

A SYSTEMS APPROACH TO THE EVALUATION OF RADIO FREQUENCY IDENTIFICATION (RFID) IN THE DEFENSE INDUSTRY

By

Ronak R. Shah

B.S. Computer Systems Engineering, Boston University (1999)

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 2005

© Massachusetts Institute of Technology, 2005. All rights reserved.

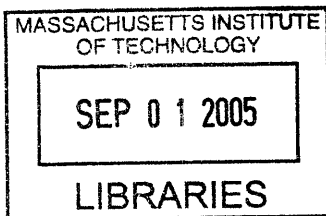
Signature of Author _____
Engineering Systems Division
Sloan School of Management
May 6, 2005

Certified by _____
Daniel E. Whitney, Thesis Supervisor
Senior Lecturer, Engineering Systems Division

Certified by _____
Stephen C. Graves, Thesis Supervisor
Abraham J. Siegel Professor of Management

Accepted by _____
David Capodilupo, Executive Director of Masters Program
Sloan School of Management

Accepted by _____
Richard de Neufville, Professor of Engineering Systems
Chair, Engineering Systems Division Education Committee



ARCHIVES

[THIS PAGE INTENTIONALLY LEFT BLANK]

A SYSTEMS APPROACH TO THE EVALUATION AND IMPLEMENTATION OF RADIO FREQUENCY IDENTIFICATION (RFID) IN THE DEFENSE INDUSTRY

By

Ronak R. Shah

Submitted to the Sloan School of Management and
Department of Engineering Systems on May 6, 2005
in partial fulfillment of the requirements for the degrees of
Master of Business Administration and
Master of Science in Engineering Systems

ABSTRACT

Radio Frequency Identification (RFID) is a wireless technology with possible applications in the supply chain. RFID tags' fast read rates, non-line-of-sight identification and large storage capacity may revolutionize supply chains in the defense industry and commercial world. Widespread adoption of RFID will require that companies achieve a return on their investment.

System interactions between the implementation decisions, costs, benefits and performance of an RFID installation makes determining the optimal RFID system difficult. This thesis enumerates the various choices which affect the return on investment and describes how each is dependent upon the others. Formulating the problem as a optimization program allows one to maximize the return on investment.

A three-stage process is proposed for evaluating RFID opportunities in any complex enterprise. RFID swim lanes, a new process mapping tool, is used in order to understand the complexities of material flow through facilities. A Microsoft Excel™ tool is used to formulate the optimization for the specific facility or enterprise contemplating RFID. Finally, financial modeling is used in conjunction with optimization algorithms in order to determine the best course of action.

In order to validate this approach, the process was followed to evaluate inbound materials opportunities at Raytheon's Integrated Air Defense Center. For this facility and others, there may be tremendous difficulty in achieving a return on investment at this time. However, the process ensures that the evaluation of RFID is performed thoroughly.

Thesis Supervisor: Stephen C. Graves
Title: Abraham J. Siegel Professor of Management

Thesis Supervisor: Daniel E. Whitney
Title: Senior Lecturer, MIT Engineering Systems Division

[THIS PAGE INTENTIONALLY LEFT BLANK]

ACKNOWLEDGEMENTS

I would like to thank Raytheon for sponsoring this internship. In particular, I would like to acknowledge the immense support I received from Zack Noshirwani, George Ellis, Dick Chenard and Daniel Judge in the Integrated Supply Chain organization. Without their leadership and willingness to trust an unproven intern, this research would not have been possible.

I would like to thank Mike Donahue, Claudine Dupere, Jim McTigue, Jeff Mullin and Jeff Pellenz for the on-the-ground support they offered while I was at Raytheon. Their knowledge of procurement, “real-world” supply chains, materials distribution processes, Six Sigma and Raytheon were invaluable.

Roger Hinman has always been an integral part of any Andover-based Raytheon internship, and this was no exception. Without his knowledge of the many initiatives going on, I would have never found out about the RFID project. Ed Verryt and Alice Thomaidis were essential to navigating through the Raytheon organization. Special thanks to my LFM advisors Steve Graves and Dan Whitney for their advice and support. The author wishes to acknowledge the Leaders for Manufacturing Program for its support of this work.

Finally, I would like to thank my wife, Angela, for her support and direction during the internship and writing of this thesis. Without her gentle reminders to work on this thesis, I would have spent the month of April locked away in the library instead of with her.

[THIS PAGE INTENTIONALLY LEFT BLANK]

TABLE OF CONTENTS

Chapter 1: Introduction and overview	10
1.1. Raytheon overview	10
1.2. Project motivation	11
1.3. Thesis structure	11
Chapter 2: RFID primer	13
2.1. History of RFID and current expectations of the technology	13
2.2. Tag and reader communication and reliability	15
2.3. Benefits of RFID as an automatic identification technology	17
2.3.1. Field-based area identification	17
2.3.2. Fast reads and high throughput	18
2.3.3. Memory storage and unique identification	18
2.4. Components of a complete RFID system	18
2.4.1. Hardware	19
2.4.2. Software / Middleware	21
2.4.3. Business processes	22
2.5. Industry structure and the role of EPCGlobal™	23
2.5.1. Value Chain Analysis	23
2.5.2. Challenges posed by the RFID value chain	24
2.5.2.1. Challenges in coordination of the supply chain	24
2.5.2.2. Challenges with an emerging technology	25
2.5.2.3. Consumer concerns	25
2.5.3. The role of EPCGlobal™	25
2.5.3.1. EPCGlobal™ and standards	26
2.5.3.2. A single industry voice for RFID	27
2.5.3.3. EPCGlobal™ and knowledge sharing	28
2.5.4. The need for mandates	28
2.5.5. The DoD RFID Policy	28
2.5.5.1. Three dimensions of the policy rollout	29
2.5.5.2. Workflow requirements of the RFID policy	32
2.6. Primer conclusion	32
Chapter 3: Challenges identified in the current state	33
3.1. Challenges in achieving compliance to the DoD RFID Policy	33
3.2. Challenges in achieving business process improvement	34
3.2.1. Developing a business case for using RFID	34
3.2.1.1. The materials distribution process at the IADC	34
3.2.1.2. Systems interactions in RFID evaluation	40
3.3. Hardware performance and tag read reliability	41
Chapter 4: Developing a business case using systems optimization	43
4.1. Background	43
4.1.1. Definitions	43
4.1.2. Usage scenario types	43
4.1.2.1. Receiving identification	44
4.1.2.2. Identification speed	44
4.1.2.3. Carousel cycle counting	44
4.1.2.4. Asset visibility	45
4.1.2.5. Injury prevention	46
4.2. Process diagramming RFID material flows	46
4.2.1. Advantages and disadvantages of existing diagramming techniques	46
4.2.2. RFID swim lanes	47

