A Radio Frequency Identification (RFID) Evaluation Strategy for Customer Fulfillment Centers

by

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Submitted to the Sloan School of Management and the Engineering Systems Division in partial fulfillment of the requirements for the degrees of

Master of Business Administration
and
Master of Science in Engineering Systems

In conjunction with the Leaders for Manufacturing Program at the

Massachusetts Institute of Technology
June 2006

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ABSTRACT

Radio Frequency Identification (RFID) is a wireless technology that can be used to track inventory labeled with microchip-embedded identifiers communicating passively with scanners without operator involvement. This non-line-of-sight technology has the potential of dramatically increasing the level of visibility throughout the supply chain for many types of products, assisting in defect reduction, increased granularity in inventory tracking, and decreased direct labor.

In recent years, developments in RFID technology have decreased the cost of RFID equipment, and several large U.S. retailers have started to use RFID to track consumer products. However, what is not clear is whether or not these RFID implementations have yielded economic returns. Although RFID promises higher read rates and increased accuracy, how the technology works in particular warehouse settings is not clear. The first step to determining the feasibility of RFID in any organization is the complete evaluation of RFID technology.

This document discusses an evaluation strategy using the Six Sigma DMADV framework. The strategy was carried out at internet retailer Amazon.com. The document discusses the various steps required for a complete implementation of the evaluation strategy and refers to the evaluation at Amazon.com as a case study. The purpose of this document is to recommend a complete evaluation strategy of RFID system components for any customer fulfillment center that is thinking of implementing this technology to replace existing tracking technologies such as bar code or other manual forms of tracking.

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Acknowledgements

First and foremost, I would like to acknowledge the Leaders for Manufacturing Program for its support of this work. I have learned a great amount in classes, during my internship, and throughout my two years as an LFM Fellow. To the faculty, staff, and students of LFM: Thank you.

I would like to thank Amazon.com for sponsoring the internship which was the foundation of this thesis. The success of both the internship and this thesis was the cumulative accomplishment of many dedicated and helpful individuals at Amazon, both in Seattle and in Reno. Thank you, everyone, for your support. In particular, I would like to thank Matt Montie, my daily mentor and friend who first helped a clueless intern come up to speed in the Amazon world, and helped him along through the very end. This internship would also have been impossible without the guidance and direction of Tim Collins, long-time supporter and friend of the LFM program.

In addition to the people at Amazon, I could not have gotten through this experience without the help of my professors, friends, and colleagues at MIT. First, my advisors: Prof. Stephen Graves, Prof. David Simchi-Levi, and Prof. Sanjay Sarma. Thank you for your guidance and support both throughout my internship and then through the process of completing my thesis. I still do not know how you find time to do research, teach, and advise us through these projects, but thank you for taking it all on. Your expertise is priceless. And to my friends in the Sloan and LFM classes – thanks, everyone, for keeping me sane and my spirits up throughout the course of these two years.

No amount of thanks can be sufficient for my family through this, just as any of life's trials. Thanks, Mom, for worrying and caring – the things you do best. And, Dad, I am always looking up to you, for you are the man I aspire to be. Thanks, Grandma, for all the calls, love, and support (and food!).

And, of course, I have to thank my better half, my Emily. She is my constant, my inspiration, and my motivation. Thank you for always being there, on the phone, in Reno, in Seattle, and everywhere that my travels have taken me.

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Chapter 1: Introduction

Radio Frequency Identification (RFID) technology has been in existence since the mid 1940's. However, it was not until the last decade that RFID has entered into the mainstream of tracking technology. Recent years have seen an increase use of RFID in many industries including consumer retail. One of the last nodes that a product passes through before reaching the end customer is the customer fulfillment center. This document will explore an evaluation strategy of how to incorporate RFID into a customer fulfillment center.

Many white papers and much industry documentation exist today on the many uses for RFID technology from shrinkage reduction to inventory tracking. However, it is often difficult to know just how RFID will work in any specific setting, such as a customer fulfillment center where inventory in a consolidated location is shipped directly to end user customers. Because the throughput of inventory in these fulfillment centers can be very high, accurate tracking of inventory is needed at several points in the warehouse. Where does one start to implement RFID? How does one go about figuring out where the best *initial* use for the technology will be? Will the technology be accurate enough? This document will not answer these questions directly for any one warehouse. However, this document will set up the strategic frameworks required to allow the reader to answer these questions in a systematic method.

The majority of the research and development of this paper was conducted between June 2005 and January 2006 at Amazon.com. The author executed the recommended strategy at Amazon's fulfillment center in Reno, NV, and selected results of that evaluation appear in the appendix of this document as a detailed case study to how one would implement such an evaluation strategy.

1.1 Document Overview

This document is the result of many months of research by the author and the cooperation of a countless number of Amazon.com operators, managers, and employees. This thesis is organized into three main sections, with ten total chapters as follows:

Chapter 1: Introduction. This chapter which outlines the thesis.

Part I - Background

Chapter 2: Technology Overview
    An overview of RFID technology, its history, development, and recent progress.

Chapter 3: Amazon.com – The Internet's Largest Online Retailer
    An overview of Amazon.com and the reason behind the RFID project. The author will also explore typical Amazon processes, fulfillment centers, and the way that process improvements usually take place in Amazon's customer fulfillment operation.

Part II - Implementation Strategy

Chapter 4: Project Definition

This chapter will suggest a framework to help determine where first to implement RFID in a customer fulfillment center. The discussion will use the determination of the initial RFID implementation at Amazon.com as an example.

Chapter 5: Problem Analysis

Once a defect is targeted and deemed appropriate for an RFID solution, the defect should be analyzed to determine the estimated impact of the original impact as well as how RFID can help. Integration of RFID hardware equipment is a large part of the analysis of how RFID can be used in a fulfillment center to increase the metrics that an organization cares about most.

Chapter 6: Equipment Analysis

Equipment analysis is crucial to determine how, when, and where to implement an RFID solution. This is by far the most important of the analyses. This chapter will discuss how to determine the correct protocol and standard, how to select vendors, and offer some guideline on how to complete an RFID equipment evaluation.

Chapter 7: Cost-Benefit Analysis

Almost all companies depend on a sound financial analysis to determine whether or not to adopt new projects or technologies. This chapter goes into detail regarding the cost-benefit analysis at Amazon, and discusses the important aspects of financing the RFID decision.

Part III – Conclusions and Additional Considerations

Chapter 8: Conclusions

This chapter summarizes the main recommendations from the previous chapters including the key lessons learned from conducting the Amazon case study. The final section touches on the key next steps in an RFID implementation.

Part I - Background

Chapter 2: Technology Overview

2.1 A Brief History of RFID

Like many of today's advanced technologies, RFID was first used in the military, in WWII. The British Royal Air Force used the technology to identify whether planes in the sky were to be considered enemy targets or friendly aircrafts not to be fired upon. In this application, a radio signal (or the lack of one) coming from the planes was enough for the ground stations to distinguish friend from foe.

One of the main reasons that RFID has not been used in mainstream consumer retail products is because of its traditionally high costs. [18] Recent developments and advancements in manufacturing have driven down the costs of RFID systems to the point where it is becoming viable for the consumer retail industry to start the tracking of pallets, boxes, or even individual products with RFID systems. The consumer retail industry has traditionally relied on the scanning of bar codes to keep track of inventory levels, consumption patterns, and the movement of products. RFID technology offers a new, more precise method of tracking inventory without need for line-of-sight scanning that bar codes require.

2.2 RFID System Components

In order to understand RFID and its advantages, it is helpful to first understand what an RFID system encompasses. A complete RFID system includes the following components:

1. Scanners. These devices are the workhorses of RFID systems. They are devices which send out radio signals to the RFID tags and collect the information sent from the tags. Scanners come in many shapes and sizes, but most of the scanners on the market consist of a central computing unit, often called an interrogator, and one or more sets of antennas. The antennas send and receive the signals to and from the tags. The interrogator is usually linked to a central database or network so that tag information can be logged and tracked. Scanners come in various shapes and sizes. Below are a few common scanners used in various industries today:

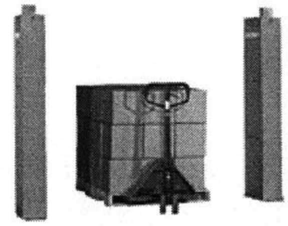

Figure 1: Scanner System from Symbol Technologies [2]

Figure 2: Portable hand scanners from Intermec [3]

2. RFID Tags. RFID tags are the devices that one attaches to the item, box, or pallet which needs to be tracked. As these tags pass by the scanners, the tags will send signals to the scanner so that the scanner knows the item has been "seen". There are two main types of RFID tags: active tags and passive tags. Active RFID tags require their own power source, i.e. a battery, and are usually not used to track products in the consumer retail industry because of the cost and size of these tags. Below is a picture of an active RFID Tags used today:

Figure 3: A high-performance active RFID Tag [4]

More common in the consumer retail industry are passive tags, which are much cheaper and usually disposable. These tags consist of a small microchip, and an antenna which are usually inset into a sticker or label stock. Along with the embedded microchip is an antenna which is printed with a metallic ink. This antenna picks up radio waves from the receiver and uses the power of the radio waves to power up the microchip, acting as the chip's power supply. The antenna then transmits the signal from the microchip back to the receiver for identification. The information transmitted is usually in the form of an electronic product code, or EPC, which is a 96-128 bit identifier. There are many different types of passive tags which differ in antenna design, sensitivity, and, of course, price. Because the signals from these tags are sometimes weak under extreme conditions, passive tags often need to be specially designed for difficult-to-read material such as liquids and metals. Below are a few of the common passive RFID tags on the market today:

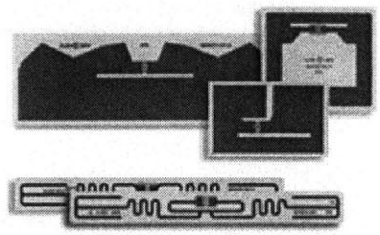

Figure 4: Three different RFID tags from Alien Technology [5]

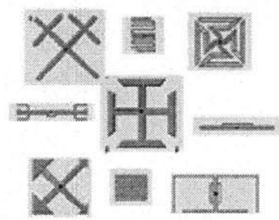

Figure 5: Various passive RFID antenna designs from Symbol [6]

3. RFID Software. When scanners receive signals from the tags, the system will know what tags have been "seen" by certain scanners. This information has little significant meaning without the software and databases needed to maintain and keep track of system variables. If one was to build a new system completely based on RFID, the software component would be the most complicated to complete. Fulfillment centers and warehouses that are planning for a transition to RFID technology are usually already using some sort of ERP (Enterprise Resource Planning) or MRP (Manufacturing Resource Planning) system as well as some other software systems to keep track of their inventory. Incorporating RFID technology to an existing software system adds yet another layer of complication. It is crucial that the new system interfaces with the existing system before a complete deployment can be released.

2.3 Advantages of RFID

RFID has the potential to change the way that people exchange goods or inventory. Imagine going to the grocery store and loading a grocery cart full of items for purchase. At the checkout lane, instead of having a cashier scan each item and total your grocery bill, you just walk through an RFID portal which reads all of the RFID tags in your grocery cart and charges you the correct amount. This not only adds convenience for the customer, but also for the store. With enough scanners, the store can know at any time how much inventory is remaining of each product, and where it is in the store (in the customers aisles, in the storeroom, in the back of the freezer, etc.). When the inventory hits a certain level, the store's computers can automatically re-order items which may run out soon, or suggest sales for overstocked items. Moreover, this information can be extremely accurate since no human intervention is necessary to collect it. Traditionally, a full inventory audit would take many teams of employees several days or even weeks to carry out; and there would still be a large possibility of error. With RFID, these audits can happen on a daily or even hourly basis and real-time decisions can be made to either help control inventory, or even shape demand.

In a customer fulfillment center, inventory can usually be split into three categories – inbound inventory, items in storage, and outbound shipments. RFID can assist in the tracking products as they move through these various stages. During inbound, RFID systems can log the movement of goods into a warehouse and verify shipment from suppliers. Currently, most of this is conducted through human scanning of inventory and a lot of manual labor. Once a product arrives in a fulfillment center, it usually has to be sorted and placed into the right areas or storage locations, which can also be tagged and tracked. RFID has the power to make sorting and locating inventory a lot easier by offering real-time tracking and location information. Even more critical and time sensitive than inbound inventory are outbound shipments. Because there is usually a customer waiting for every outbound shipment, the time that it takes to locate and ship an item directly impacts the customer. The benefits of RFID in this system are not only the decreased time to locate an item and the increased accuracy of the information, but with a passive system such as RFID, less handling is required leading to less damages of the inventory.

2.4 Increased Demand for RFID Technology

Although RFID has been around since WWII, the high cost of tags has prevented this technology from being used widely to track products and shipments in the consumer retail space. When Wal-Mart® announced, in June 2003, a mandate that its top 100 suppliers must affix RFID tags to all shipments bound for Wal-Mart® distribution centers, RFID suddenly got pushed into the supply chain spotlight. [7] Wal-Mart's original mandate is for these top 100 suppliers to comply by January 2005. In August 2003, Wal-Mart mandated that *all* suppliers must tag pallets and cases of product by the end of 2006, making RFID an even more profitable new commodity.

Also in 2003 , the United States Department of Defense (DoD) indicated that it would soon be requiring RFID tags on inventory from members of its supply chain.[10] The combination of these two events led to increased investment and development of RFID technologies. With the prospect of volume sales to Wal-Mart® and DoD suppliers, makers of bar code scanners and labels started to look more deeply into RFID technologies. Many small RFID companies also sprouted up in high-tech centers around the world hoping to capitalize on sales of RFID scanners, tags, and software. [10]

Chapter 3: Amazon.com – The Internet's Largest Online Retailer

The increased adoption of RFID in the consumer retail industry in recent years prompted Amazon.com to start looking into adopting this technology in their fulfillment centers. Amazon.com started as an online bookseller in 1996, and has now expanded its product selection to include all sorts of media (books, movies, and music), electronics, kitchen items, toys, tools, and basically anything else one can possibly imagine. Amazon's aim to be the greatest selection of consumer products on the internet is fast-becoming true, and their customer base has grown significantly as well. Using its network of customer fulfillment centers throughout the world, Amazon fulfills customer orders from the internet in the most efficient ways possible. Tracking millions of items from the warehouse to the customer is a daunting task, and the advent of a more accurate and passive tracking technology is something that can be of obvious use to companies with customer fulfillment operations like Amazon.com.

3.1 Processes vs. Products

Product companies, such as Sony, Intel, Ikea, and Maytag are all around us. Their products are used in homes, offices, and businesses, and most people have a pretty good idea how they work – that is, how they make money: design innovative and useful products, market, sell, and repeat. Between iterations of different innovations, they make improvements to previously launched products, and sell the updates as newer versions. This is not exactly the way that Amazon makes money, but, as the following table shows, it is not all that different. Amazon, and any other customer fulfillment center, is not a product-focused company, but rather a process-focused company:

Company	Amazon.com	Intel
Moneymaker	(Fulfillment) Processes	Products
Moneymaker Improvement Processes	Defect analysis and reduction (Six Sigma)	New features and designs; defect analysis and reduction
When improvements reach limit	Introduce new process or technology	Introduce new protocol, or technology
Critical indicators	Productivity, speed of delivery, efficiency	Product sales, adoption
Consumers	Target, Amazon customers, etc.[1]	Dell, Sony, etc.

