 100$, and lead time variances = 10, 20, 30, and 40%. The sensitivity analysis illustrates the compound effects of reduced lead time and reduced lead time variation in high and low risk factor situations. The inventory level reduction is greater for a higher lead time variation. The range of inventory level reduction is 10% to 25% when the lead time variation is changed.

Case	$LT_{i,t}$	itv%	$LTV0_{i,t}$	RF	$D_{i,t}$	$DV_{i,t}$	$C_{i,t}$	$IL0_{i,t}$		
A	20	10%	2	1	90	10	100	2200		
B	20	20%	4	1	90	10	100	2400		
C	10	40%	4	1	90	10	100	1400		
D	10	50%	5	1	90	10	100	1500		

Case	$LT_{i,t}$	itv%	$LTV1_{i,t}$	RF	$D_{i,t}$	$DV_{i,t}$	$C_{i,t}$	$IL1_{i,t}$	Inventory Level Reduction	
	10%		2%							
A	18	10%	1.764	1	90	10	100	1976.4	10.2%	
B	18	20%	3.528	1	90	10	100	2152.8	10.3%	
C	9	40%	3.528	1	90	10	100	1252.8	10.5%	
D	9	50%	4.41	1	90	10	100	1341	10.6%	

Case	$LT_{i,t}$	itv%	$LTV0_{i,t}$	RF	$D_{i,t}$	$DV_{i,t}$	$C_{i,t}$	$IL0_{i,t}$		
A	20	10%	2	3	90	10	120	3120		
B	20	20%	4	3	90	10	120	3840		
C	10	40%	4	3	90	10	120	2640		
D	10	50%	5	3	90	10	120	3000		

Case	$LT_{i,t}$	itv%	$LTV1_{i,t}$	RF	$D_{i,t}$	$DV_{i,t}$	$C_{i,t}$	$IL1_{i,t}$	Inventory Level Reduction	
	10%		4%							
A	18	10%	1.728	3	90	10	120	2782.08	15.4%	
B	18	20%	3.456	3	90	10	120	3404.16	18.2%	
C	9	40%	3.456	3	90	10	120	2324.16	22.6%	
D	9	50%	4.32	3	90	10	120	2635.2	24.3%	

Figure 6: Sensitivity Analysis for Excess Inventory Model

7.2 Reduction in Inventory Loss/Shrinkage

Inventory loss or shrinkage involves all forms of loss of the products available for sale. Shrinkage can occur because of theft by employees, customers/shoppers, or by the supplier. Products that become obsolete, out of date, damaged, or spoiled can be deemed as inventory loss. According to [8], stock losses can be categorized into known and unknown. Unknown stock loss creates inventory record inaccuracy, which can be improved through the use of RFID. Improved product reconciliation and control may reduce inventory loss or shrinkage. RFID also can reduce or avoid obsolescence through better FIFO management and preventing "wrong location" mistakes which leads to "forgotten products" turning obsolesces.

The variables used in assessing the benefit from reduced levels of inventory loss/shrinkage models are defined below.

- i = SKU number, for $i=1, \dots, n$
- t = Echelon number, for $t=1, \dots, 5$
- $ILS_{i,t}$ = Units of inventory loss/shrinkage of SKU $i=1, \dots, n$ and echelon number, for $t=1, \dots, 5$
- $IC_{i,t}$ = Item cost of SKU $i=1, \dots, n$ and echelon number, for $t=1, \dots, 5$
- $ils_{i,t}$ = Percent of inventory loss/shrinkage currently – Percent of inventory loss/shrinkage after implementation of RFID of SKU $i=1, \dots, n$ and echelon number, for $t=1, \dots, 5$

The cost savings due to reduced levels of inventory loss/shrinkage can be calculated using Equation 10.

$$\text{Cost Savings due to Reduced Levels of Inventory Loss/Shrinkage} = \sum \sum ILS_{i,t} \cdot IC_{i,t} \cdot ils_{i,t} \text{ of SKU } i=1, \dots, n \text{ and echelon number, for } t=1, \dots, 5 \quad (10)$$

8 Lead Time Reduction

As discussed earlier, RFID can result in improved lead time performance of the supplier's operations. With higher inventory visibility, information sharing between supplier and retailer, and appropriate store replenishment policies, the lead time performance improvement will also extend across the supply chain as a result of supply chain dynamics.

Lead time improvements affect not only inventory levels, but also increase flexibility of logistics processes of the supply chain and the ability of suppliers to respond quickly for inventory replenishment. RFID's ability to

automatically trigger store shelf replenishment with back room inventory, and the increased visibility of this data to suppliers coupled with their ability to quickly replenish inventory, can result in lower inventory and safety stock levels across the entire supply chain, while also reducing the probability of stock outs.

[13] reports that increased information visibility in the supply chain when complemented with lead time reduction can further reduce the bull whip effect in the supply chain than through information sharing alone. The various benefits of lead time reduction on supply chain performance and analytical models to estimate these benefits are described by [18] and others in the research literature on time based competition.