4.3.	System optimization framework.....	49
4.3.1.	Decision variables.....	49
4.3.1.1.	Usage scenarios.....	49
4.3.1.2.	Material types.....	49
4.3.1.3.	Reader sets.....	50
4.3.1.4.	IT modules.....	50
4.3.1.5.	Independent decision variables.....	51
4.3.2.	Constants and constraints.....	51
4.3.3.	Objective function.....	52
4.3.3.1.	Financial benefits.....	52
4.3.3.2.	Initial costs.....	54
4.3.3.3.	Recurring costs.....	56
4.3.3.4.	Evaluation functions.....	57
4.3.4.	Optimization algorithm.....	58
Chapter 5:	Excel™ RFID Calculator.....	59
5.1.	Ubiquity, usability and extensibility.....	59
5.2.	Stage 1: Entering system-wide parameters.....	59
5.3.	Stage 2: Constants and Usage scenario detail.....	61
5.4.	Stage 3: Optimization and sensitivity analysis of financial results.....	63
Chapter 6:	IADC business case evaluation.....	66
6.1.	Stage 1: System parameters.....	66
6.2.	Stage 2: Usage scenario benefit calculations.....	72
6.3.	Stage 3: Financial results optimization.....	73
Chapter 7:	Conclusion.....	74

LIST OF FIGURES

Figure 1: Raytheon IDS Integrated Supply Chain Org Chart	10
Figure 2: Fishbone analysis of tag read failures	16
Figure 3: Active RFID Tag []	19
Figure 4: Two Passive RFID Tags []	20
Figure 5: RFID Interrogator with 4 antenna ports []	20
Figure 6: Two different RFID antennas []	21
Figure 7: RFID Industry Value Chain	23
Figure 8: Commodities covered under the DoD RFID Policy	30
Figure 9: Depots requiring RFID tags	30
Figure 10: DoD Container Hierachy []	31
Figure 11: Warehouse receiving material flow	37
Figure 12: Main Stores material flow	38
Figure 13: Main Stores carousel and lift station	39
Figure 14: RFID swim lanes building blocks	47
Figure 15: RFID swim lanes with diverging and converging flow	48
Figure 16: RFID swim lanes with container actions	48
Figure 17: Wizard interface for Excel™ RFID Calculator	60
Figure 18: Clickable cells for collecting binary constants	61
Figure 19: Entering constants into the RFID Calculator	62
Figure 20: Usage scenario sheet in Stage 2	63
Figure 21: RFID calculator Stage 3 decision variables	64
Figure 22: Financial results summary in calculator step 3	65
Figure 23: RFID swim lanes representation of IADC inbound material flow	69
Figure 24: Reader sets required for usage scenarios (X_{ij})	71
Figure 25: IT modules required for usage scenarios ($Y_{i,l}$)	72

LIST OF TABLES

Table 1: Representative costs of hardware components in 2004	21
Table 2: Classes of supply in the military []	29
Table 3: Business case definitions	43
Table 4: RFID optimization model constants	51
Table 5: Candidate usage scenarios at the IADC	67
Table 6: Candidate material types at the IADC	68
Table 7: Required reader sets for IADC RFID evaluation	70
Table 8: Candidate IT modules for the IADC evaluation	71

Chapter 1: Introduction and overview

1.1. Raytheon overview

Raytheon is a leader in defense electronics, radars, space systems, and several other industries. As a \$20B company with over 80,000 employees worldwide, it faces many challenges and opportunities as it strives to be “the most admired defense and aerospace systems supplier through world-class people and technology” [1].

Raytheon Integrated Defense Systems (IDS) is a \$3.1B business within Raytheon, and has launched programs like the Patriot missile system, the DD(X) next generation surface combat ship, and radars for the Ballistic Missile Defense System [2]. In doing so, IDS has realized the advantage that comes from an effective supply chain, and has recently reorganized to better align its organization structure with customer expectations.

IDS’s Integrated Supply Chain organization serves as the model for supply chain and product lifecycle management within Raytheon. An organization chart shown in Figure 1 describes a small portion of the reporting structure for Integrated Supply Chain and the Integrated Air Defense Center (IADC) based in Andover, Massachusetts.

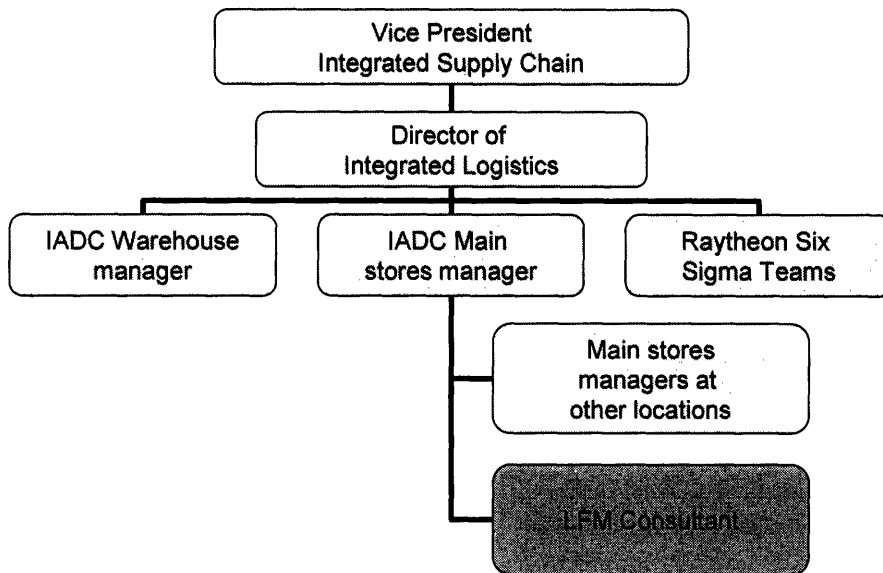


Figure 1: Raytheon IDS Integrated Supply Chain Org Chart

Among other responsibilities, the Director of Integrated Logistics is responsible for meeting logistics requirements set by the customer. A new logistics requirement from the United States Department of Defense, Raytheon’s largest customer, resulted in the project described in this thesis.

1.2. Project motivation

Radio Frequency Identification (RFID) is a well-known technology that is now being proposed for use in the supply chain. In 2003, the Department of Defense indicated that it would soon be requiring the use of RFID by members of its own supply chain. This new requirement gave Raytheon the opportunity to evaluate and implement this emerging technology as an early adopter.