Table 1: Process vs. Product Companies

[1] Amazon.com currently fulfills the online customer orders for Target.com and several other online retailers.

At Amazon, processes are the bread and butter of the business. The better they are at these processes, the better they can serve their customers, and they better their bottom line. The same can often be said about traditional manufacturing facilities such as Intel or Ford and General Motors. However, the difference there is that these traditional manufacturers can innovate on the materials and designs of their core products, while Amazon must focus their efforts on core operations, such as how best to use capacity in a warehouse, how best to stow and find books, and the most efficient way to get a book from a shelf deep in the warehouse to the customer's doorstep.

Using this framework, it is easy to see where RFID would fit into a discussion. Currently, Amazon, like many other companies, either process or product oriented, are using bar codes to track products. One of the goals of many companies is to improve the processes which use bar codes to reduce defects (often caused by human error). Reduced defects here lead to more accurate tracking of products, and, in general, better management of inventory and overall operations. However, like any technology, bar code technology has a limit. There is only so much one can do to improve manual scanning a bar code multiple times. Human error is often estimated to have approximately a 2% error rate, or 3.55 Sigma, on tasks such as bar code scanning[2]. Of course, with enough redundancy, manual bar code scans can reach six-sigma standards, but there are often better uses for labor and capital. RFID is a technology which can bring tracking up to beyond six-sigma in a warehouse. The key question then becomes, when does the benefit of RFID outweigh the costs of continuously improving on bar-code-dependent processes? What is the right time to introduce this new, albeit much more expensive, technology into a fulfillment center? This document will not directly answer this question for a fulfillment center, but will offer the framework and models to use in order to evaluate this technology.

3.2 Amazon.com vs. The Traditional Retailer

Just as Amazon's "Moneymaker" is different from that of a product company, Amazon has a very different business model than traditional retailers in that their fulfillment centers are the only links between the end consumer and the supplier. A traditional retailer, such as Wal-Mart®, has many links between the supplier and the end customer:

[2] This estimate is used at Amazon for purposes of error estimation and will be used in this document for consistency.

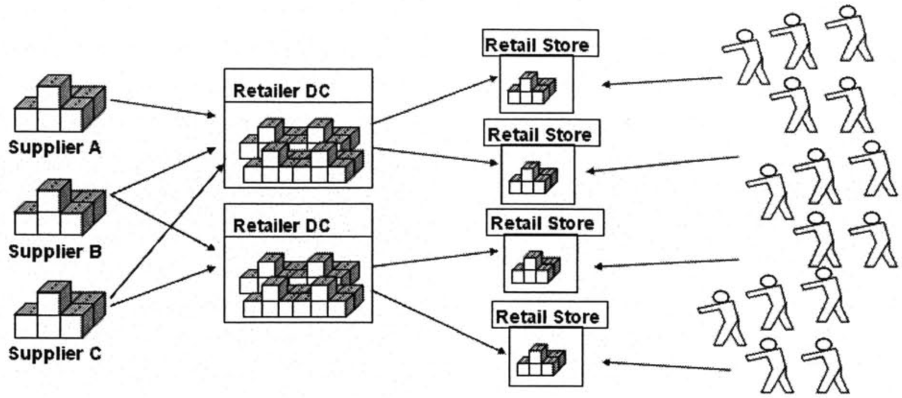

Figure 6: Traditional retailer supply chain.

RFID makes a lot of sense for traditional retailers because decisions on inventory usually have to be made at various links in the supply chain. For example, it is very important for these companies to track the movement of inventory between the distribution centers (DCs) and the actual retail stores since all of the inventory in transit is owned by the retailer. Because such complex networks of distribution centers and retail stores exist, the benefits of RFID are more far-reaching. Increased information regarding the movement of inventory between the DCs and retail stores (and even within the walls of a retail store) can be used to balance inventory across the network and increase service levels at each point of sale. The costs of RFID are high, and a complex network with which to use this technology has a greater chance of making up the costs in multiple efficiencies gained. In contrast, customer fulfillment centers (FCs) such as the ones owned and operated by Amazon.com, have only one link:

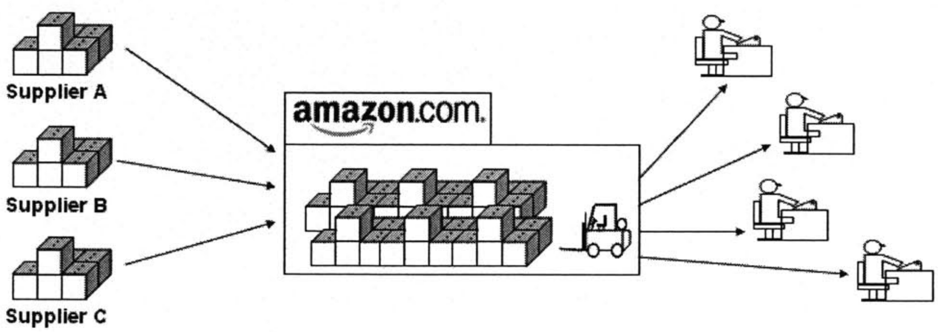

Figure 7: The Amazon.com supply chain

The remainder of this document will use Amazon.com as an example of an FC based fulfillment system with a shortened supply chain. This model is common to all companies which fulfill customer orders directly from the fulfillment center or warehouse. Amazon and other customer fulfillment facilities do not have the luxury, or headaches, of having various nodes and distribution centers across the nation, and a network of stores from which to source inventory. The challenge at Amazon is to be the most operationally efficient company in the consumer retail space. Thus, it makes sense that Amazon look into RFID, a technology which has the potential to increase efficiency beyond what is possible through manual processes. However, the evaluation of this technology at Amazon is something that will not have the upside of leveraging information across a complex network.

From a financial standpoint, it is an advantage that Amazon does not own any of the inbound or outbound inventories in transit. The inventory is owned by the supplier until Amazon receives it, and customer payments are processed when the product leaves an Amazon FC. However, from an RFID perspective, it is more difficult to justify the use of expensive tracking technologies because the supply chain benefits of RFID technology cannot be realized. Wal-Mart®, on the other hand, has three key advantages over Amazon.com in their use of RFID. First of all, Wal-Mart® does benefit from tracking inventory through their multi-step supply chain throughout which Wal-Mart® owns the inventory. Wal-Mart® has the added advantage that, with their massive volume and a small number of suppliers compared to Amazon.com, they are able to leverage their volume and ask the suppliers to tag the inventory thus not incurring the variable tag costs of RFID. Because Amazon has a low-volume, high mix supplier base compared to that of Wal-Mart®, a mandate from Amazon will most likely not be successful. Finally, since Wal-Mart's customer experience is heavily dictated by the store-front experience, Wal-Mart® can use RFID to reduce out-of-stocks at the customer level in their stores. Wal-Mart® has already realized benefits of reducing out-of-stocks at the store level using RFID technology to improving the tracking of items on the shelf, an activity that has traditionally been a manual process.[20] This final advantage is something that is not of concern for Amazon since every customer order is logged and checked against the master inventory sheet and restocks are automatically triggered with present systems. The "storefront" for Amazon.com is a website – which is never stocked out, unless Amazon has already made a decision to not stock something because of obsolescence, low margin, or other economic reasons.

Of course, whenever one has to track every item in a large fulfillment center – tracking products as they arrive, are stowed, then retrieved, then shipped – the use of a more sophisticated and error-free tracking technology may increase efficiency, and save defects in the tracking process. How to justify the use of such a technology like RFID, especially when having to pay for both the fixed costs of scanners and the variable costs for tags, for these purposes in a customer fulfillment center like Amazon's is one of the main purposes of this document.

3.3 Operational Improvement at Amazon.com

Customer fulfillment centers are, at their foundation, a combination of operational processes. Any improvement in the efficiency, speed, or cost of these processes usually has a positive impact on the business – either from a customer service or a financial standpoint. It follows that a fulfillment center would focus significant attention on the improvement of processes, and has a standard way or framework of defining, evaluating, and implementing such process improvements. Like many other operations-focused companies, Amazon.com has such standards. Two of the frameworks that Amazon.com operations managers most commonly use are the DMAIC and DMADV frameworks. [19]

3.3.1 The DMAIC Framework

DMAIC stands for Define, Measure, Analyze, Implement, and Control. This framework is one that is often used for improving a process that is already in place. An example of such a process would be one where an operations manager attempts to improve the throughput of a certain process (i.e. the sorting of books) by adding an additional processing unit (i.e. sortation machine).

An operations manager with a certain problem will first Define the problem, and how it affects the company either operationally, financially, or both. Then, the manager will Measure the effects of the problem in further detail, often using real, collected data. After the data is collected, the manager will Analyze the data in an attempt to find root causes and the impact that it will have in the present and future operations of the company. These first three phases should offer insight as to what the solution may be. Implementation, usually the longest part of the process, requires the manager to apply the best possible solution. The final phase, Control, requires the manager to monitor the progress of the improvement and measure the real benefits of the improvement.

At first glance, this framework may seem to be the correct one with which to apply for an RFID evaluation. A problem that one may find is that inventory is being lost or misplaced. A higher resolution tracking technology such as RFID could be used to improve the process of tracking inventory. However, the problem with this framework is that it is usually used to improve an existing process. Introducing RFID into a traditional fulfillment center which was still using bar codes to track inventory is actually replacing an existing process (the manual scanning of bar codes) with a new one (the passive detection of RFID tags). Not only is a completely new process being introduced, but completely new equipment is also being injected. Unlike the previous DMAIC example of adding an additional sortation machine, implementing RFID is a much more drastic change both in terms of equipment and process. Thus, although over 90% of Amazon's operational improvement projects are done using the DMAIC framework, it was not used for the implementation of RFID.

3.2.2 The DMADV Framework

DMADV stands for Define, Measure, Analyze, Develop, and Verify. The purpose of this framework is to introduce new processes or new equipment to solve a problem in the fulfillment center. The first three phases of this framework mirror that of the DMAIC framework both in name and in function. However, after an Analysis is completed, the manager is asked to Develop a new process or explore new equipment to solve or improve the problem. After development, the manager is asked to Verify the initial hypothesis and assumptions, often using a test or pilot implementation. The difference between a test and a pilot implementation is that tests are done on a control subset of products or processes while a pilot is conducted on actual inventory in the fulfillment center.

The DMADV framework is one that is much better suited for the introduction of new technology into a fulfillment center, and is what the RFID implementation study at Amazon was based on.

Part II – Evaluation Strategy

The following sections of this document will outline a top-level evaluation strategy of implementing RFID technology into a customer fulfillment center. The research involved in developing the strategy was conducted during a seven month internship at Amazon.com. Information regarding the application of the implementation strategy at Amazon will appear in the Appendix of this document and have been edited for confidentiality.

Chapter 4: Project Definition

The DMADV process starts with Define, which is usually the most straightforward part of the process. In most implementations, project definition starts with a problem, in this case a process problem. Process problems in an operations setting usually come in the form of a bottleneck, an unusually high number or percentage of defects, or a process in a series of processes with a relatively lower throughput or efficiency rate. Once this problem is defined, different solutions or technologies can be evaluated using the rest of the DMADV framework to determine the best or most cost efficient solution.

However, in the case of RFID and where best to make the first implementation in the fulfillment center, this process is anything but trivial. Most DMADV projects start with a problem and finish with a solution. The question of where first to introduce RFID into a fulfillment center starts with a solution, RFID, and must first look for a problem. This is actually completely opposite to what most managers and process engineers are used to when completing projects. At Amazon, and most likely other companies looking to adopt RFID, some of the big questions regarding this technology involve how much the solution would cost and how complex the integration would be with traditional, bar-code-dependent processes. Customer fulfillment centers are often on very cyclical schedules and production stoppages must be very well timed or may not even be possible.

4.1 To a Hammer, everything looks like a Nail

Because of the nature of trying to incorporate RFID into a fulfillment center setting, the project often starts with a solution looking for a problem. Of course, many of the problems that RFID can theoretically solve would cost millions of dollars in capital equipment and may not yield sufficient benefit to the company. Many people make the mistake to think of RFID as an indoor GPS system.[3] Although it is possible to simulate the effects of a GPS system using RFID

[3] GPS here refers the Global Positioning Satellites, or the Global Positioning System which uses orbiting satellites to triangulate the position of receivers on Earth.

equipment, these types of setups are usually cost prohibitive because of the number of scanners that would have to be installed and the quality of the tags that would have to be used. RFID may seem like the answer to many problems – and it can be. The difficult task of the Define phase of the project is to determine the right nail, or nails, for this relatively expensive hammer.

The recommended first step to completing an RFID implementation is to map out each major process at the customer fulfillment center. Because RFID benefits will come in the form of increased tracking granularity, the process map should be made with product or inventory tracking as the main theme. Selected sections of the Define Document from the Amazon case study appears in Appendix A. Section 2 of this Appendix shows the process map of RNO2, the non-sortable Amazon fulfillment center in Reno, NV. RNO2 was the site chosen for the initial Amazon RFID implementation because of the items in the warehouse. Non-sortable sites at Amazon are special fulfillment centers where large items, which do not fit onto regular size conveyors, are stored. These items range from awkwardly shaped items such as kites (too long to fit lengthwise on a conveyor) to large and heavy items such as dining tables and chairs.

4.2 Work on the Line, Define possible Projects

After a process map focused on tracking has been completed, proceed to locate processes where either tracking visibility is low, or where improved tracking would be beneficial to either the company or downstream customers. One suggestion to help determine where these processes lie is for the RFID project manager to take the time to work on each step in the process for a few hours. A common mistake during such a technology evaluation and analysis is to think of tracking or traceability completely in the academic or theoretical sense. The best way to understand how a process works is to work the process. Working "on the line" or taking a shift in the work area where tracking may be a problem will yield vast insights both from actually doing the work and talking to the operators whose jobs will be directly impacted by the new technology.

Appendix A, Section 3 shows the list of projects that were compiled for the Amazon case study after the author worked on each process in the line. The project ideas were compiled both from the experience on the process lines as well as talking to the line operators and area managers in various parts of the Amazon fulfillment center as well as managers of operations departments at Amazon's headquarters in Seattle, Washington. The projects include opportunities in both RNO2 as well as other facilities in the Amazon network. It is recommended that both local and network-wide opportunities be evaluated since RFID tags, once installed, can be used to help out more than one problem. Of course, each suggested solution would usually entail the installation of scanners at different locations, but for most organizations, it is the cost of the tags that is of greater concern. It is very likely that any one specific implementation of RFID may not yield enough benefit to justify the recurring cost of RFID tags. The sum of several implementations using the same RFID tags has a much greater chance of recouping the cost of tags. This is exactly the same idea as the one described in Section 3.2.1 where Wal-Mart® uses the same RFID tags in different parts of its supply chain to gain a greater benefit.