9 Industry Application of our RFID Benefit Assessment Framework

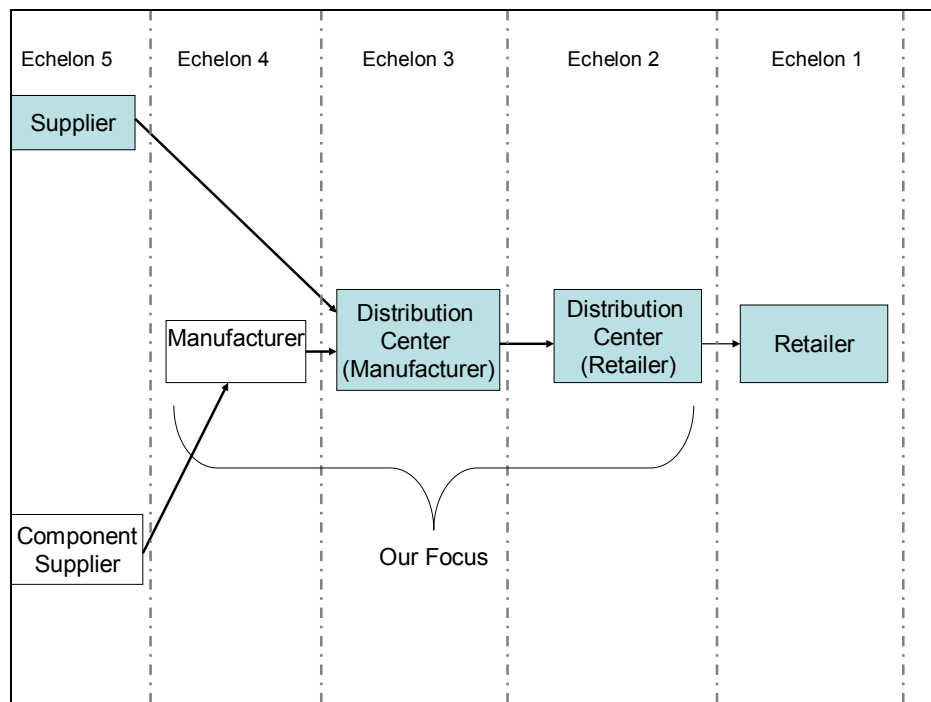


Figure 7: Material Flow for Company Used in Field Study

Table 2: Summary of Estimated Benefits for Company in Field Study

ANALYSIS	SCENARIO	BENEFIT
Lower Operating Costs		
<i>Direct Labor Utilization Gain</i>	Conservative	5.7%
<i>Warehouse Dock Capacity Gain</i>	Conservative	5.7%
<i>Efficiency Cost of Inventory Inaccuracy</i>	Conservative	\$35.5 K
Increase in Revenue		
<i>Realizable Sales</i>	Conservative	\$16.6 M
	Optimistic	\$20.9 M
	Pessimistic	\$12.1 M
Lower Overhead Costs		
<i>Realizable Savings</i>	Conservative	\$282 K
	Optimistic	\$338 K
	Pessimistic	\$226 K
Total Benefit of RFID		
Conservative	\$16.9 M	
Optimistic	\$21.3 M	
Pessimistic	\$12.4 M	

The RFID benefit assessment framework and models described in this paper have been applied successfully in the context of a company that is a tier-one (top-100) supplier to Wal-Mart. As a result of Wal-Mart's RFID mandate, the company did not have much choice regarding the use of RFID. It, however, needed to assess whether it was justifiable to deploy RFID within its own operations and further upstream, as opposed to implementing RFID in merely a "slap-and-ship" manner (i.e., applying tags to cases and pallets prior to shipment to Wal-Mart) to meet the Wal-Mart mandate.

The company does not do any significant manufacturing of its own, and imports almost all of its products fully assembled from its suppliers. Hence, the material flow for this company occurs in the manner shown in Figure 7. To assess the potential benefits of RFID to this company, we did a comprehensive analysis addressing all the five primary areas of benefits in our framework.

When applying our models and equations, we considered scenarios representing three different settings: conservative, optimistic, and pessimistic. The reason for the scenario analysis was to understand a range of possible benefits. For example, we could vary the conditions related to different sources of stock out to understand how different levels of RFID technology deployment affect the amount of realizable sales. The summary of total benefits estimated for this company is shown in Table 2. The results for this company show that when we viewed collectively across the primary benefit areas, there can be significant benefits to implementing RFID within its operations and those of its suppliers. This made RFID deployment justifiable even at the current cost of around 10 cents per RFID tag. As a result of this analysis, the company has already moved beyond their initial "slap-and-ship" approach to internal deployment in its distribution center processes. After implementing RFID within its own operations, the company plans to incorporate RFID further upstream in its supply chain.

10 Summary

The difficulty in assessing the potential benefits of RFID implementation is one of the key barriers to adoption of this promising technology. All the tier-one suppliers of major retailers such as Wal-Mart are implementing RFID in a limited manner (such as the "slap-and-ship" approach) because they do not fully understand how to assess the impact of a broader deployment of RFID across their operations and further upstream. Unfortunately, companies adopting the slap-and-ship only incur additional costs and will not gain all the potential benefits of RFID. In this paper, we have presented a framework and some of the underlying models for assessing the five primary areas of benefits of RFID implementation by tier-one suppliers to major retailers. Even though the models have been developed in the context of tier-one suppliers, they can be readily adapted and applied to assess the benefits at upper echelons of the supply chain. Based on this work, we have developed an RFID ROI Assessment Tool. Further, we have verified and validated our methodology and models through their application to one of Wal-Mart's top-100 suppliers.

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