As details of the policy emerged, teams at many Raytheon locations and from all Raytheon businesses began to experiment with the technology. In order to coordinate these teams, the IDS Director of Integrated Logistics sponsored a two-day kickoff meeting in July 2004.

The author of this thesis had just started a six month internship at the Integrated Air Defense Center (IADC), an IDS manufacturing plant. The author had a good understanding of RFID based on his experience at LFM, and attended the kickoff meeting. Over fifty Raytheon employees and several outside experts and vendors helped to make the kickoff meeting a success.

It quickly became clear that existing Six Sigma project teams were effectively gauging the implications of the DoD's RFID policy and formulating an appropriate response. Many of these teams were also researching opportunities within their businesses to use RFID to achieve business process efficiency improvements. Several of these teams were finding this evaluation difficult, and the author worked with them to identify the root causes and propose a solution.

1.3. Thesis structure

This thesis is one result of the cooperation between the author and dozens of Raytheon employees. The thesis is organized into six chapters, described below:

Chapter 1: Introduction and overview: This chapter describes the project at Raytheon which led to the research in this thesis. It also outlines the structure of the thesis.

Chapter 2: RFID primer: This chapter provides the layperson with an introduction to Radio Frequency Identification and the Department of Defense's policy requiring the use of RFID in its supply chain.

Chapter 3: Challenges identified in the current state: This chapter analyzes the root cause behind the difficulty of evaluating RFID for business process improvement. It also describes the current state processes for inbound material flow at the Integrated Air Defense Center.

Chapter 4: Developing a business case using systems optimization: This chapter proposes a solution to the problem described in Chapter 3. Using a new diagramming technique (RFID swim lanes) and an optimization model, analysts can determine the most financially beneficial RFID system implementation parameters.

Chapter 5: Excel™ RFID Calculator: This chapter describes a software tool developed to assist analysts in formulating their own models based on the framework described in Chapter 4.

Chapter 6: IADC business case evaluation: This chapter describes the results of using the calculator at the Integrated Air Defense Center.

Chapter 7: Conclusion: This chapter summarizes the findings in previous chapters and proposes options for future study and research.

Chapter 2: RFID primer

Radio Frequency Identification has been used for over half a century, but many aspects of the technology and its usage are still misunderstood by those evaluating the technology. This chapter seeks to provide sufficient background information so that the reader can approach later chapters with a critical eye. It covers the history, capabilities, costs, and limitations of RFID. The chapter also describes the current structure of the RFID industry and how the Department of Defense is driving adoption at suppliers like Raytheon.

2.1. History of RFID and current expectations of the technology

Much of the literature about RFID focuses on the accelerated activity performed in the last five years since the formation of EPCGlobal™. However, radio frequency identification has been used since World War II to solve identification and asset tracking problems. Progressing through its history with a focus on specific aspects of the individual usage scenarios gives an insight into how current expectations have formed.

The first known use of Radio Frequency Identification was during World War II. The British Royal Air Force used the technology as an identification tool in its Identify Friend/Foe (IFF) systems. Allied planes outfitted with an IFF transponder would respond to queries from ground-based radars with a specific response; Axis planes could then be identified since they would not respond to the signal [3].

All remote IFF transponders would respond with the same signal, and so IFF was not used to identify individual planes. The later use of RFID for preventing inventory shrinkage is a similar usage scenario, since the presence or absence of a signal is sufficient data to require a reaction. The fact that the system was not line-of-sight and could operate under adverse weather conditions was fundamental to its usability. This continues to be a stated advantage of RFID.

A number of research laboratories and private firms continued to improve the technology, specifically on adding the capability for unique identification of individual transponders [4]. By the late 1970s, RFID was being used for the tracking of livestock. Individual heads of cattle were tagged with their own identification beacon, usually implanted under the skin or on the ear. RF readers were placed at points of entry into barns, feeding stalls and other locations.

The ability to identify individual cows without human interaction allowed better tracking of feeding and health irregularities. Unique identification has since become a feature of current RFID usage scenarios. The RF tag also replaced the older process of branding cows with a hot iron. This had advantages in terms of employee safety. This is often identified as a possible advantage of RFID when compared with repetitive stress disorders caused from manual scanning of barcodes. Up to a third of a cow's leather output can be ruined during branding, and here RFID also offered industry-specific advantages [3]. Companies have continued to find significant advantages in using RFID beyond the more commonly documented expectations. Even though these do not translate into other industries, they are nonetheless important.

By the early 1980s, railroad companies were using RFID to tag rolling stock. This was among the first uses of RFID for asset tracking over a large geographic area. An earlier initiative with bar codes failed due to poor read reliability in adverse weather conditions, high travel speeds and especially direct sunlight [4]. While read reliability of passive RFID tags continues to lag expectations, many users are planning for a possible future in which they are good long-term tracking solutions compared to competing automatic identification technologies.

By the early 1990s, RFID had arrived in suburban malls throughout the United States as an enabling technology for Electronic Article Surveillance (EAS). RFID readers positioned by store exits would trigger an alarm if an EAS tag passed through the field.

The capability of the tags was limited to the same level of functionality as the IFF transponders of five decades ago, and only indicated the presence of the tag in the field. It was the first major use of RFID for controlling inventory shrinkage, a usage scenario which is driving many companies to invest in RFID. In addition, these tags were relatively low-cost and did not require a battery for power. While the read range was limited, this was one of the first widespread uses of passive RFID tags. The majority of this thesis focuses on this type of tag.

Around the same time, RFID was being used to identify vehicles during the collection of road tolls. A vehicle would have a battery powered transponder attached to the windshield, which would be read as the vehicle passed through a toll portal at highway entrances and exits.

The term “RFID license plate” probably comes from this early use of the technology, since only a unique identifier is read from the transponder. This identifier is then cross-referenced with a separate database containing billing information. While this is not the first significant IT implementation supporting an RFID-enabled automatic identification system, it was one of the first that the public became aware of. In Dallas, a TollTag® could be used to pay tolls on the North Dallas Tollway, pay parking at the airport and at downtown parking garages and also gain access to third party business campuses [4]. The requisite sharing of IT data presaged similar requirements in current supply chain visibility applications.

The United States Department of Defense (DoD) became involved in RFID during the 1990s due to the identification of supply chain challenges. During Operation Desert Storm in 1991, logistics and materiel distribution was a major problem. The Defense Logistics Agency (DLA) became known for “iron mountains” of unopened shipping containers in the middle of the Saudi Arabian desert [5]. The lack of supply chain visibility required 25,000 of the 40,000 containers to be opened in order to identify their contents [6]. A Defense Research Projects Agency (DARPA) grant was awarded to Savi Technology to identify whether RFID could help prevent similar supply chain problems in the future. This resulted in several initiatives over the next few years.