The most important initial ideas to capture in terms gathering project ideas is to define process change details such as where the scanners need to be placed, where in the process the RFID tags will be applied, and what type of data will need to be recorded. In many cases, RFID solutions can directly replace existing bar code solutions or work together with traditional systems. In other cases, the jobs of certain operators will completely change which will require either new training or additional labor. Another useful thought project during this process is to document the "Non-RFID Fix" for the defects identified. Having an idea about how to implement non-RFID solutions will allow one to more easily identify which project ideas would best leverage the advantages of RFID. All of these details will have to be flushed out further if the project idea becomes the one your organization decides to target as their initial RFID implementation, but the more one flushes out details in the beginning, the more realistic the idea becomes when it is brought to the attention of others.

In general, the more one talks to others, operators in the fulfillment center, managers, or engineers, the more people will be excited about RFID and the possibility that their work will be made easier with the technology. These are all great ways to gather as many project ideas as possible. Although only one project will be implemented in the end, the collection of projects can be beneficial for future implementations as well as being additional implementation ideas in case the original chosen idea meets an insurmountable obstacle or needs additional benefits, either upstream or downstream in the process, to justify costs.

When talking to people about RFID, one must keep in mind the darker side of RFID – its reputation to be an invasive technology that either replaces blue-collar workers, or watches over them. Most front-line operators are very willing to talk about new technologies during the idea generation phase because you may install something that will help them be more efficient at their jobs. However, some may worry that their jobs will be completely replaced by the technology. Nonetheless, it is crucial to get the buy-in of these operators and address their concerns about the technology early on. The front-line operators will be the ones who will use the technology to gather data on a day-to-day basis, so their agreement that the technology will work and increase productivity and/or decrease defects is invaluable.

4.3 Prioritization of Projects

Once the project list has been compiled, the work of prioritizing begins. The goal of this part of the project is to put into order the list of possible project ideas. The list in Appendix A Section 3 is actually in the order of which ones would be most feasible and most appropriate to implement as an initial RFID project for Amazon. One of the most difficult tasks in project definition is to figure out what the most important things are to a company when it comes to exploring RFID. In Amazon's case, the project was to target a specific defect, to not be too expensive, and to be a full-scale implementation – with hardware, software, tags, and real data to collect. Amazon did not need the resulting data and defect reduction to completely pay for the RFID equipment and installation costs, but the cost could also not exceed a maximum limit. Amazon was willing to take on a small initial loss with their initial RFID implementation to understand the complexity and process of incorporating this new technology into their operation.

Like the process of generating the project list, the task of prioritizing the list will involve talking to a large number of people, in this case managers. The people one engages for this task has both tactical and strategic implications. Managers of processes in a fulfillment center are often excited that RFID can help their particular process become more productive or efficient. It should be expected that each manager will champion the project idea that is most important to their part of the fulfillment process, especially if the funding for the RFID project comes from a different department. Therefore, when speaking with various managers about RFID-related changes to their process, many managers will over-estimate the benefit of RFID and under-estimate the costs. Regardless of their inherent biases for or against various projects, the goal is to have all managers involved in the discussion to agree on the prioritized order of the projects in the project list. This may take many hours of meetings and presentations, but it is highly recommended that the entire company agrees on the projects with the highest prioritization. In the end, all the managers will have to agree to work with the RFID implementation whether the defect analyzed is in their department or not since the result of an RFID implementation involves a change in the way that data is collected; and data is something with which each and every manager will have to work. Thus it cannot be emphasized enough the importance to manage expectations both up (to managers) and down (to floor operators) to generate a list that everyone agrees on.

When deciding this list, it is often easier to eliminate projects or increase the priority of other projects by looking at the possible list of projects with the major advantages of RFID in mind. Two of the biggest advantages of RFID in the warehouse are:

a) It is a passive technology – no active, line-of-sight scanning is required.

b) Throughput is extremely high – the speed of scanners is sufficiently higher than that of most conveyor systems.

Of course, the major disadvantage for RFID is that the cost of the system is much higher than that of traditional systems. Not only is the fixed cost of the scanners very high, the variable cost of tags is, and most likely will be, many times that of bar code labels, at least for the foreseeable future.

4.4 High-level Cost/Benefit and Choosing a specific Implementation

Once the prioritized list is in place, one must figure out the best project to implement. Often, this is the top project on the list, but not always. It is recommended here to conduct a very high-level cost-benefit analysis for the top two to three projects to determine which one best fits the company's RFID agenda. If the process chosen has a measurable defect rate, it is advised that one measure this defect rate for a short time such as one or two days. This will be sufficient for a high-level benefit analysis. A high level cost analysis is also something that can be done relatively quickly. The cost of the specific scanners and tags necessary for a project can be estimated to a high degree of accuracy by simply calling and talking to RFID equipment vendors. At this stage in the process, costs and benefits need only be approximations used to determine which of the top ideas is the most feasible and appropriate for the fulfillment center.

In Appendix A, Section 4A, the high-level cost-benefit analysis is completed for the top two project ideas on the list in Section 2[4]. After this analysis, it was agreed that the best place to conduct Amazon's first implementation of RFID is at the outbound sorting dock – the very last process in the Amazon fulfillment center before the customer shipments are given to various shipping companies (UPS®, FedEx®, etc.) to bring to the customers. The defect in question is that of packages which are miss-sorted onto the wrong carrier trucks. The sorting process is completely manual, and involves having an operator read the destination of the package off of a shipping label. After the shipping label is applied by one of four label operators, all packages converge onto a single, very short conveyor belt. At the end of this conveyor belt is one operator whose job it is to sort the packages onto three or four other conveyor belts which lead the packages into the cargo bays of outbound carrier trucks. All of the conveyors described here are manual (non-automatic) conveyors. However, because the associate is often pressured to sort and load packages at fast rate, miss-sorted packages are inevitable. The worst part is that whenever a shipping label is printed, it is assumed (digitally) that the package is sorted onto the correct truck. Nobody, including Amazon, will know that a miss-sort has occurred until the package is returned to the fulfillment center by the carrier. The delays and customer service costs associated with such a miss-sort had never been measured at Amazon primarily because the types of inventory at RNO2 present physical prevent the installation of automated sort machines or scanners to check the work of manual sort. RNO2, and other fulfillment centers like it in the Amazon network, carries only large, bulky items which do not fit well onto a mechanized conveyor belt. Therefore, the items are manually sorted and carried throughout the various processes on their way out to the customer.

[4] Exact calculations are omitted from the high-level analysis in the Amazon case study because they are to be used here purely as an example. The costs and savings calculated are estimates that were used only to make the decision of which project to implement.

Chapter 5: Defect Analysis

The initial, high-level cost analysis should isolate the best defect to improve with an initial implementation of RFID. The next step is to analyze this defect and the potential RFID solution. The two processes suggested here are to analyze the defect in terms of Defect/Solution Estimation and Process/Equipment Integration. The following sections will go through the thought processes associated with each process. Once again, we will use the Amazon case study here as an example of one company's journey through these processes.

5.1 Defect and Solution Estimation

In order to determine how and where to implement RFID, the first analysis should be completed on the defect and the processes surrounding the defect. A careful analysis of the process will reveal where in the process, as well as where in the fulfillment center, RFID can best be leveraged.

The first step in analyzing the defect process is to determine the causes of the defect, commonly referred to as a root cause analysis. Defects which are most appropriate for RFID are ones where operator error is difficult to avoid or tracking of inventory is particularly difficult. Once the source of the defect is concluded to be something that process changes cannot easily improve, and that RFID would be an acceptable solution, one should gage the exact defect level, and the expected improvement with RFID equipment. The improvement possible with RFID will depend on the speed and accuracy of the equipment at the time of the analysis. We will go into more detail on the exact calculation of the speed and accuracy of RFID equipment in the next chapter, but for this initial estimation, it is appropriate to estimate either 99% or even 100% accuracy for the RFID equipment to figure out the maximum possible savings. The actual read rates for RFID will become available after we conduct the equipment analysis which is detailed in Chapter 6.

Using the example of the Amazon Case, an analysis of the defect selected for the RFID implementation is miss-sorted packages at the outbound doors. The defect and solution estimation were analyzed and shown in Appendix A, Section 4B. The manual sorting of customer packages was estimated to be a 4.2 Sigma process[5] based on one day's worth of data. Anecdotal data from the warehouse shows this defect to be relatively stable at around 4.24 Sigma. As can be seen with the example, the defect analysis need not be extremely detailed. The analysis is completed to understand the scale of the defect and what tests need to be conducted when RFID equipment arrives.

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[5] Amazon has an internal approximation that manual processes have an accuracy of 98%, which corresponds to 3.55 Sigma.

5.2 RFID Integration

A key issue that will effect the cost analysis, equipment analysis, and testing of an RFID implementation is the issue of integration. By this stage, one probably understands the defect that one needs to track and most likely where the tags have to be placed on the inventory (either on the inventory itself, on cases of the inventory, etc) in order for the defect to be reduced or eliminated by a more accurate scan. (If tag placement is not yet clear at this stage, it will be after the equipment evaluation stage described in Chapter 6.) The integration and placement of the following pieces of the RFID puzzle must be determined early in order to make accurate assumption on the costs and benefits of this new technology, both now and in the future:

1. Where in the fulfillment center and in which process are the **tags** to be placed.
2. Where in the fulfillment center are the specialized RFID **printers** to be placed.
3. Where in the fulfillment center are the RFID **scanners** to be placed.
4. Where in the **data** chain will the new RFID data be used.

The best way to think about these questions is to take a look at both the physical and process views of the warehouse. A careful examination of how best to integration RFID will reveal the answers to the questions for any specific organization. During the Define phase of the project, we did a rough estimation of where various pieces of the equipment would be placed without much analysis given to the details of the integration (see Appendix A, Section 3). The following section will detail the process which took place at Amazon in 2005 which is a useful example in highlighting some of the common ideas that may enter into the decisions process for any fulfillment center attempting to integrate this technology.

5.2.1 RFID Integration at Amazon.com

Like Amazon, most customer fulfillment centers will have roughly three physical sections of the warehouse:

1. The Inbound location – where inventory arrives at the fulfillment center from suppliers, often referred to as the inbound dock.
2. The Outbound location – where the completed orders leave the warehouse to go to various delivery companies, often referred to as the outbound dock.
3. The Storage location – this is where inventory sits between the time of inbound and the time of outbound.

In the Amazon example, since the defect that was to be eliminated came at the outbound dock, one may assume that the physical integration of the RFID equipment to be near the outbound process. This is both true and untrue – depending on the specific equipment that needs integration.

5.2.1 Scanner Installation

The most obvious piece of equipment to integrate was the RFID scanners. Since we wanted to make sure that all miss-sorted orders were caught before they left the Amazon fulfillment center, the clear choice was to place scanners at the point of exit – the outbound dock doors. This way, a tag that was detected going through the wrong door could set off an alarm and be rerouted immediately, and save both Amazon and the customer the frustration of a miss-sorted package. This assumes, of course, that by the time the customer orders get to this final stage in the process, they are already equipped with tags whose identifiers are linked to their appropriate carrier destinations[6]. Because dock or warehouse doors are common places where the tracking of inventory is useful, many companies have designed scanners to fit around doors. The decision of where the scanners would be installed physically was the simplest of the hardware decisions.

5.2.2 Tag Integration

Amazon uses bar codes in many places to track various items, associations, and locations. At any one time, an item of inventory could have as many as three or four bar codes on or around it to track different things. Some of these bar codes would already be on the product when it arrived at Amazon's fulfillment center (applied and used primarily by the supplier). Others are printed and placed on the products by Amazon to internally track the items. Two of the Amazon printed bar codes were prime candidates to be replaced by RFID. Since RFID labels can be thought of as bar code stickers with smart microchips embedded within, they can really go to replace any existing bar code sticker without any loss in bar code functionality.

During the outbound process, associates have to go into the storage locations and find items that a customer has ordered. When this item is found, the associate places a new, internally tracked bar code sticker, called a "tote sticker" on the item. The placement of the tote sticker is arbitrary, so no orientation or standard is followed. This is the case because items in RNO2 are of such various sizes and shapes that there is not always a well-defined orientation. The tote sticker will stay on the item even after the box is boxed, gift-wrapped, both, or shipped directly with no further packaging. The tote sticker is attached at this stage in the outbound process to make sure that the specific item which carries the tote sticker is shipped to the customer for whom it is destined. As one can imagine, Amazon may very well ship four of the same car seats (with the same manufacturer's UPC code) to four different customers, each paying for a different speed of shipment. When the associate finds one of these car seats, the associate is picking out the car seat for a specific order with a specific customer and a specific shipper and shipping method. In the database, all of this information is all associated to the unique number of the tote sticker.

[6] At Amazon's RNO2 facility, each dock door is assigned to a different carrier. This is a variable that can be changed with the original database system. So, if a package "knows" which carrier it is to be shipped to, it also knows, by database association, through which dock door it is to exit the facility.

The second place which offered a seamless integration for RFID tags is the shipping label. The shipping labels have a series of different bar codes on them which are used by the different carriers for their internal purposes. Amazon prints different shipping labels for each of their carriers with the specific requirements of each shipper designed into the label. FedEx®, UPS®, DHL®, etc. all require different shipping labels. The outbound sorting associate reads and recognizes the different labels for the different carriers and uses these labels to sort the packages to the different trucks. Although these labels are all different in some way, they also contain similar characteristics, which is why miss-sorts often happen. These shipping labels are associated with the abovementioned tote stickers to make sure that the item attached to the tote sticker gets the correct shipping label.

It is not clear from these process descriptions which label is the best one to replace with an RFID label. From a readability standpoint, it would be best to replace the shipping labels because the shipping label is always on the outer-most box. Tote stickers go right on the product box, which are often placed in another box for protection or gift-wrapped with gift packaging. Therefore, tote-stickers are sometimes one or two layers or cardboard (over-box) or cloth (gift-wrap) from the line of sight of the scanner. However, since RFID is a passive radio-frequency technology, line-of-sight should not really be a significant consideration. For a tie-breaker between the tote sticker and the shipping label, we need look no further than our next integration question: the RFID printer.

5.2.3 Printer Placement

Amazon used slightly different printers for the tote stickers and the shipping labels primarily because these two bar codes stickers are different sizes and needed to be printed at different speeds. Tote stickers are approximately 2"x 4" and are printed in batches to be given out to associates which go to the storage locations looking for customer orders. Shipping labels, on the other hand, are approximately 4"x 6" and are printed at the final stage of production, after the box reaches the final staging area[7]. At this final staging area, the packing associate scans the tote sticker and the computer system automatically generates a shipping label at the packing associate's station. The packing associate will then a) place the shipping label directly on the item or b) put the item in another box to protect the original packaging and place the shipping label on the outer-most box or c) gift-wrap the item and then place all items into a larger box for gift delivery, placing the shipping label on the outer-most box.

The final decision was made that the tote sticker be replaced with the RFID tag and the tote sticker printer to be replaced with RFID-enabled printer. The RFID-enabled printer has the capability to both print the bar code on the outside of the sticker as well as program the microchip embedded in the printer. Two main factors decided this decision – fixed and software upgrade costs. To replace the tote sticker printers with adequate RFID printing equipment,

[7] Because of the multiple carrier-specific bar codes and numbers required on the shipping label, it is much bigger than the internally used tote sticker.

Amazon had to replace one printer, the one that printed all the tote stickers in the entire building. However, since each packing associate had his/her own printer (they all worked in parallel), Amazon would have to replace a total of eight shipping label printers. At approximately $5,000 per printer, it was definitely cheaper in terms of fixed costs to install the RFID printer for printing tote stickers than to replace all eight shipping label printers with new RFID-equipped printers[8]. Furthermore, because the shipping label software was much more complicated than the tote sticker software, a decision to change the shipping label printers would require more time to integrate in terms of software. The strain that any RFID integration imposes on a software team is going to be significant, and it was an additional objective of the Amazon RFID project to minimize this impact as much as possible. A high level analysis of the costs and benefits of replacing the shipping label instead of the tote-sticker label was completed at Amazon and is shown in Appendix D.

5.2.4 Software and Data Integration

Once the integration of the hardware is determined, the pieces of software that need to be added or changed to incorporate the new RFID functionality should be clear. At Amazon, software integration was scheduled to be completed at the very last stage of implementation – well after the equipment analysis (Chapter 6) and cost-benefit (Chapter 7). The main pieces of software integration at Amazon included associating the RFID identifier with the tote sticker bar code identifier, detecting the passing of a miss-sorted package through the wrong door, and sending a system message to the main fulfillment center computers to set off the alarm when appropriate.

The main recommendation here is that to ensure a smooth software integration, make sure that the software team is brought on early in the project. The actual implementation and integration of the software may not happen until very late in the evaluation of RFID, but the input of the software team and the estimation of the amount of work it will take to implement and maintain a new software subsystem will most likely decide some of the integration factors like it did at Amazon in 2005. It is always wise to bring in as many affected parties as possible during the Define and Analyze phases of the project.

5.2.5 Lessons from Amazon's Integration

The above sections focused on Amazon's integration of RFID equipment for the outbound miss-sort improvement project. As the reader can see, many factors will go into the decisions of where to place RFID equipment. These factors can be uncovered by looking at where (both physically and process-wise) to integrate the various pieces of RFID equipment necessary to any RFID implementation. With a clear understanding of the processes surrounding the defect and where in the fulfillment center the defect occurs, one can narrow down the places where

[8] It is interesting to note here is that in the initial, high-level cost analysis for the outbound dock implementation (Appendix A, Section 3, Part 1A), we actually estimated the cost of six printers because the original assumption was to replace the shipping label printers. We also thought that six printers would be enough, not knowing that there Amazon actually used up to eight printers during the Peak holiday season.

integration can happen and decide the final place for integration based on tradeoffs of time, money, or process. Fro example, at Amazon's RNO2 facility, a clear understanding of the purposes and processes surrounding the tote stickers and shipping labels, it was easy to narrow down the labels in the current processes to replace with RFID labels, and which printers to replace with RFID-enabled printers. These factors and decisions will be different for each RFID implementation at each company, but the steps to integration outlined through the Amazon case study should provide a good starting point for those considering such an integration project.

Chapter 6: Equipment Analysis

By far the most important analysis of any RFID installation is of the equipment itself. One can read all about the near-perfect read rates of RFID, the numerous advances the technology has made in recent years, quarters, or months, and the constantly decreasing cost of tags. However, what the media and white papers cannot tell anyone is how well RFID is actually going to work in a given facility. That is why it is imperative that one brings the appropriate equipment into the fulfillment center and test RFID with the environmental and inventory variables that only a fulfillment center setting can produce.

This chapter will first touch on the subject of deciding between different RFID standards, protocols, and vendors. Then, in the following section, we will touch briefly on the differences to keep in mind between various RFID equipment vendors. Finally, we will discuss the main topic of equipment evaluation in a fulfillment center. An extensive evaluation of the equipment was completed for Amazon's analysis of RFID, which will be presented to aid the discussion. In the end, the result of this analysis was the most important element in making the decision for RFID at Amazon in 2005.

6.1 Standards and Protocols

The world of RFID is full of acronyms, standards bodies, and confusing abbreviations. Most of these have to do with the organizations which set the standards and the standards which they set. Below are some of the most important acronyms to know, not necessarily for installing an RFID system, but just to understand the common literature:

- ISO – International Standards Organization. This international organization creates standards which all countries and technologies must obey. Various generations of RFID standards must be submitted and approved by this organization in order to become "RFID Law" which is adhered to globally.

- The Auto-ID Center. An institution set up to develop the Electronic Product Code (EPC), which is meant to track products in a global supply chain.

- EPCGlobal – Electronic Product Code Global. An organization that has set out to commercialize the Electronic Product Code (EPC). This organization is not international, but is hoping to submit its EPC standardized protocols to the ISO for international acceptance.
- Gen1, Gen2 – Generations of RFID technology. EPCGlobal created standards for generations of RFID technology. The difference between Gen1 and Gen2 RFID tags and readers include read rate requirements and memory capacity requirements. At the time of publication, Gen1 and Gen2 are the only EPCGlobal standards. Gen1 has many differing protocols which satisfy its requirements, and therefore is not likely to be approved by the

ISO (EPCGlobal did not even submit an application for approval). However, EPCGlobal is hoping to standardize a single Gen2 protocol for use in global supply chains, and it appears that ISO is likely to accept the standard by Q32006.

- Class 0, 1, 2,...5 – Classes of RFID technology. Within each generation of RFID, there exist various classes. Each class has its own characteristics for types of memory (read, read/write), passive, active, etc. The higher the class, the more sophisticated the technology. Class 0 tags are passive, read-only, and can only be written to once - at the time the microchip is made. On the other end of the spectrum, Class 5 tags are active and can not only talk to readers but also to other Class 5 tags [11].

The list of abbreviations, standards bodies, and generations of protocols can go on quite a bit longer, but the most important ones necessary are mentioned above. The bibliography of this document contains many useful web pages and other documents which can further explain the intricacies of RFID vocabulary [11, 12].

At the time of the Amazon project, Gen2 RFID chips and tags were just starting to become available at a premium to Gen1 technologies. So, it was a fairly simple decision to stick with the Gen1 standard. Furthermore, since Amazon's initial use experiment was completely internal, none of the global supply chain benefits of RFID could be realized. Amazon simply wanted to increase the accuracy of moving inventory within the walls of their own fulfillment center, so the Gen1 standard was more than enough.

Choosing between which class of tags to use for Amazon's initial implementation was not as trivial as the choice between Gen1 and Gen2. Although it is tempting to evaluate the various classes based on their respective capabilities and attempt to match the capabilities with the intended use for RFID, the author recommends first evaluating the market to see which tags are the most economically conservative. In the Amazon case study, Class 0 tags would have been sufficient for the purpose of catching miss-sorts. However, at the time of the study, Class 0 tags were being phased out by many manufacturers and an order of Class 0 tags would have meant a special manufacturing run, which made the Class 0 tags more expensive than Class 1 tags. Therefore, even though the Amazon RFID implementation did not require the full capabilities of Class 1 tags, the decision was made to move forward with the cheaper Class 1 tags over the antiquated Class 0 tags. As RFID technology continues to advance, it is very likely that any fulfillment center implementation will be planned during the transition between two classes or generations. It would not be unexpected that future implementation decisions and choice of tags be determined based more on market conditions for certain classes of RFID tags rather than on the specific needs of the project.

6.2 Vendor Selection

For the purposes of this document, it is not necessary to understand everything about RFID, its history, and its vocabulary. The most important thing is to understand which tags, readers, and scanners a fulfillment center has to purchase for the type of project that is being considered. The easiest way to figure this out is to call the vendors of bar code technology hardware that the facility is currently using. The vendors of bar code hardware almost always have lines of RFID products that they are ready to supply to current customers. If the specific vendors do not make the necessary equipment, they will most likely know a partner company or vendor which can provide the necessary hardware. The main decisions to make are usually between various classes of RFID tags and the various vendors that are competing for RFID profits.

The selection of which vendor to use will most likely depend on a company's relationship with vendor networks, pricing, and various other internal matters that are beyond the scope of this document. However, it is highly recommended that fulfillment centers looking to adopt RFID as a technology first attempt to borrow evaluation equipment to complete the evaluation of hardware in the fulfillment facility. This was a common practice for RFID vendors contacted for the Amazon project. As the reader will see in the following chapters, evaluation and testing of the equipment yielded many answers to the RFID mystery which allowed Amazon to make decisions on the eventual purchase of the expensive RFID capital equipment.

6.3 Equipment Evaluation

Following the flow of the implementation strategy suggested in this document, the fulfillment center will have, by this point, targeted a defect for the RFID implementation. Different defects will require different RFID equipment, so this document will not detail which types of equipment to test. What we will discuss here is the types of metrics with which to measure the RFID equipment and show how the metrics were measured in the case of the Amazon RFID implementation.

6.3.1 RFID Experimental Design and Useful Metrics

When one reads about RFID read rates at near 100% levels or the first pass yield of RFID in various white papers and industry journals, it is often not clear how this performance was achieved. Specifically, it is usually not specified what the environmental obstacles were that the tags had to overcome. For example, on average, how far apart were the tags from the tags? How fast were the tags moving through the readable range of the scanners?

These questions may not be important to academics or equipment vendors, since every facility and RFID implementation is different, but these questions are of extreme importance to any fulfillment center looking to install RFID to combat a particular defect. The first suggestion here is that one must design an experiment which can realistically measure the RFID equipment, simulating the envisioned operation with RFID as much as possible.

For the Amazon miss-sort project, it was decided that dock door scanners would be used on the outbound doors with tags on products going through the doors, on their way to the shipping companies. To simulate the conditions exactly, we used an actual outbound door at RNO2 and pulled a truck right up to the door. We then installed the type of dock door scanner that we would use on all doors for a full implementation on just this one door, and passed RFID-tagged products through the door to get a sense of the actual read rates. We selected twenty products at random from the warehouse, and placed RFID tags on these items, and "loaded" the truck with these items in the various ways that operators load items at the time of the experiment. Environment variables that we changed for various runs of the experiment were the exact decisions which needed to be made for RFID. For example, we tested the reading of products with the scanners placed at various distances to the products themselves. We also tested different ways that the products normally get loaded, such as in a batch with a pallet jack and one at a time by hand. The details of the Amazon experiments can be found in the Amazon Measure and Analyze Document in Appendix B.

We will call each setup that is tested an "experiment". It is recommended that each experiment be run multiple times for redundancy. In the nomenclature below, we will call each run of a particular experiment a "run". Also, because RFID tags are not incredibly durable, it is not uncommon for a tag to get damaged during an experiment and stop working. The resulting data analysis should take this variable into consideration both from a financial and operational perspective.

So, first, we must define the basic variable for these experiments:

Total Reads = The total number of reads recorded of each product or tag during an experiment.

Total Seen = The total number of unique tags seen during all runs of the experiment. For this measurement, regardless of how many times a tag is seen during each run, it is only counted once.

Total Possible = Total number of possible reads taking into account that some tags may have been damaged or died prior to the start of the experiment.

Alive / Visible Rate = Total Seen / Total Reads (known as the "visible" or "alive" rate)

Actual Seen = The actual number of unique tags seen during an experiment. It is not certain that all tags will be seen during each run of the experiment. For example, let us assume four runs per experiment. If a tag is seen across three runs and not the fourth, it counts as "3" in this count.

Read Rate: Actual Seen / Total Possible (This rate discards invisible/non-readable tags during an experiment).

Success Rate: Read Rate x Alive Rate = Success rate including visibility and readability.

These variables are the ones which the author found to be the most useful in determining the effectiveness of RFID when conducting the implementation at Amazon. Of course, for a different installation or different type of inventory tracking, it is expected that other variables and metrics may arise. These variables here are offered as a guideline to get the project manager thinking about the types of equipment testing that needs to be completed.

6.3.2 Using the Evaluation Metrics at Amazon

In order to illustrate how these variables were used at Amazon, below is a description of one of the test experiments conducted during the Amazon case study. The complete report which was produced at the end of all the tests conducted at Amazon can be found in Appendix B, sections 1-3. Pictures and detailed descriptions of how the experiments were set up and conducted can be found in Appendix C.

At Amazon, we concurrently tested three different RFID tags named here as "AD_IN", "AD_ST", and "Zebra"[9]. We placed three RFID tags on each of the twenty products that were passed through the scanners. It is recommended that if multiple tags are to be used, that they are oriented in the same direction, and be placed relatively close to each other. Environmental variables that varied between different sets of experiments included the distance between the scanner and the tags, how the products were loaded (either all together on a pallet or one-by-one on a conveyor), and whether or not the scanners were set at an angle. Details on the experimental variables and the tags used for these experiments can be found in Appendix C.

	AD_IN	AD_ST	Zebra
Total Reads	329	309	200
Total Seen	20	18	15
Alive/Visible Rate	100%	90%	75%
Total Possible	80	72	60
Actual Seen	59	57	46
Read Rate	74%	79%	77%
Success Rate	74%	71%	58%
Missing #s		2, 12	2, 7, 12, 15, 19

Figure 8: Sample experiment results from Amazon's Equipment Evaluation

For this experiment, we loaded 20 products (a.k.a. RFID tags on Amazon products) at the same time on a pallet through the set of dock door scanners. A simple computer program (supplied by the scanner company) recorded the tags that were seen. Since there were only 20 unique products, the **Total Seen** could not be greater than 20. We did four runs of this exact experiment, thus the **Total Possible** unique tags could not exceed 80.

For purposes of this example, we will explain the performance of the AD_ST tag. During the four runs of the experiment, 309 total reads occurred. **Total Seen** was only 18, which means that two of the products were completely missing, given four chances to be read. These two products were identified as product #2 and product #12. 18 out of 20 products identified yields an **Alive**

[9] Not surprisingly, these tag names referred to the vendors who contributed these tags for our experiments. "AD" tags were contributed by Avery Dennision®, and the "Zebra" tags were from Zebra Technologies®.

Rate of 18/20 or 90%. Assuming that the AD_ST tags for products #2 and #12 were destroyed before the experiment even started (a safe assumption since it is rare that a tag be missed by scanners in all four runs), the **Total Possible** during this experiment of the AD_ST tag was 4 x 18 = 72. Sifting through all 309 reads revealed that 57 of the reads were unique in each run, thus, our of a **Total Possible** of 72, **Actual Seen** = 57. This yields a final read rate of 57/72 ~ 79%. We must still take into account the fact that two of the tags were not seen at all. It may not be the fault of the scanners that these tags were broken during testing, but they are, nonetheless, missing[10]. The **Success Rate** reflects this quality difference as it is **Read Rate** x **Alive Rate**, which in this case is 90% x 79% ~ 71%. So, we conclude from this test, that under the experimental conditions of Test 6, the success rate of reading an RFID tag was 71% for the tag AD_ST. This measurement of the **Success Rate** was the one used in the final analysis at Amazon because it took into account the quality and performance of all of the pieces of the RFID puzzle.