Evaluations of the Defense Logistics Agency’s effectiveness during Operation Desert Storm focused on the high cost of the DLA’s supply chain. In 1995, the Joint Total Asset Visibility office was formed with a charter to provide asset visibility in-storage, in-process, and in-transit to optimize the DoD’s operational capability [7]. This had several results. First, it organized all RFID supply chain initiatives under one office, instead of being managed by individual armed forces or distribution depots. Second, it provided a source for funding future RFID initiatives. By 2004, the DLA had spent over \$100 million on RFID initiatives; this level of funding would not have been available under the previous organizational structure [8]. Finally, the implementation plan tied RFID usage to the overall strategic goals mandated by the department’s charter. This forced a necessary pragmatism around RFID’s relative advantages compared to other automatic identification technologies. These realistic expectations were a key contributor to the success of the DLA’s RFID initiatives.

By 2004, the DoD had joined EPCGlobal™, an organization described later in this chapter. In 2004, it ran a pilot implementation using active and passive RFID tags attached to Meals-Ready-To-Eat (MRE) combat rations under the Combat Feeding Program [9]. The rations were tracked from the vendor to the consuming unit through several supply chain participants and locations.

The pilot was important for several reasons. The DoD was using RFID tags on a difficult-to-read material: MREs are packaged in metal foil. The tags involved also tracked temperature variation in order to better determine the final shelf-life of the MREs. The combination of sensors and RFID provides the DoD with significant capabilities in tracking supply chain quality in several key classes of material, especially ordnance and perishables.

Finally, the value of end-to-end supply chain visibility with RFID cemented the importance of having DoD suppliers participate in RFID implementations. The DoD RFID Policy was finalized several months later, and is described in section 2.5.5.

2.2. Tag and reader communication and reliability

A layman's understanding of how tags and readers communicate is helpful in understanding the complications that arise when evaluating, architecting and implementing RFID systems.

In many ways, the physical processes involved are the same across all types of wireless communications systems, including WiFi, cordless telephones, and even baby monitors. There is a transmission of an interrogator signal from an antenna to a transponder, and a separate transmission of a reply from the transponder to a receiving antenna [10]. Most interrogator designs allow for a single antenna to be used for transmission and reception.

The RFID hardware components referenced in this thesis achieve far-field coupling through the transmission, propagation, and reception of electromagnetic waves [11]. The RFID tags referenced in the DoD's policy document work at a frequency around 900 Mhz. At this frequency, energy propagation under far-field dynamics predominates at ranges greater than 50mm [10]. Far-field coupling is therefore the assumed communication pathway in supply chain RFID implementations, and these implementations will be limited by the additional constraints posed under this coupling method.

In the presence of an electromagnetic field, an RFID tag's antenna functions as a voltage generator. This current powers a microprocessor which modulates the radar cross-section of the tag and therefore its reflected power. The modulation applied is usually specific to the tag, and so information on that tag can be sent to the receiver [12].

The information transmitted is usually a binary string. Depending upon the usage, the length of this string can be anywhere from a single bit to many kilobytes of data. The necessary length is driven by the needs of the usage scenario and constrained by cost and the capability of current technology. The tags referenced in the majority of this work store between 64 or 96 bits of usable data. The format of the information is described in section 2.5.3.1.

The ability of a transmission field to successfully power a tag and a receiver to collect the reflected signal is affected by a variety of factors. This, in turn, affects the reliability of tag reads within a field. Most of these factors are characterized in Figure 2.

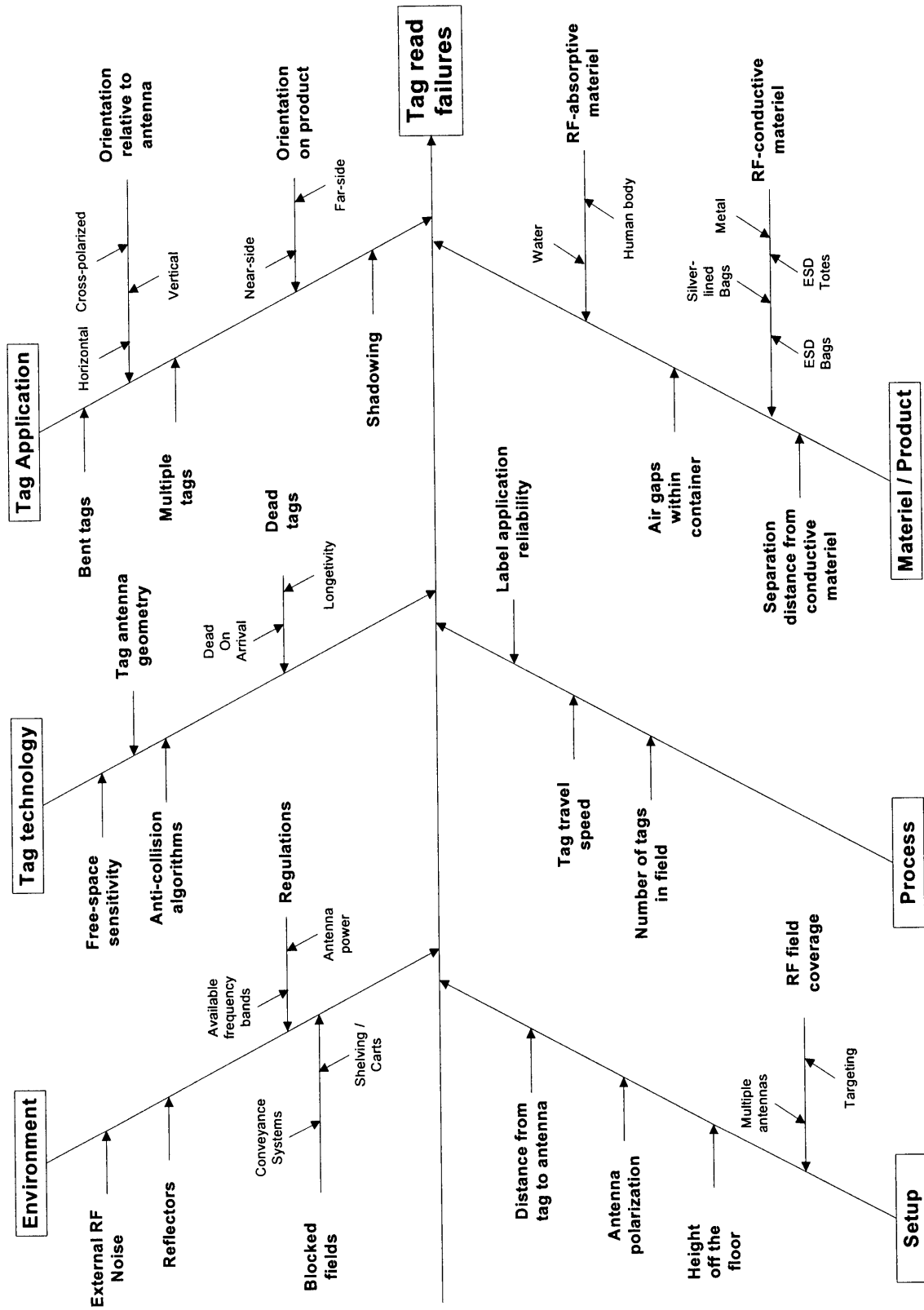


Figure 2: Fishbone analysis of tag read failures

Many of these factors are fixed by government bodies, vendor selection and the physical environment. A simple design of experiments was performed at Raytheon to gauge the relative importance of the remaining factors. Several were significant and should be considered when architecting the RFID infrastructure.

The most important factor was the material being tagged. RF-absorptive or RF-conductive products can eliminate any chance of reliably reading a tag, even if all other factors are optimally set. In some situations, the sensitivity difference observed was 12dB, or 16X lower performance.

The distance between the reader and tag is also significant. Electromagnetic theory predicts that transmitted power is inversely correlated to the square of the distance between the transmitter antenna and the RFID tag [10]. This was confirmed by the experiments performed, and the findings suggest that systems should be architected to limit the distances between reader and tag.

Finally, the experiment confirmed the importance of proper tag orientation relative to the RFID field. Certain tag orientations significantly limit the read reliability of an RFID tag. Cross-polarization, in which the tag antenna is oriented in-line with the direction of the field, can reduce performance by a factor of 4X, or 6dB. Solutions to this include multiple antennas, orientation-insensitive tag designs and including tag orientation in the business process.

This thesis does not delve into the specifics of how physics and electromagnetic field theory affect an RFID implementation. Nonetheless, RFID is a technology based on physical phenomena and governed by their immutable laws. The design of experiments performed at Raytheon helped identify some of the important factors, and a similar process is recommended for any organization implementing RFID.

2.3. Benefits of RFID as an automatic identification technology

Several automatic identification technologies already exist. Barcodes were first implemented in the 1970s, and became ubiquitous in the following decade. The DoD has had success with memory contact buttons, which can store large amounts of information. GPS tracking systems are used on high-value items when exact location information is critical. Each of these technologies has to compete with old-fashioned manual marking and identification; in many cases the old-fashioned method is still the most appropriate.

RFID offers a suite of capabilities, which when taken together make it better suited for a variety of usage scenarios.

2.3.1. Field-based area identification

Unlike most other automatic identification technologies, RFID does not require line-of-sight in order to read or write marking information. The electromagnetic field radiated from an antenna is usually a wide cone, and several multiplexed antennas can effectively cover a dock door or similar portal. Any tag entering this field can be identified. In comparison, a barcode must be presented to a reader, while memory buttons require physical contact.

This feature of RFID provides many advantages. Pallets and containers do not need to be broken down in order to identify their individual components. The orientation of packages is less important, and the human interaction with high-volume automated processes can be simplified. In some cases, RFID can be used where the physical environment precludes the use of barcodes: barcodes on railcars did not work in inclement weather.

There are some disadvantages, however. With RFID, it is far more difficult to identify a specific tagged item within a large group. The Raytheon training class begins with an exercise to separate similar tags from a large disorganized set of tags. It usually takes participants some time to realize that they must physically separate the tags in order to read just one at a time. This problem can be removed with the addition of human-readable information or a modification in the business process.

2.3.2. Fast reads and high throughput

RFID also allows tag reads at extremely high speeds. Current interrogator models can read a single tag several hundred times a second, and multiple tags at over fifty times per second. In real-world environments it is difficult to achieve reliable reads of all the tags in the field, but this is likely to improve as the technology matures.

There are several implications of this capability. There is little improvement over other technologies in scenarios where a single tagged product is being read at a time. Companies have been successful at reading RFID tags on a conveyor moving at 600 feet per second. However, this specification is more a requirement of the existing conveyance infrastructure than an enabling technology.

The ability to read multiple tags at high speeds is the key capability. Reading all the tags on a pallet is more financially beneficial if the forklift transporting the pallet does not need to stop while the cases are being identified. The cycle time reductions which result from this capability contribute towards the benefit calculations in most return on investment analyses.

2.3.3. Memory storage and unique identification

The third capability driver is the ability of RFID tags to hold a large amount of information. A simple barcode usually stores between 20 and 30 bits of data. This is more than enough to uniquely identify a manufacturer and a product type. One is unable, however, to distinguish between two items of the same product. For example, two identical boxes of cereal will have the same UPC code.

Passive RFID tags can store 96 bits of data, more than enough to uniquely identify every atom in the universe. A more practical use is the ability to uniquely identify individual items being manufactured. This allows the tracking of individual items through the supply chain, and makes usage scenarios based on shrinkage reduction and counterfeit protection feasible.

Active RFID tags can store even more information. Currently available products offer up to 256 kilobytes of storage space, but larger amounts are certainly possible. This amount of memory is often used to store a manifest list of the products within a container. Active RFID tags are sometimes connected to sensors, and the onboard memory is used to store a profile of temperature, vibration or other environmental characteristics.

2.4. Components of a complete RFID system

Over the past few decades a certain dominant design has emerged for complete RFID systems. In general, a system is composed of hardware, software and business processes. More recent events in the vendor landscape have suggested the possibility that some of these components are converging. For example, hardware components now contain some of the functionality previously provided by standalone software.

2.4.1. Hardware

The hardware components of an RFID system are usually very easy to identify. At a minimum, this includes:

- Tags, which are programmed with binary data and respond to commands propagated through the electromagnetic field;
- Fixtures which attach the tag to the object being tracked;
- Interrogators which power antennas to transmit commands to tags and interpret the response;
- Antennas which transmit and/or receive data by propagating the electromagnetic field. An interrogator and its attached antennas are often called “readers”;
- Network infrastructure, to allow communication between interrogators and the enterprise systems which evaluate hardware data;
- Power infrastructure, to provide power to the readers. Most current readers require AC power, while handheld models use rechargeable batteries.

There is often significant product variety in each of these component categories. Tags can be classified into two main types: passive and active. Active tags have an onboard battery which amplifies the transmitted signal and/or powers the semiconductor chip. At frequencies around 900Mhz, these can be read even if they are 30 meters from an antenna. Active tags are relatively expensive, but can often store large amounts of information and are appropriate for some usage scenarios.