Multiple environmental factors were altered and the products retested at Amazon. This will be the case at most facilities since there are almost always corner cases or special processes that are also using RFID. For example, at Amazon, multiple experiments were conducted on items that were gift wrapped using an oversized cloth bag, over-boxed[11], and not wrapped at all. Surprisingly, these various types of packaging did, in the end, affect the read rates of the RFID tags at Amazon, even though the materials used for packaging (cardboard, paper, and cloth) are not known to be prohibitive to the transmission of radio frequencies.. For detailed analysis of all experiments described here, please refer to Appendix B, sections 1-3.

6.3.3 Final Notes on Equipment Evaluation

It cannot be stressed enough the importance of on-site equipment evaluation. The metrics suggested in this chapter are by no means exhaustive, but should give any project manager a good start in terms of thinking about what is important to their specific implementation. Equipment often takes a long time to get to the warehouse. It is advised that once the defect has been determined and the equipment necessary is obvious, that the test equipment be acquired as soon as possible. The defect analysis portion of the project is important, but can be done concurrently with equipment acquisition.

RFID continues to improve both in terms of read accuracy and read range. However, no amount of improvement will be able to guarantee that RFID equipment will work to the level of accuracy advertised by the academic white papers or by vendor advertising. So, in short, get test equipment as soon as possible and set and run the experiments promptly.

[10] All tags were qualified before use in experiments to be in readable by the scanners.

[11] Products which were deemed unsafe to travel in the manufacturer's packaging were placed inside an additional Amazon box and then shipped. Since the RFID tags in the Amazon experiment were applied prior to this decision, over-boxed items had RFID tags on the inside instead of the outside of the shipped box.

Chapter 7: Cost-Benefit Analysis

Every company has a different way to value projects and capital equipment expenditures. Depending on the type of company or the mindset of the financial arm, the exact method of cost benefit analysis can range from strictly financial[12], to one that is more accounting focused[13], or even one that is designed specifically for new products[14]. In his thesis for how RFID should be evaluated for the defense industry, Shah actually includes an "RFID Calculator" to assist in the financial calculations of RFID. [9] RFID integration usually involves a heavy capital investment, and no implementation strategy would be complete without a thorough cost-benefit analysis. However, this chapter will not suggest how one should go about doing a cost-benefit analysis. It is assumed that the organization which is implementing the RFID solution will have a systematic way of conducting such an analysis already in place, or one can be constructed from one of the financially- focused sources documented above. The following sections will highlight some of the main costs and benefits of RFID technology to keep in mind as one conducts such an analysis, as well as present the cost-benefit analysis completed for the Amazon case study as an example. Exhibits here include snapshots of actual documents created at Amazon during the extensive financial analysis to give the reader a good idea of the types of expenses and savings involved. Of course, much of the exact data specific to Amazon's operations have been removed from the original analysis for confidentiality purposes.

7.1 Key Cost-Benefit Variables

As expected, the hardware and software components of RFID mentioned in section 2.2 of this document make up most of the costs of the implementation. The table below summarizes the main costs of the implementation:

Fixed Costs	Variable Costs
Scanners (portable or stationery)	RFID Tags
RFID-enabled printers[15]	Software maintenance
Software Development	
Installation (networking, power, contractor, etc.)	

Although every RFID implementation is different, most of the costs associated with an initial implementation are included in one of the categories above.

Unlike costs, the benefits derived from an RFID implementation will be very different for every implementation, every company, and even different implementation at the same company. One

12 See Brealey & Meyers, Chapters 2, 5, 6, and 7. [15]
13 See Zimmerman, Chapters 3 and 8. [16]
14 See Ulrich and Eppinger, Chapter 15. [17]
15 Some bar code printers can be converted to RFID printers by adding an additional module. For simplicity, this document will treat printers as complete entities.

of the most difficult things to quantify is the benefit of improved tracking of inventory to a company, especially in the case where the tracking is internal, rather than across the supply chain. Benefits of higher resolution of one's inventories can start as soon as the data is tracked, such as in the Amazon example where defects are caught before they leave the warehouse. Additional benefits are realized whenever the data logged by RFID is referenced. Traditional methods of tracking inventory inevitably contain certain levels of error. Using an RFID system to cut down on instances of error will only make sense if the benefit of having more accurate information is worth the cost.

It is a common myth that the labor savings gained from RFID will pay for the technology.[55] The fact is that, especially at the prices of today's RFID systems, the labor savings alone will not be sufficient. Thus, it is prudent that every RFID manager search for the various places in the internal and external supply chain to understand the full benefits. The table below lists some of the common benefits of having increased tracking granularity from having an RFID system compared to a manually operated bar code system:

Operational Benefits

- Decreased direct labor
- Increased inventory visibility
- Decreased incremental labor cost to adding additional scanning points
- Increased confidence in data (due to less operator error)

Customer Service Benefits

- Increased customer goodwill
- Increased positive word-of-mouth advertising
- Decreased defects lead to decreased costs in customer service, customer concessions
- An RFID-enabled Fulfillment Center increases consumer/customer confidence

It is a common myth to believe that the biggest RFID savings will come from a decrease in the amount of direct labor needed to track packages, and that this labor savings will also be the easiest to measure. Believers of this common myth are wrong on both counts. In most cases of RFID implementation, and certainly in almost all cases within a fulfillment center environment, tracking is already being done within the warehouse. One will be able to replace physical operators with machines that scan automatically, and this will lead to a cost savings. However, it is only in the case that operators are present to do nothing other than scan packages, an unlikely occurrence, can one count their salaries and benefits expenses directly as RFID savings. Most operators also have other jobs such as ensuring quality, and checking for defects on boxes, which cannot be done with RFID scanners. In the end, a complex formula will have to be calculated to represent the percentage of the actual labor force is saved. Not only is the percentage of an operator's time reduced because of RFID difficult to quantify, the increased accuracy of RFID is also a financial challenge. For example, if we assume that a manual sorter is at best 98% accurate with a single scan for verification, we would have an operational accuracy of 3.55 Sigma as a package goes by the operator at the point of tracking. With RFID, several factors change. Let us also assume that, in the simplest case, you replace this operator (and his annual salary) with an RFID scanner. This scanner most likely has an accuracy beyond Six Sigma, and performs over 1,000 scans in the time that it takes the operator to complete a single scan. The increased accuracy is phenomenal, and to replicate the RFID accuracy manually would take hundreds of manual operators that do nothing but scan the same bar code multiple times at a single point.

Additionally, the benefits outside of direct labor savings become even more difficult to measure. Amorphous cost objects such as increased customer satisfaction, decreased customer complaints, increased goodwill, and the ability to access information in two fewer mouse-clicks are difficult to measure financially. Nevertheless, these are the challenges that every project manager must face when evaluating a disruptive technology like RFID. At the time of this document, RFID is still an emerging technology, which often means that the decision to adopt the technology is both a) heavily financially based (because of limited network effects) and b) extremely unclear. This usually means that an exhaustive cost-benefit analysis must be completed in accordance with the rules and regulations of the parent company. A finance professor once said something about risk and return that very appropriately applies to the cost-benefit decision of an RFID project: "In the real world, you can be sure of one thing: All the easy decisions in finance, where the risk can easily be justified by the return or vice versa, have already been made. What will be left to you are the corner cases and close calls where the risks and returns are fairly well balanced, and the decision is completely unclear." [14]

7.2 Upstream, Downstream, and Tag Cost considerations

When analyzing the cost-benefit of the RFID implementation, it is highly recommended that the manager considers various upstream and downstream benefits – both within the walls of the fulfillment center and beyond. It is very likely that the defect that is targeted for experimentation and initial implementation may not have enough benefit to justify the full cost of the RFID system. This is the exact reason that we construct a full list of possible projects (during the Define process in Chapter 4). With these other projects in mind, it makes it easier to consider other uses for the same RFID tags within the same fulfillment center, or fulfillment center network, to derive benefit. Additional, serial uses of the same RFID tags will lead to minimal additional costs, and a step function in terms of additional benefits.

When one starts to think about the additional benefits of RFID in a serial context, we start to see the full supply chain benefits of RFID which we discussed in Chapter 3. One recommendation here is that if the variable costs of RFID (a.k.a. the cost of tags) are difficult to justify, one may benefit from negotiating with companies adjacent to the fulfillment center in the supply chain such as transportation or storage companies. An agreement that may benefit all parties may be one where the costs of tags are shared between consecutive links in the supply chain. Of course, if one can convince a supplier to pay for all tags to be used in their facility, one can derive the most benefit and just link up the software systems and scanners to "look" for the supplier tags when they enter the fulfillment center. The "Who is going to pay for the Tags?" question is one that is common to all RFID implementations.

7.3 An Overview of the Financials behind the Amazon Case Study

The Amazon cost-benefit model was completed as a Microsoft Excel® spreadsheet, which is highly recommended. As the cost of RFID scanners and tags continue to drop with advances in technology and manufacturing, it is likely that a dynamic spreadsheet can be used many times to compute and re-compute the financial figures with periodic updates. It is also quite possible that not only will costs decrease, but that additional benefits will be added on to justify the costs. Furthermore, if the prevention of a single defect by a proposed RFID system is not sufficient, it is possible that a series of RFID implementations, where a single tag can be reused to solve many different defects, may be enough to justify the costs. In a spreadsheet, it would be trivial to add additional projects and benefits to offset the high costs of an RFID system.

To assist with the difficult task of generating a complete cost-benefit, this section will present the rough costs and benefits categories used during the Amazon Case Study. The main categories considered for the RFID analysis at Amazon are listed below:

Cash Flow Analysis
Cost
Equipment
Dock Door Scanners (8x Symbol DC600)
RFID Printers (2x Zebra R170Xi)
RFID Tags
Estimated Freight
Site Preparation
Total Cost
Benefit
Labor savings
Problem solve
Extra scans necessary to get accuracy
Reduction in consumables usage (labels)
Free Replacements
Customer Contacts Savings
Preventable Consessions
Preventable Upgrades
Other Benefits
Total Benefit
Net Cash Flows

Figure 9: Amazon RFID Project Top Level Cost-Benefit Analysis

After many detailed interviews with managers from various departments within Amazon Operations, we established the above categories as the ones which would make the biggest difference in the financial decisions regarding RFID. We then set out to determine the actual financial impact of each of these categories using historical and measured data at Amazon fulfillment centers. Some of the details regarding the subcategories and assumptions made for this analysis are listed in Figure 10 below:

Labor Calculations
Direct Labor
Problem Solve (min/missort)
Scanning Speed (scan/sec)
Indirect Labor
Training/HR/Hiring
Customer Service Costs[10]
Variable Cost/customer contact[1]
Average cost/concession[2,3]
Free Replacements (Q304-Q405)
Total Free Reps at RNO2[5]
Missort controlable[4]
Measured Data
RFID Read Rate at Outbound
Avg. Reads/Item
Cost per Tag
Daily number of missorts Non-peak[7]
Estimated daily missorts at Peak[8]

Missorts at RNO2
Estimated Off-peak missorts
Projected Peak Missorts[8]
Total missorts
Missorted Packages at RNO2
Total Days Measured (8/15 - 10/3)
Total Missorts
Estimated Upgrades (< 2 days)
Estimated Free Reps (< 0 days)
Avg. Contact / missort
Avg. Concession / missort

Figure 10: Details of Cost-Benefit Analysis Spreadsheet at Amazon.com

These examples are placed here for purposes of an example only since the exact number have been excluded for purposes of confidentiality. As can be seen here, the financial factors used at Amazon include the following:

- Labor rates: direct and indirect
- Customer contact costs - the cost to Amazon whenever a customer calls to complain about a late or missing shipment
- Free replacements - the cost of Amazon shipping a customer a new item because the original item never arrived
- Concession costs – the average cost of concessions that Amazon makes to customers because their package never arrived
- Total miss-sorts per day: during peak and off-peak periods

Through this example, it can be seen how the Success Rate discussed in Chapter 6 is a vital part of the analysis and must be mathematically inserted to calculate the quality of RFID. Many people assume that RFID is a near-perfect system that has close to 100% read rates. This is definitely the case if you believe all the white papers on RFID and the vendor information regarding read rates. This is the exact reason that one must complete the analysis described in Chapter 6 to evaluate and qualify the equipment in the facility that it is to be used and under the environmental variables that will stress the RFID systems.

Part III – Conclusions and Additional Considerations

The previous sections of this document include a complete set of recommendations for the implementation of an RFID system in a customer fulfillment center. In the following sections, we will summarize the major recommendations as well as touch on some of the peripheral issues regarding RFID technology that the project manager should keep in mind when attempting an implementation.

Chapter 8: Conclusions and Final Verification

8.1 Summary of Project Recommendations and Project Learnings

Throughout this document, recommendations were made regarding various decisions that a project manager must make during the course of an RFID evaluation. Below are the main recommendations and lessons learned from this document taken from selected chapters:

Project Definition

- Start off with a well-defined framework to go through a technology evaluation (DMADV)
- Work on the operations line to create a list of possible initial implementation projects
- Prioritize the list by talking to as many people in the company as possible
- Conduct a high level cost-benefit for the top projects to determine which defect to go after first
- As soon as defect is targeted, start process to PROCURE TEST EQUIPMENT

Defect Analysis

- Perform root-cause analysis of defect targeted for initial implementation
- Use the results from analysis to determine tests for the equipment when it arrives
- Analyze processes to determine the best (most unintrusive) places to integrate RFID scanners, printers, tags
- Determine where the resulting RFID data will be the most helpful in eliminating defect

Equipment Analysis

- Select or use market data to determine protocols and vendors for test equipment
- Perform real-life equipment evaluation with real products, real defects, and real equipment
- Choose the appropriate variables (such as **Success Rate**) to measure during testing
- Run exhaustive tests with test equipment in an attempt to catch all corner cases

Cost-Benefit Analysis

- Use Success Rate as the final read rate for RFID in cost-benefit analysis

- Beware of complex calculations of labor savings – it will most likely not be the driver of either cost or benefits of the RFID installation
- Look for upstream and downstream benefits whenever possible – both within the fulfillment center and beyond
- Use a dynamic tool such as a spreadsheet for cost analysis so that future analyses can be done quickly when the cost of equipment or tags decrease

8.2 Next Steps in the Implementation of RFID

Once the equipment testing and cost-benefit analysis are complete, the project manager should know with a good degree of confidence whether or not RFID will be a worth investment in for the fulfillment center. In the spirit of the DMADV framework, it is recommended that one develops a test or pilot to stress the RFID system and verify the impact of the new technology using the pilot. The difference between the pilot and the experimental testing is that the pilot would take place during normal business operations and the goal would not be to understand the read rates and the effect of environmental variables, but to understand at a greater scope, how the RFID system would impact operations and the business as a whole. There is a limit to how accurately one can estimate affects such as labor savings and increased customer satisfaction. The only real way to know how big of a difference RFID can make will be through actual use of a full scale system. Depending on the size of the fulfillment center network, this pilot may first start out at one fulfillment center, and then get pushed out to other ones with similar equipment or geographies. How to expand an existing RFID implementation is beyond the scope of this document, but it is the hope of the author that, by that point, the most complex process of testing, evaluating, and qualifying RFID has been completed, and that this document was helpful to the user during the initial implementation process.