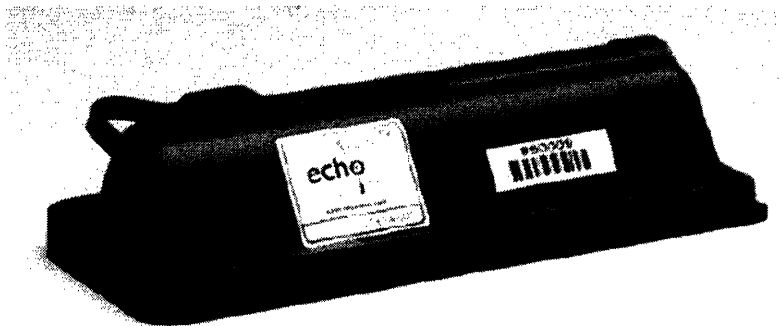


Figure 3: Active RFID Tag [13]

Passive tags do not have an onboard power supply, and their semiconductor chips draw power from the electromagnetic field they are in. This reduces both the useable range and cost by an order of magnitude. The antennas on passive tags are often tuned for specific orientations or fixturing scenarios, and a wide variety of tags are available. Passive tags hold only 64 or 96 bits of user-programmable data, much less than what is available on active tags. This is enough, however, to uniquely identify and serialize a manufacturer's products in the supply chain.



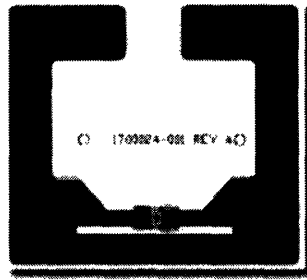


Figure 4: Two Passive RFID Tags [14]

Most passive RFID tags are sold in one of two fixturing modes. Some are available as small adhesive inlays which can be peeled off and stuck onto a product or packaging material. Others are embedded into standard sized label rolls. These are fed into an RFID label printer which prints barcodes and human-readable data while programming the tag. These “smart labels” are then affixed to the product or packaging material.

Interrogators come in a wide range of capabilities and formats. The majority are “black boxes” with connectors for antennas, power and networking. Others are embedded into label printers as described above or handheld units similar to barcode scan guns. The functionality they can support also varies. Many provide some filtering capabilities in order to identify events and export data in compliance with industry standards. At the other end of the complexity spectrum, some interrogators simply sound a siren if a tag enters the field.

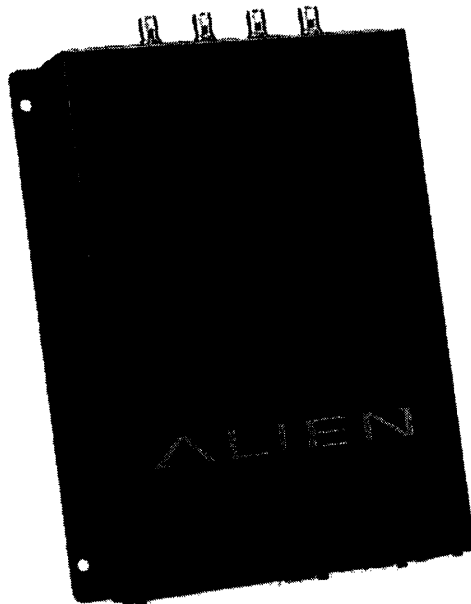


Figure 5: RFID Interrogator with 4 antenna ports [15]

Antennas are far simpler. These are usually very simple hardware components, containing metal wire, strips or plates in a rugged housing. Coaxial cable connects the antennas to the interrogator. The interrogator modulates the power to the antennas, creating the electromagnetic field. Some interrogators multiplex several antennas in order to cover a larger area with a single virtual field.

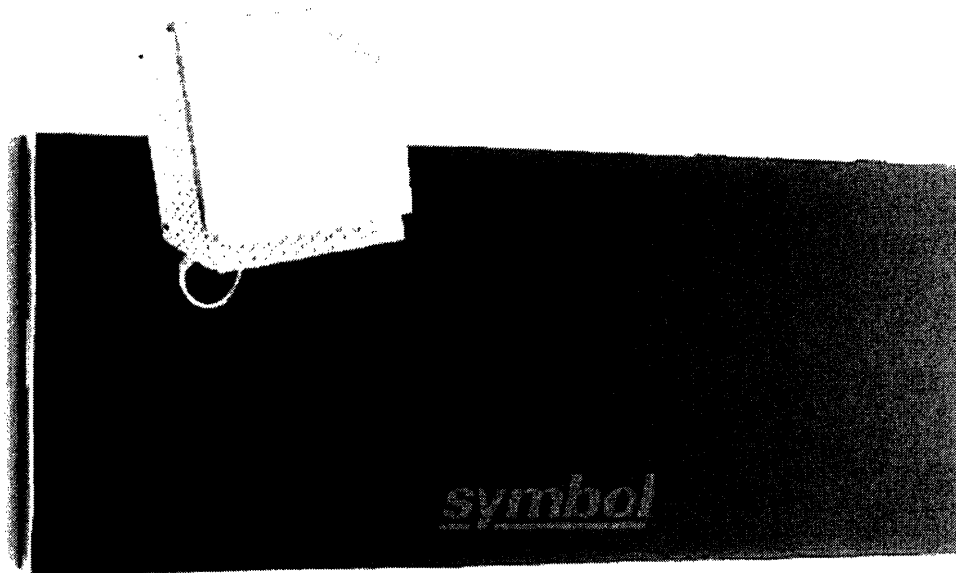


Figure 6: Two different RFID antennas [16]

The network and power infrastructure is an oft-forgotten aspect of every RFID system. Interrogators have input/output capability in the form of RS-232 (serial) ports, Ethernet ports, 802.11b wireless cards, or proprietary RF protocols. Obviously this requires something to connect to: either a dedicated computer or a server-based infrastructure. Power infrastructure usually means AC power, since the antennas can require several watts of power. Power limitations generally limit portable readers to line-of-sight applications and short bursts of activity.

For reference purposes, the table below shows the cost of many of these components in 2004. These are not average or median values, but representative of a rough order of magnitude. Significant price reductions are possible when hardware is bought in large quantities.

Hardware subcomponent	Cost in US Dollars
Active tag (minimum price)	\$1.50
Passive tag	\$0.30
EPCGlobal™-compliant fixed interrogator	\$2,000.00
Antenna	\$200.00

Table 1: Representative costs of hardware components in 2004

2.4.2. Software / Middleware

RFID interrogators can provide a great deal of data or very little useful information in the absence of software (depending upon your viewpoint). The interrogator can determine that one or more tags are in the presence of a field irradiated by its antennas, and do this many times a second. This is not very useful in and of itself, since most usage scenarios require information on the changes that occur. The fact that a new tag has been identified within the field could mean one thing; the sudden absence of a previously identified tag would indicate something different. Reading the same tag from the same reader over and over again, however, means very little.