Appendix A: The Amazon Case Study Define Document

Section A-1: Project Summary

Chartered by: Operations Management **Priority:** Evaluation

Overview

This project will evaluate the costs and benefits of using Radio Frequency IDentification (RFID) at Amazon fulfillment centers, particularly FC/NC facilities.

Project Scope and Deliverables

The scope of this internship project will be to develop an RFID business case analysis and implementation strategy for AMZN's US fulfillment center network. One possible deliverable for this project is the development and implementation of an RFID pilot project at RNO2.

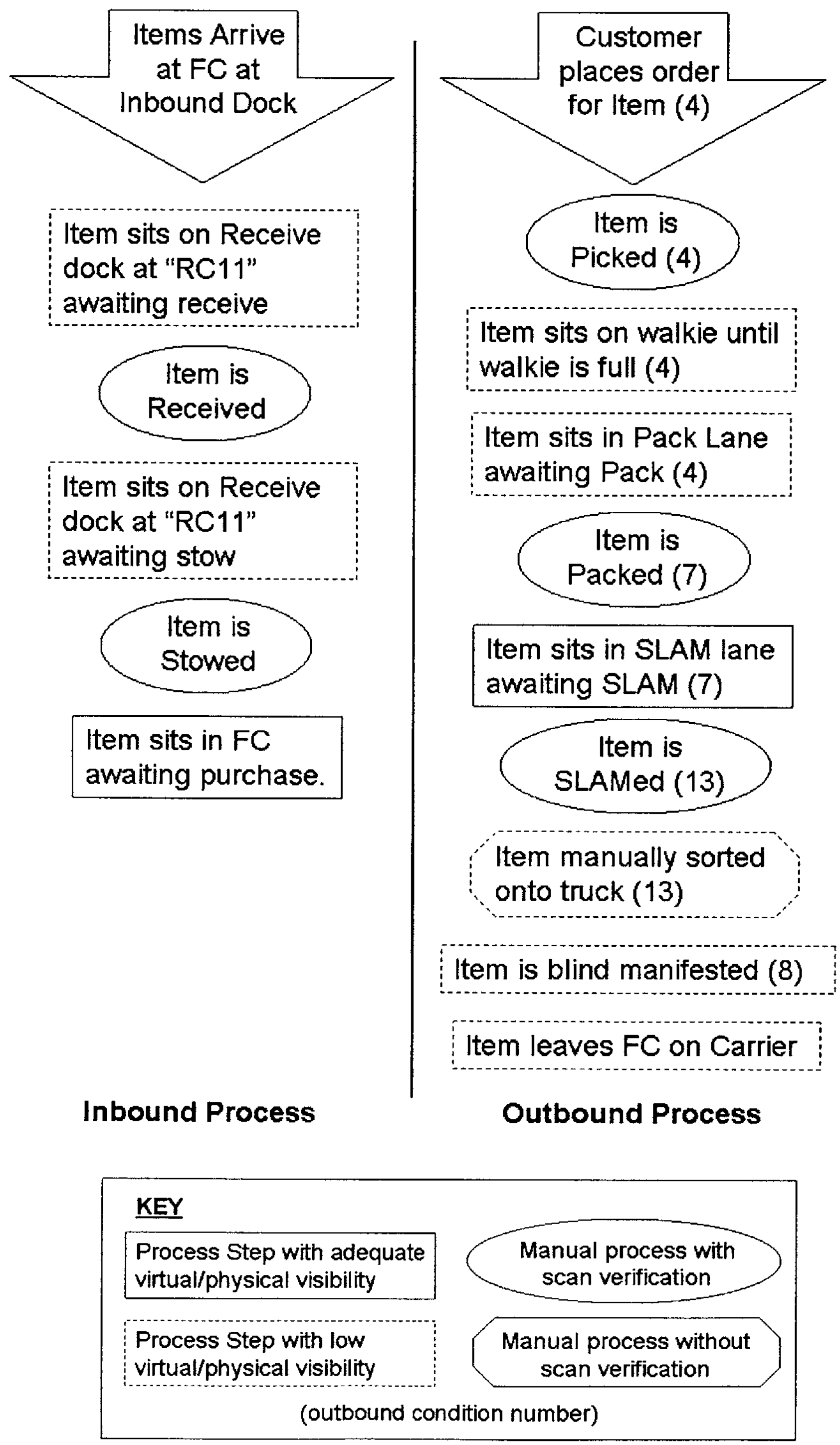
Preliminary Problem Statement

Tracking of orders and shipments at FC/NC facilities is more difficult than that of sortable sites because of the dimensions and properties of FC/NC items. A new technology which can help with higher resolution tracking of such items is RFID. Amazon would like to evaluate this technology - its accuracy, costs, and benefits - and determine possible implementations in the FC/NC fulfillment centers.

Project Notes

Unlike most DMAIC or DMADV projects this project starts out with a new technology solution (RFID) and seeks a problem or defect to solve that is most beneficial to Amazon at this point in the solution's technological progress. The approach taken for the Define portion of this project was to complete a thorough analysis of the various process paths at the Reno FCs and look for appropriate places to implement a pilot project utilizing this new technology. All of the possible projects found during this analysis are listed in a prioritized order in Section B of the Appendix. A high level cost-benefit analysis was then completed for the top two potential projects (Section C).

Section A-2: High Level Process Map for RNO2



Section A-3: Summary of potential uses of RFID

1. Area: RNO2 – Outbound ship dock
Problem: Packages are going out on the wrong trucks cause delay in shipping
Items to Tag: packages to be shipped
Tagger location: Ship lanes (when shipping sticker applied). (Could also be combined with #2 below when tagging picked items.)
Scanners: Placed at each outbound door (7)
Why RFID: RFID presents an easy, passive solution to present an audio/visual signal at the very last stage of the outbound process without disrupting current workflow or SOP.
Non-RFID fix: Truck packers can be asked to scan each item as it goes into the truck. This would cause an additional stage in the process and add both complication and process time to flow.

2. Area: RNO2 – Pick Path
Problem: Little to no visibility between item's picker and SLAM line
Items to Tag: either all picked items or all premium picked items
Tagger location: Pickers (apply tag when applying FC stickers)
Scanners: All walkies (8), scanners on packing lanes (4)
Why RFID: Because the pick path is often long and spread out throughout the warehouse, management has a difficult time locating associates and picked premium packages during critical periods. RFID technology would allow for packages to be automatically tracked and linked to the associate or walkie that the packages are linked to.
Non-RFID fix: Most of this information will be available or can be made available when RF pick is fully integrated at FC/NC facilities such as RNO2. Software enhancements and possible changes to SOP will have to be made to current processes to make pick path information available to management.

3. Area: RNO2 – Receive Lanes
Problem: We often have FUD sitting in receive lanes which are all labeled RC11 even after receive.
Items to Tag: items or pallets as they arrive into the FC
Tagger locations: Receive lanes
Scanners: above receive lanes (for grid)
Why RFID: Because items are often moved and re-moved during the receive process to make room for other items, it is difficult to have accurate, high resolution tracking of received items until they are put away into bins.
Non-RFID fix: Assign drop zone locations (and associated bar codes) in the receive lane and require associates to scan each item/pallet when moving product.

4. Area: RNO1 – High-value item theft.
Problem: Associates are stealing high value items from bins, goldfish

Items to Tag: anything over $100 or a certain value AND associates to detect inappropriate access.
Tagger locations: Receive dock / RSR
Scanners: high value cage, other discrete locations such as employee exits
Why RFID: This passive technology would be added method of security with higher resolution tracking of associates and valuable items.
Non-RFID fix: Increased security and more cumbersome searches of associate items upon leaving the FC.

5. Area: Premiums at Deadline
Problem: It's tough to find premium totes in a buffer of totes waiting for processing. Right now, you have to go through the buffer and scan every tote to figure out if it's high-priority
Solution: RFID tag on each tote. Develop a "metal detector" type reader that you wave in the vicinity of totes, and it beeps faster/louder when the reader is near a tote containing premiums
Why RFID: Using RFID would allow items in multiple totes to be read at one time.
Non-RFID fix: More optical readers for reading totes could be installed along tote buffers. (There is no way at the moment to read individual items in totes but this type of resolution may not be necessary.)

6. Area: Pack-line labor management
Problem: It's tough to measure/manage team productivities on pack/SLAM lines. People are moving quickly from station to station, going on and off task as they pack, then get supplies, then solve a problem, then move to another packing station, etc. It's unreasonable to ask them to log into the labor management tool for each change, because they might spend less than a minute on one activity before moving to another – in other words, non-RFID techniques have not been found.
Solution: Place RFID tag on each person (only to be worn while working on the pack line, if necessary for privacy concerns), and associate each physical zone in the pack area with a different activity
Why RFID: Able to give high resolution to associate positions without requiring time-consuming login time at each station.
Non-RFID solution: Install a high number of badge readers at each position so that it is as time efficient as possible for an associate to scan his/her badge as he moves from station to station.

7. Area: RNO1 - Problem Solve / DC Analysts
Problem: We need a better way to track "exceptions" that may be premium orders.
Items to Tag: Amnesty totes/items, problem solve items/totes
Tagger locations: Pickers, Stowers
Scanners: DC Analyst locations, DZs for items to be restocked
Why RFID: Because items marked for problem solve or DC Analysts are moved frequently based on space needs and processing priority, it is often difficult to track their

movement accurately. RFID would allow for higher resolution tracking without requiring associates to scan each item every time something needs to be moved.
Non-RFID fix: Requiring associates to scan each item to each location when moved. This solution would also require bar codes for "zone" that the item could be in.

8. Area: RNO1/RNO2 – Asset Management
Problem: We need a way to track various non-consumable assets to make sure we can find these asset (and the products associated with them) when needed.
Items to Tag: totes / trucks / pallets / people
Tagger locations: Receive department of non-inventory process
Scanners: depends on use
Why RFID: Using this technology would make the tracking/receive process of these assets as passive as possible.
Non-RFID fix: Assign bar codes to all items and require all receivers and users of these items to scan assets when using/moving them.

9. Area: RNO1 – High-value customer returns
Problem: We need a way to authenticate high value returns on items
Items to Tag: high-value items which are shipped to customers
Tagger locations: Pickers or receivers or manufacturers
Scanners: Customer returns desk/area
Why RFID: This would give each item a unique identification so that we can tell which customer received/returned the same item.
Non-RFID fix: An additional bar code to identify each item uniquely which can be tracked through the Amazon system.

10. Area: RNO1/RNO2 – Transfers (Outbound)
Problem: It is difficult to track totes/pallets when transferring inventory between FCs.
Items to Tag: pallets/totes/items tagged for transfer
Tagger locations: Transfer/outbound Dock
Scanners: Transfer/outbound Dock and transfer/inbound dock
Why RFID: Using this technology would make the tracking/receive/transfer process of these totes/items as passive as possible.
Non-RFID fix: Assign bar codes to all totes/items and require all receivers and of these items to scan totes/items when receiving/transferring.

11. Area: RNO1 – Jackpots / RNO2 - Kickouts
Problem: These are often premiums and fastrack orders which sit and expire.
Items to Tag: kickouts and jackpot packages
Tagger locations: TBD
Scanners: TBD

12. Area: RNO1 – Crisplant / SLAM
Problem: Condition 4 is too broad. We need higher resolution for premium orders.
Items to Tag: Premium totes or items

Tagger locations: Pickers
Scanners: Various stages of Crisplant (picker conveyor, chutes, inductors stations)

13. Area: RNO2 - RSR
Problem: In RNO1 RSR, we are scanning pallets to vehicles. We need a parallel process in RNO2.
Items to Tag: Pallets to stock.
Tagger locations: Receive dock.
Scanners: Walkies

14. Area: Rental DVD's
Problem: time spent scanning the DVD over and over again, and inaccuracy at inbound because it's easy for customers to switch DVD from one package to another.
Item to tag: Rental item
Tagger location: initial stock receive
Scanners: Anywhere item scans exist today

Section A-4: High Level Cost-Benefit Analysis for Top Potential Uses

1. Outbound Ship Dock

A. Cost Analysis (Calculated on Daily Basis)

Calculator Input		
Packages shipped / day	PkgShip	
Non-RFID Solution		
Number of Associates needed for Scanning	4	
Daily Labor Cost	4 x Labor Costs = L	
Daily Variable Cost (Labels)	PkgShip x LabelCost	
Total Daily Cost:	Daily Labor + L = A	
One time Equipment Cost	$1,840.00	
RFID Solution		
Number of Dock Doors to track	8	
Cost of Tag	$0.15	(Gen0 = 0.15, Gen1 = 0.4)
Daily Variable Cost (Tags)	PkgShip x Tag Cost	
Total Daily Cost:	PkgShip x Tag Cost = B	
RFID Saving	B - A	
Fixed Equipment Cost		
Scanners	$25,828.80	
Printers	$24,480.00	
Total Fixed Cost	$50,308.80	

* Some numbers had to be removed from these calculations for confidentiality purposes.

B. Defect Analysis

Defect Analysis	
Packages shipped 7/20/05**	PkgShip
- Estimated FedEx Packages	NumFedEx
Mis-sorts returned on 7/20/05*	Miss-sort
- Estimated for FedEx Ground	(NumFedEx / PkgShip) * Miss-sort = X
- Does not include internal/external transfer	
Defect rate for FedEx Packages	X / NumFedEx
Current Number of Manual Scans	1
RFID Scans	
Single Scan at time of entry to truck	3000
- 1000 scans per second	
- 3 seconds of singular scan	
Scans while in truck	3000
- Assume one of 20 packages being scanned	
- Total visible time of 1 minute	
Number of RFID Scans	6000

Estimated Mis-ship Returned by Carrier*		
Eagle	0%	
Fed Ex Ground	20%	(No Internal Transfer)
FedEx Air	5%	
UPS Next Day	0%	(Internal Transfer OK)
UPS Ground	65%	(mostly FedEx Packages)
Airborne	5%	
USPS	5%	

Actual Shipments on 7/20**	
Eagle	0.74%
Fed Ex Ground	15.61%
FedEx Air	1.69%
UPS Next Day	0.36%
UPS Ground	77.93%
Airborne	1.14%
USPS	2.54%

* Some numbers had to be removed from these calculations for confidentiality purposes.