The information of value to supply chain applications are the events corresponding to movement of tagged material between multiple interrogators. Software, termed “middleware”, interprets events from the raw data streaming from an array of interrogators. More importantly, it coordinates the updating of information in other enterprise systems like MRP, ERP and CRM.

For example, middleware may recognize that a specific tag has disappeared from the field of one interrogator only to later appear in the field of another. If the first interrogator is situated at the outbound dock door of a manufacturing plant and the second is situated at the inbound dock door of a distribution center, this probably indicates that a finished product sent from the plant has arrived at the distribution center. In this event, middleware might credit and debit the appropriate accounts in an enterprise cost accounting system, update the order status in a customer’s extranet portal, and place a replenishment order in the manufacturing plant’s MRP system.

Interfacing with enterprise IT systems can be a time-consuming and expensive project. The vast amount of data produced by the RFID infrastructure and the need for redundancy due to performance limitations complicate this further. In one early manufacturing implementation done by a consulting firm, \$1,425,000 of the initial \$1,710,000 investment was attributed to business process, application and system integration costs [17].

2.4.3. Business processes

Feature-rich middleware solutions often provide the ability to overlap supply chain process diagrams onto a physical network of RFID interrogators. This lets the software translate interrogator event signals into knowledge about the movement of material through the supply chain. However, this interpretation can often be very difficult since material in real-world supply chains does not always follow the same physical flow.

There are several possible causes for this. Human material handlers may not be disciplined about material placement within a facility, resulting in tags passing through the wrong interrogator fields. Tags may be inadvertently blocked or accidentally broken, resulting in a loss of visibility information. Finally, the documented process may be substantially different from real-world behavior. This behavior often evolves into a complex fire-fighting system erected to bridge the gap between IT systems, customer requirements and the documented process.

Most substantial RFID implementations will require large changes to the current business processes in order to take full advantage of the technology’s capabilities. Overlaying an RFID infrastructure onto existing business processes is likely to solidify inherently inefficient methods. This has been likened to “paving the cowpaths” which once existed in Boston’s North End: less effective than rethinking the transportation network in light of technological advances [18].

The effort required to develop and implement these changes to business processes can be substantial. Wholesale modification to existing systems is complicated by the limitations of current technology. Redundant systems, like barcodes and manual entry, will need to co-exist with RFID until the technology is sufficiently reliable. The warehouses of many companies have not seen significant change since the rollout of warehouse management systems, and a new technology will be entering an environment slow to adopt change.

Still, the majority of RFID investments will only achieve high returns in conjunction with business process improvement. This often ignored third component of a complete RFID system is as fundamental to its success as either hardware or software.

2.5. Industry structure and the role of EPCGlobal™

As enterprises became interested in using RFID to improve the performance of their supply chains, an overall value chain structure evolved in the RFID system industry. It was in everyone's interest to ensure that RFID did not stumble on the same obstacles that slowed adoption of previous technologies like the barcode. A consortium named EPCGlobal™ was formed as a result of this evaluation. This section describes the players in the RFID value chain, some challenges this industry structure poses, and how EPCGlobal™ attempts to meet these challenges.

2.5.1. Value Chain Analysis

Figure 7 shows an abstracted view of the value chain for RFID systems. This includes the RFID system components described in section 2.4 and users of the data that results from tracking RFID tags through to the end consumer. A description of each segment of this value chain provides a foundation for understanding the challenges facing the adoption of RFID.

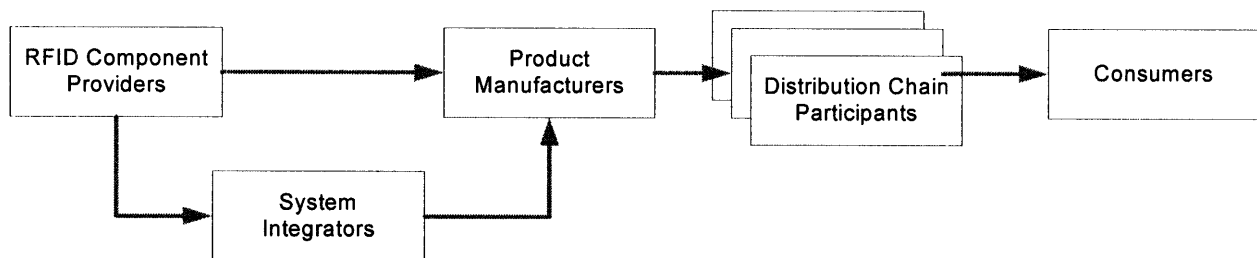


Figure 7: RFID Industry Value Chain

At the source of the chain are RFID Component Providers. These hardware and middleware companies make hardware and software components for the completed systems. These providers sometimes work directly with Product Manufacturers who have chosen to in-source their implementation projects. Of those RFID Component Providers that already have products in the market, the majority are small startups focused exclusively on developing components for complete RFID systems. Larger, established companies are only beginning to provide middleware solutions, and few have entered the hardware space. However, it is expected that consolidation and acquisitions will occur, and this part of the value chain will see a lot of changes in the future.

System Integrators work with RFID Component Providers to provide the business process components and integration required for a fully functional RFID system. System Integrators' experience helps Product Manufacturers shorten the learning curve and overcome the difficulties of working with early stage technologies. The large consulting companies have made a significant investment in helping their clients implement RFID. Several smaller system integrators also exist in the marketplace, but any consolidation that occurs will happen for reasons other than RFID.

Product Manufacturers purchase RFID components either separately or as a complete system. Raytheon Integrated Defense Systems falls into this category of value chain participants. A Product Manufacturer's core business is making products for end consumers, and RFID is simply an enabling supply chain technology. In most cases, these are the companies applying

tags to individual cases or pallets of material and enter the corresponding “traveler” information into product tracking software. The level of investment in RFID is dependent upon the approach taken by the manufacturer. Some will simply “slap and ship” a tag onto product as it leaves the dock.

Distribution Chain Participants are the departments within Product Manufacturers and / or third-party companies which deliver the product to the end consumer. They are participants who did not apply the tag to the material but have the opportunity to use the tag information to track the product as it flows through the distribution channel. They will often have purchased RFID system components themselves, but mostly to read the tags of Product Manufacturers. These companies may be able to reap significant benefits through the additional supply chain visibility RFID provides.