2. Pick Path

A. Cost Analysis

Non-RFID Solution		
Number of packages shipped	PkgShip	
Number of hours spent hunting critical packages	2.5	
- From 3pm - 5:30pm daily		
Number of associates required on 7/20/05	2	
Numer of packages shipped on 7/20/05	PkgShip	
Packages per associate	PkgShip / 2	
Total Cost of Labor (based on num packages)	2.5 x 2 x labor rate = A	
Daily Variable Cost (Labels)	PkgShip x CostLabels = B	
Total Daily Cost:	A + _B = C	
Total Fixed Costs:	$0.00	

RFID Solution		
Cost of Tags	$0.15	(Gen0 = 0.15, Gen1 = 0.4)
Daily Variable Cost (Tags)	PkgShip x $0.15 = D	
Total Daily Cost:	D	
RFID Savings	D - C	
Fixed Equipment Cost		
Scanners (2)	$3,996	
Printers (1)	$4,896	
One-time fixed cost	$8,892	

Section A-5: Reviewer's Guide Questions

- Why is a DMADV required as opposed to a DMAIC?
  => Because RFID is a new technology that Amazon is not currently using, this project is a better fit for the DMADV framework.

- What data was used to identify this new opportunity?
  => Miss-sort estimates, associate interviews, current information regarding pricing on RFID.

- What is the need for this process or its redesign?
  => Higher tracking resolution is needed to improve on current processes.
  - What is the gap in the existing process (if any)?
    => Many gaps in virtual-physical mapping throughout RNO2.
  - What is the preliminary assessment of benefits?
    => Higher resolution tracking data for increased accuracy in virtual-physical map.

- Who are the customers?
  => Internal – All individuals requiring more detailed tracking.
  => External – All parties downstream of Amazon supply chain – carriers, customers, etc.

- Show me how this project links to the business core processes and Top Level Indicators (TLIs).
  - What outcome indicators are you addressing?
    => Customer satisfaction, labor, item-level resolution.
  - What is the anticipated impact on the TLIs?
    => Increased visibility of products in the FC is expected to lead to decreased labor costs, increased efficiency when locating packages, and fewer defects in associated processes. Fewer defects should result in a higher level of customer satisfaction.

- Show me the high-level process flowchart. What are the boundaries of the redesign?
  => See Appendix, Section 2.
  => The boundaries of the redesign will depend on the final implementation of RFID for the pilot project. Processes shown with dotted lines indicating low virtual/physical visibility are specifically being considered for the pilot implementation.

- What are your projected resource needs and project milestones? Show me your project plan.
  => Project needs include equipment capital, software engineering, and data acquisition. The project timeline can be found in Section 1.8 (omitted).

Appendix B: The Amazon Case Study Measure & Analyze Document

Section B-1: Project Summary

Overview
This project will evaluate the costs and benefits of using Radio Frequency IDentification (RFID) at Amazon fulfillment centers, particularly non-sortable facilities.

Project Scope and Deliverables
The scope of this internship project will be to develop an RFID business case analysis and implementation strategy for AMZN's US fulfillment center network. One possible deliverable for this project is the development and implementation of an RFID pilot project at RNO2.

Preliminary Problem Statement

Tracking of orders and shipments at non-sortable facilities is more difficult than that of sortable sites because of the highly variable dimensions and properties of non-sortable items. A new technology which can help with higher resolution tracking of such items is RFID. Amazon would like to evaluate this technology - its accuracy, costs, and benefits - and determine possible implementations in the non-sortable fulfillment centers.

Project Notes
Because this project works with a new technology, the project plan roughly follows that of the DMADV framework. This document and the presentations associated with it are designed to be a combination of the Measure and Analyze components of the DMADV framework. However, unlike most DMAIC or DMADV projects this project starts out with a new technology solution (RFID) and seeks a problem or defect to solve that is most beneficial to Amazon at this point in the solution's technological progress, rather than starting the problem and seeking a solution.

Section B-2: Project Progress

The approach taken for the Define portion of this project was to complete a thorough analysis of the various process paths at the Reno FCs and look for appropriate places to implement a pilot project utilizing this new technology. At the end of the Define process, the project team decided that RFID would be most realizable and applicable in improving the sorting accuracy of the outbound process at RNO2.

Miss-sorts at Outbound
The defect that was identified as the most appropriate to address with an RFID solution is the miss-sorting of packages onto the wrong carrier trucks at the outbound doors of RNO2. Based

on the analysis of one day of preliminary data on 7/20/2005, this defect is estimated to be approximately 4.2 sigma, or about 10 packages per day (non-peak). Because of the physical challenges presented by shipments at non-sortable sites, conventional solutions involving conveyor belts, automatic readers, optical scanners, etc. are not able to address this problem. It was decided that this would be the best place to measure, analyze, and possibly pilot an RFID solution. RFID tags would be placed on each item (or shipment) and scanners placed at the outbound doors to verify that each item went into the correct carrier truck. If an item goes through the wrong door, an andon light would go off with an appropriate audio alarm to signal an operator or manager to correct the miss-sort before it leaves the fulfillment center.

Section B-3: Measurement of RFID Equipment

The first step was to understand where best to place the tags and scanners to maximize read rates without exploding costs. To measure the actual read rates, we acquired, via loan, a set of dock door scanners (DC400) from Symbol Technologies, and RFID tags from various vendors.

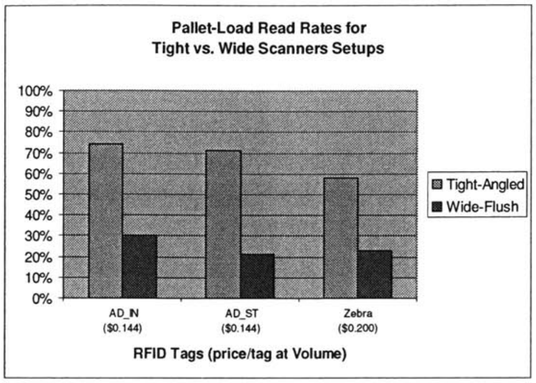
Scanners – Readers and Antennas

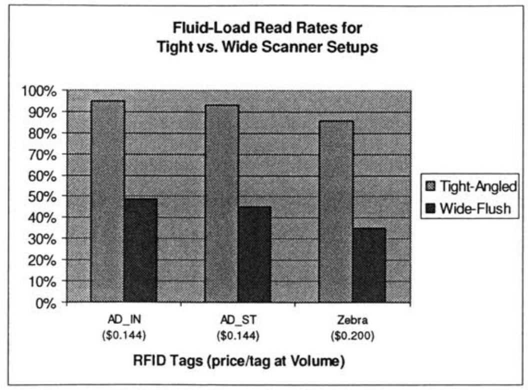
The main decision to make regarding scanners was where to put them. This involved measuring how far apart the portals scanners could be and still have sufficient read rates. For normal operations at RNO2 during Peak, we would need scanners at eight dock doors simultaneously. There were two ways to set up scanners at these eight dock doors:

a) Wide-Set: Place one reader between each set of doors, equidistant from each door and have antennas on either side of the reader facing opposite directions.
b) Tight-Set: Place one set of dock door scanners at each of the eight doors. Because each dock door reader is dedicated to a single door, we can angle the readers into the carrier trucks for higher read rates.

Variable	Tight Set	Wide Set
Distance between scanners	8 feet	24 feet
Avg. distance to tags	4 feet	12 feet
Estimated Scanner Cost	$67,500	$40,000
Key Advantage	Higher read rate	Cost Savings

In testing each scenario, we needed to test both single-piece "fluid-load" methods as well as multiple-piece "pallet-load" procedures. In practice, over 75% of shipments at RNO2 are fluid-loaded. Details and pictures of these setups can be found in Appendix A-1. The tables below show the difference between tight-set dock doors and wide-set dock doors using three different RFID tags:





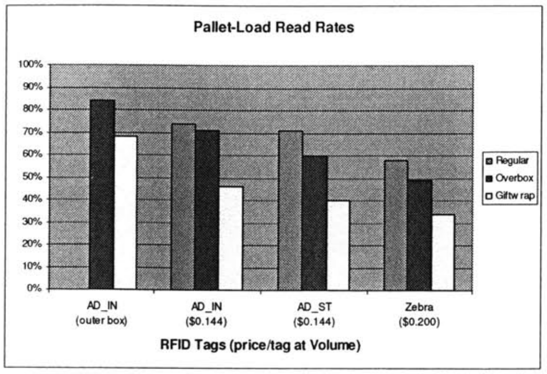
From these results, it can be concluded that the increased cost of using tight-angled dock doors provides approximately twice the number of tags read than the wide-flushed setup. The rest of this document assumes that we will use the tight-angled (more expensive) setup for Amazon's RFID installation at RNO2.

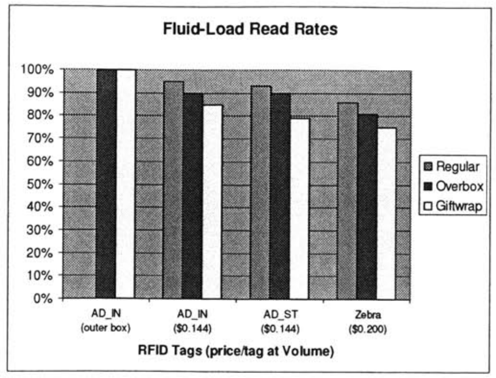
Tag Selection and Placement

With three different RFID tags, we explored where to place them on the items/shipments with the goal of replacing a label which was already used in the current process, so as to minimize the impact to the SOP of RNO2 operators:

Replacing the tote sticker. This solution would replace the tote sticker which pickers use to tag items during the picking process. This allows us to tag each item at the very beginning of the outbound process, allowing us to leverage the use of these tags in the future for purposes other then the defect targeted here. Another advantage here is that tote stickers are smaller (2"x4") and thus slightly cheaper and only two RFID printers would be needed.
Replacing the shipping label. This solution would replace the bigger, 4"x6" shipping label we place on shipments at the end of the outbound process. The advantage to this solution is that the label would always be on the outer-most layer of the item, not obstructed by overbox or gift wrap operations. This solution is discussed in more detail in Appendix B-2.

The following tables show the read rates of each tag during testing of each of the scenarios for both pallet-loading and fluid-load. Because the AD_IN tag was found to have the highest read rate in the previous test, it was chosen as the "shipping label" for further testing. Each item loaded in the tests below had the original three tags on the product with the overbox and gift-wrap tests having an additional AD_IN tag on the outside of the box:





From the above measurements, it makes the most sense for us to be using the AD_IN tags from Avery Dennison because these tags were able to achieve the highest read rates at a low price. The remainder of this document assumes the use of these tags on the inside of the box (tote stickers) with a read rate of 95%. The reasoning for this decision and further discussion of the alternative appears in Appendix B-2. Details of all tests and descriptions of the tags can be found in Appendix A-2.

Section B-4: Analysis of Potential Cost / Benefit

After a thorough benefit analysis, my conclusion is that the proposed RFID solution can save approximately $0.023 per item shipped using currently tracked metrics. (See Appendix B-1 for full details, assumptions, and calculations of the cost and benefit analysis). At over $0.14 per tag, it is difficult to justify the implementation and use of RFID at RNO2 purely based on these estimates and projected measurements. However, three topics to further consider are:

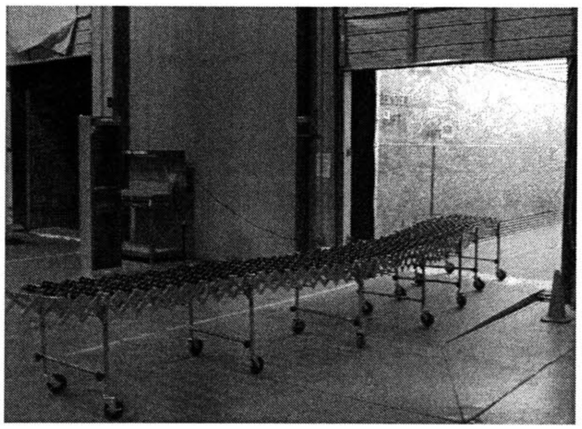
a. The most important benefit of having the proposed RFID system in place at RNO2 is increased customer goodwill, which does not appear in the analysis. The decision of how much this increased goodwill, arising from a decrease in shipment delays, damaged products, and contacts and/or concessions, is difficult to measure.
b. It is estimated that this defect, originally estimated at a 4.2 sigma level, can be improved to beyond 6-sigma with RFID. Other solutions to minimize this defect have not been determined to be physically possible or are cost prohibitive at this time.
c. The advantage to replacing the tote stickers mentioned in Section 2 is that we will have RFID labels on every outbound item. Miss-sorts alone will not justify RFID costs at this time, but it is very possible that other benefits can be realized without increases in variable cost.

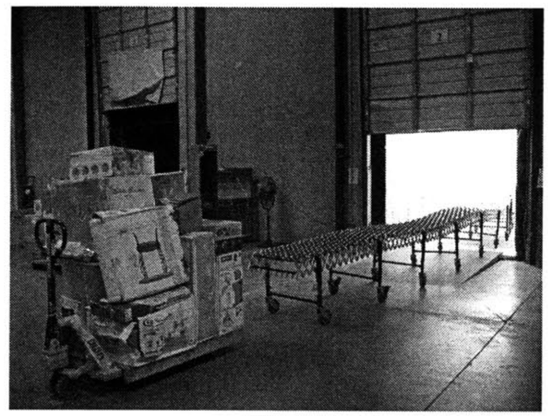
It should be noted that the cost analysis conducted is very realistic as it is based on actual costs of equipment quoted to us by vendors for a full-scale implementation. However, the benefit analysis was extremely conservative, based on estimates and projections that the author collected from various sources at RNO2 as well as corporate headquarters.

Appendix C: Equipment Testing Details at Amazon.com

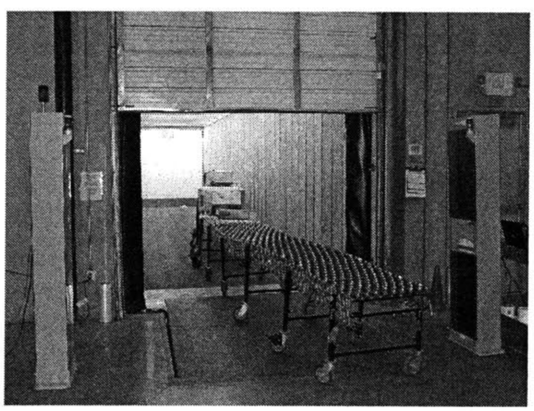
Section C-1: Scanner Placement Testing

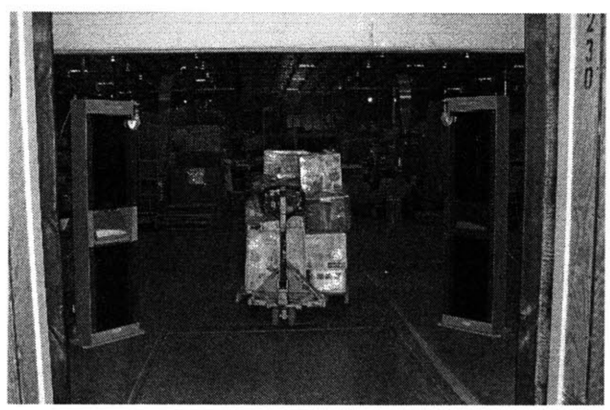
With over $27,000 difference in equipment costs, we had to measure the effect of placing the scanners farther apart, thus having adjacent dock doors share readers, or close together, dedicating two readers for each dock door. Below are some pictures of what the layout would look like at RNO2 if scanners are wide-set:





As mentioned previously in Appendix B, the wide-set scanners provided much lower read rates. Even though the tags we used were rated at read distances of 25 feet, all tags read at or below 50% at this distance. Alternatively, we can set the scanners closer by adding more readers:

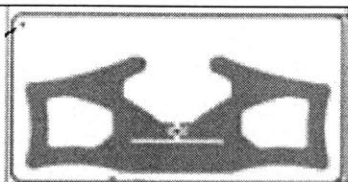
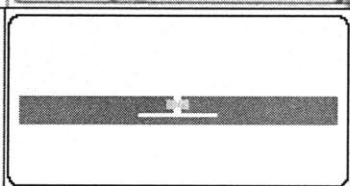
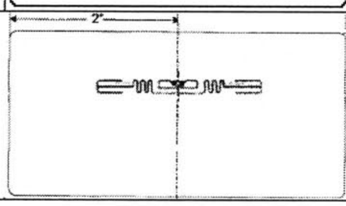




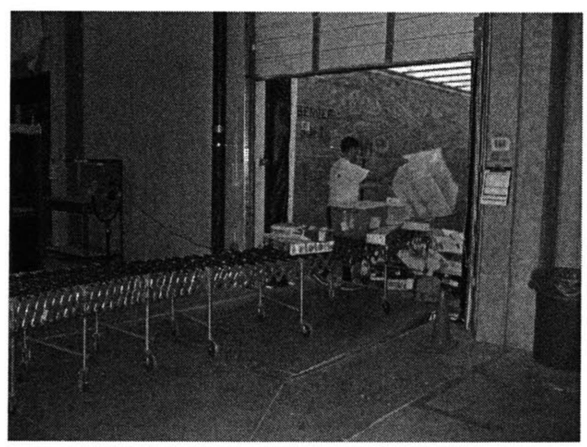
The read rates using this setup were dramatically increased. In addition, to being closer together, since the readers are dedicated to individual dock doors, we can set them at an angle so as to face the interior of the carrier trucks (see picture on right). This dramatically increased read rates as well as the total number of (redundant) reads during the loading process. Later tests omitted wide-set configurations.

Section C-2: Tag Selection and Placement Testing

We were able to receive three tags from two different vendors for our testing and pilot purposes. All of the tags used were general purpose Class 1, UHF RFID tags with 96 bit read/write capabilities operating at 902-928MHz.

Tag	Vendor	Model	Antenna	Max (fluid) Read Rate	Price/Tag (at Volume)
	Avery Dennison	AD_410 (AD_IN)	IN	95%	$0.144
	Avery Dennison	AD-210 (AD_ST)	Strip	93%	$0.144
	Zebra	Z4M (Zebra)	Squiggle (Alien)	86%	$0.200

A series of tests were conducted on the above tags to measure their read rates if used in actual FC operations. All tests were done using both pallet-load and fluid-load processes. Tags were placed on individual items, then overboxed, and then gift wrapped and overboxed. Below are pictures from the initial tests of the tags (before overboxing/gift-wrap).



A sample of 20 products was selected at random from RNO2's damaged products area to be used in the tests. One tag of each model was placed on each item and "loaded" past the RFID scanners and onto a truck. Each tag used was qualified before testing began to ensure that all tags used were readable.

The same 20 products were then placed under overbox and gift-wrap conditions and the same tests were conducted once again. Each test condition was run four times, making a total of 80 possible unique reads for any test. After it was determined that wide-set applications were not sufficient because read rates were too low, only tight-set configurations were used for further testing. All in all, 12 sets of tests were conducted; each consisting of 4 runs of 20 products. Summarized data from select tests is shown in the following tables:

Data Key:

- **Total Reads**: The total number of reads recorded with each label during the 4 runs of the test.
- **Total Seen**: The total number of unique tags seen during the 4 runs of the test (out of 20). Regardless of how many times a tag is seen during each run, it is only counted as "1" in this count.
- **Alive/Visible Rate**: Total Seen / Total Possible (usually 20)
- **Actual Seen**: The actual number of unique tags seen. Not all tags were seen during each run, but if a tag is seen across three runs and not the fourth, it counts as "3" in this count.
- **Read Rate**: Actual Seen / Total Possible = Rate discards invisible/non-readable tags.
- **Success Rate**: Read Rate x Alive Rate = Success rate including visibility and readability.
- **Missing #'s**: This is a list of all products which were not seen in any of the test runs.

	AD_IN	AD_ST	Zebra
Total Reads	62	44	50
Total Seen	12	6	7
Alive/Visible Rate	60%	30%	35%
Total Possible	48	24	28
Actual Seen	24	17	18
Read Rate	50%	71%	64%
Success Rate	30%	21%	23%
Missing #s	1, 7, 10, 12, 13, 16, 18, 19		
		1, 2, 3, 5, 7, 8, 9, 10, 11, 12 13, 14, 16, 19	
			1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14,19
Test 3 : Wide - Flush - Pallet - RTC8			

	AD_IN	AD_ST	Zebra
Total Reads	184	234	186
Total Seen	18	15	14
Alive/Visible Rate	90%	75%	70%
Total Possible	72	60	56
Actual Seen	39	36	28
Read Rate	54%	60%	50%
Success Rate	49%	45%	35%
Missing #s	1, 5	1, 3, 5, 11, 16	
			1, 5, 10, 11, 12, 20
Test 4 : Wide - Flush - Fluid - RTC8			

Test 3 and Test 4 show the difference between pallet-load and fluid-load in a wide-set orientation. In the wide-set tests, all the antennas had to be flush with, or perpendicular to, the wall, rather than angled and facing into the carrier trucks.

	AD_IN	AD_ST	Zebra
Total Reads	180	160	92
Total Seen	18	16	14
Alive/Visible Rate	90%	80%	70%
Total Possible	72	64	56
Actual Seen	60	51	45
Read Rate	83%	80%	80%
Success Rate	75%	64%	56%
Missing #s	9, 12	2, 4, 12, 15	
			2,5,9,12,13,15,19
Test 5 : Tight - Flushed - Pallet - RTC8			

	AD_IN	AD_ST	Zebra
Total Reads	329	309	200
Total Seen	20	18	15
Alive/Visible Rate	100%	90%	75%
Total Possible	80	72	60
Actual Seen	59	57	46
Read Rate	74%	79%	77%
Success Rate	74%	71%	58%
Missing #s		2, 12	2, 7, 12, 15, 19
Test 6 : Tight - Angled - Pallet - RTC8			

For Test 5 and Test 6, the scanners were brought in closer together in a tight-set orientation. Both of these tests were done using the pallet-load method. The variable being tested here is whether or not to angle the antennas so that they face the inside of the trucks (Test 6) or to have them flush and thus face each other (Test 5). As the data shows, the angled antennas showed a 5-10% increase in the visible rate for all three tags tested as well as a pronounced increase in the total reads. Having the antennas angled does not increase costs; it is recommended that angled antennas be used for this RFID implementation.

	AD_IN	AD_ST	Zebra
Total Reads	891	874	638
Total Seen	20	19	19
Alive/Visible Rate	100%	95%	95%
Total Possible	80	76	76
Actual Seen	76	74	69
Read Rate	95%	97%	91%
Success Rate	95%	93%	86%
Missing #s		9	5
Test 7 : Tight - Angled - Fluid - RTC8			

Test 7 shows results of the ideal case – having angled antennas in a tight-set orientation for fluid-load packages. These results are very promising in terms of read rates. Since almost 80% of our packages are loaded in this method, and most of our miss-sorts happen in this scenario, it is relevant to note that it is in this very problem scenario that we have the highest read rates.

	Box_IN	AD_IN	AD_ST	Zebra	
Total Reads	307	199	189	161	
Total Seen	20	17	16	14	
Alive/Visible Rate	100%	85%	80%	70%	
Total Possible	80	68	64	56	
Actual Seen	67	57	48	39	
Read Rate	84%	84%	75%	70%	
Success Rate	84%	71%	60%	49%	
Missing #s		2, 15, 19	2, 9, 14, 20		
				5, 11, 14, 15, 19, 20	
Test 9 : Angled - Pallet - Overbox - RTC8					

	Box_IN	AD_IN	AD_ST	Zebra
Total Reads	1130	724	677	584
Total Seen	20	19	19	19
Alive/Visible Rate	100%	95%	95%	95%
Total Possible	80	76	76	76
Actual Seen	80	72	72	65
Read Rate	100%	95%	95%	86%
Success Rate	100%	90%	90%	81%
Missing #s		2	20	20
Test 10 : Angled - Fluid - Overbox - RTC8				

The decision of whether to place RFID tags on products themselves (replacing the tote sticker) or placing them on the final shipped package (replacing the shipping label) depends on the RFID tag's readability through cardboard (overbox corrugate) and gift wrap material. Test 9 and 10 reveal the impact of overboxed items in pallet-load and fluid-load processes respectively. In previous tests the AD_IN tag was found to have the highest read rate, thus we placed this tag on the outer-most box, labeled "Box_IN" in the data. Test 10 shows comparable read rates to Test 7, which is, again, a positive sign. Although the presence of the outer box decreased the total reads (by about 15-20%), the decrease in the final success rate was not severe (approximately 5%). Of the 20 test items, 17 were overboxed for these tests and the remaining three were too large for any overbox and would not be overboxed in standard operations. All 20 items were used for the testing with the three non-overboxed items receiving the additional "Box_IN" tag directly on the manufacturer's box.

	Box_IN	AD_IN	AD_ST	Zebra	
Total Reads	158	119	76	96	
Total Seen	17	12	12	11	
Alive/Visible Rate*	100%	71%	71%	65%	
Total Possible	68	48	48	44	
Actual Seen	46	31	27	23	
Read Rate	68%	65%	56%	52%	
Success Rate	68%	46%	40%	34%	
Missing #s		2, 5, 12, 19, 20			
			2, 3, 7, 14, 20		
				5, 8, 12, 15, 19, 20	
Test 12 : Angled - Pallet - Gift - RTC8					

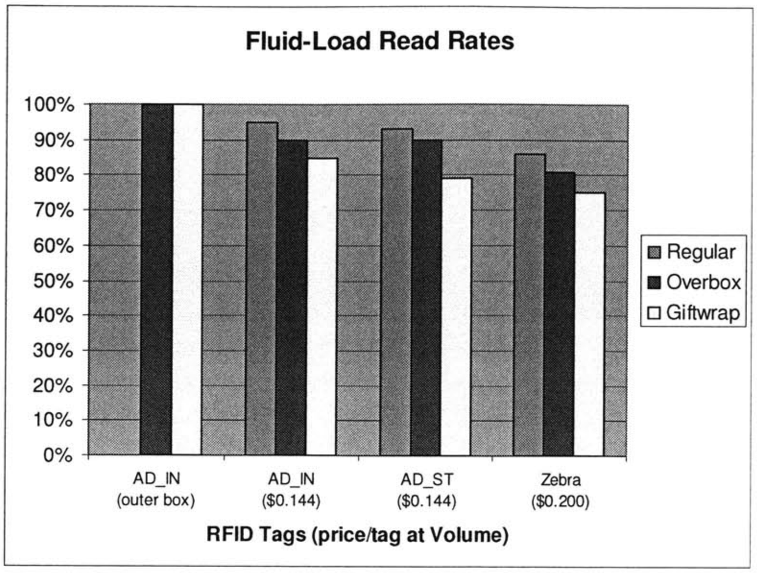
	Box_IN	AD_IN	AD_ST	Zebra
Total Reads	740	457	401	324
Total Seen	17	16	15	16
Alive/Visible Rate*	100%	94%	88%	94%
Total Possible	68	64	60	64
Actual Seen	68	58	54	51
Read Rate	100%	91%	90%	80%
Success Rate	100%	85%	79%	75%
Missing #s		2	14, 20	15
Test 11 : Angled - Fluid - Gift - RTC8				

* Because 3 of the 20 items were too big for gift wrap, they were omitted for these tests.

The final variable to measure is gift wrap, which was conducted in Test 11 and Test 12. The effect of gift wrap on read rates was, again, not severe, but the combination of gift wrap and overbox (which always happened for gift-wrapped items) is notable. Since less than 10% of products are gift-wrapped on a daily basis and success rates for gift wrapped items are not dramatically lower than those for regular boxes, it is concluded that neither overbox nor gift wrap have a problematic effect on the plausibility of using RFID in the Amazon non-sortable fulfillment centers.

Appendix D: Costs and Benefits of using Shipping RFID Labels

Recall the following graph and associated data which was discussed in Section 2 of this document:



	Box_IN	AD_IN	AD_ST	Zebra
Total Reads	740	457	401	324
Total Seen	17	16	15	16
Alive/Visible Rate*	100%	94%	88%	94%
Total Possible	68	64	60	64
Actual Seen	68	58	54	51
Read Rate	100%	91%	90%	80%
Success Rate	100%	85%	79%	75%
Missing #s		2	14, 20	15
Test 11 : Angled - Fluid - Gift - RTC8				

This data shows that if instead of replacing the tote stickers with RFID labels, we replaced the shipping labels; we can get perfect or near-perfect read rates. This is indeed true, but the decision was made to pilot a tote-sticker implementation for the following reasons:

- As mentioned in Section 2, using shipping RFID labels would limit our ability to use the RFID tags in any ways other than to track miss-sorts, because a shipping label implementation would place RFID labels on boxes at the very last stage in the outbound process. Amazon would most likely need data to support the use of RFID to be able to scan through cardboard and gift-wrap in the future. Data regarding shipping label RFID would have limited widespread applications.
- If we were to implement the pilot by replacing the shipping labels, the SDE time required would have to be increased and additional support would be necessary from the Pack/Ship team, which has indicated that this is not possible during Peak 2005.

- Implementing a shipping label RFID solution in RNO2 would also required the acquisition of six more RFID enabled printers. We could most likely get these printers on loan for the pilot, but these printers would increase the cost of the full scale implementation by approximately $20,000.
- It appears from the data above that over-box and gift-wrap have an impact of about 5-15% in total. Although these materials cause more of an impact than originally estimated, the impact is still relatively limited, and the possibility that a package is gift-wrapped (10%), then miss-sorted (4.2 sigma = 0.46%), and then missed by the system (15% max) is less than 0.007%. We believed that the above three disadvantages of using shipping RFID labels outweighs this read rate advantage.

Because of these reasons, we decided to complete the analysis for the pilot in terms of replacing the tote sticker and not the shipping label.

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