The value chain usually ends with the final consumer of the tagged product. These consumers could be a Wal*Mart® shopper in Texas or an U.S. Army infantry soldier in Iraq. Some will be concerned by factors like price and product availability, while others will also want to be assured of freshness and product safety. RFID may provide the ability to reduce cost and improve services levels for these consumers. Some consumers will be concerned by the privacy ramifications of RFID, while others will not.

In some instances, there will be a reverse logistics value chain in which the product is returned by consumers to upstream participants for service or disposal. This does not significantly affect the analysis of the industry, however, as the issues involved are similar.

2.5.2. Challenges posed by the RFID value chain

This industry structure poses several challenges to the adoption of RFID. One obstacle is the relationship between the Product Manufacturers and the Distribution Chain Participants. Another obstacle results from the peculiarities associated with forcing rapid deployment of an emerging technology. Finally, there are concerns raised by the public which must be addressed.

2.5.2.1. Challenges in coordination of the supply chain

There is a large amount of information communication which needs to occur between the distribution chain participants. A single participant, like Wal*Mart®, sources products from a large number of companies, but cannot manage an infinite number of RFID data formats and sources. Some information transport standards will be necessary in order for this to work. In addition, products must be uniquely identified across all the suppliers, as they are with barcodes.

If the consumers are concerned about the route or environment their product has traveled, this information transport is even more important. This consumer need has been voiced in the pharmaceutical industry, where counterfeit drugs present a safety problem. It is also important in the defense industry, where vibration, humidity and temperature extremes can negatively affect the performance of ammunition and other equipment.

The Product Manufacturer and Distribution Chain Participants may be located in different countries, and this presents another challenge. Different countries have different laws which govern the use of ultra-high frequency communication, and so RFID hardware and business processes may not be consistent across the entire distribution chain.

In many cases, the costs of implementing RFID are borne by the Product Manufacturer, while benefits largely accrue to those in the distribution chain. Ongoing costs are the purchase and

application of tags, while benefits will be based on gains achieved by using the data contained within the tags. This coordination problem can be exacerbated by differences in organizational power within the value chain. Effective communication and a method for transfer pricing might help alleviate this situation.

2.5.2.2. Challenges with an emerging technology

Many of the advances in RFID technology are being developed at small startup companies. This is normal with early-stage technologies, but there are some drawbacks. Downstream participants are generally established companies, and do not expect their technology suppliers to go out of business at the rate startups generally do. The Product Manufacturers will require some assurance that their investment in RFID will survive even if one of their suppliers does not.

If it is assumed that all participants in this value chain are interested in quickly achieving widespread adoption, some other conclusions can be drawn. Product Manufacturers will help RFID Component Providers grow at rates higher than would be otherwise expected in order to speed development of the technology. However, the downstream participants will not want to be at the mercy of their RFID Component Providers once the market matures. Some peaceful solution that maintains an agreeable balance of power between these groups will be necessary.

2.5.2.3. Consumer concerns

History is littered with technological innovations that failed because they did not effectively manage the concerns of consumers. In a study of emerging technologies which failed in the face of consumer concern, technologies which did not benefit from a coordinated public relations effort had significant problems with adoption. The ability to opt-out had positive results as well [19].

Several consumer privacy groups have raised concerns about the implications of widespread RFID use, and several governments have considered legislation limiting the use of tags in a retail environment [20]. Articles overstating the capabilities of RFID have been written which imagine a privacy-free world [21]. No single company is driving RFID adoption and can take the responsibility of communicating with consumers about RFID. This could lead to significant problems in the future.

2.5.3. The role of EPCGlobal™

RFID industry participants recognized these challenges and worked with MIT and other universities to create the Auto-ID Center in the late 1990s. Founding members included several hardware and software component manufacturers, system integrators and a number of product manufacturers and distribution chain participants. Its overall goal was to drive the adoption of RFID, and the center took several steps to work towards this objective. In 2003, the administrative function of the center was spun off into an organization called EPCGlobal™, while the university research components continued under the auspices of the Auto-ID Labs [22].

EPCGlobal™ works towards its goal of driving RFID adoption in several ways. Each targets one or more of the challenges presented by the industry structure or specifics of the technology. Its success in the past several years is based on a respect for these challenges and an understanding of the history of other supply chain technologies.

2.5.3.1. EPCGlobal™ and standards

First and foremost, EPCGlobal™ establishes and promotes standards for the automatic identification of items in the supply chain of any company, industry and country [23]. In practice it has been assumed that these items would be identified through the use of RFID tags. In general, these standards can be subdivided into three main groups: the EPC number, software and hardware.

EPC is an acronym for “Electronic Product Code”. The EPC number is a compact numerical naming convention to uniquely identify items in the supply chain [24]. When an EPC-compliant tag responds to an interrogator, it usually transmits its EPC number. Current versions of the EPC contain either 64 or 96 bits, and store four pieces of information:

1. A Header that identifies the format and version of this EPC,
2. A Manager Number which uniquely identifies the company associated with the product being tagged,
3. An Object Class, which is essentially a Stock Keeping Unit (SKU) identifying a product type unique to that company, and
4. A Serial Number which uniquely identifies the item being tagged and differentiates it from other instances of the same Object Class.

The software standards serve to meet the supply chain coordination challenges described in section 2.5.2.1. The Physical Markup Language (PML) offers a common vocabulary for communicating information about items across the entire supply chain [25]. This solves the hypothetical problem Wal*Mart® would have faced in interfacing with a large number of different data formats. PML is extensible, meaning that additional attributes can be appended as needed. Pharmaceutical companies could communicate manufacturing location data through the supply chain, while the DoD could track environmental characteristics.

Object Naming Service (ONS) provides for the translation of tag license plate data into useable information about the manufacturer and product [26]. It works in a method similar to the Internet’s Domain Name Service (DNS) which translates a human-readable address like www.google.com into an IP address like 64.233.161.104 which can be used to route information.

The EPCGlobal™ Network shares another similarity to the Internet in that manufacturer’s products, like web servers, must be uniquely identifiable. EPC numbers cannot be duplicated between manufacturers; otherwise the tracking capabilities would not work in any supply chain in which those manufacturers’ products intersect. In order to prevent this from occurring, EPCGlobal™ members are given unique manager numbers which define a namespace inside which all of their EPC numbers must exist. EPCGlobal™ maintains a close relationship with UCC and EAN, organizations which administer the barcode namespace, in order to allocate manager numbers.

EPCGlobal™ also establishes standards for some of the hardware components in an RFID system. The consortium has defined a hierarchy of tag types, labeled Class 0 through 5. Class 0 and 1 tags are the focus of this thesis, and the specifications describe read-only and read/write passive tags which can be produced at low cost. The storage capacity, features and expected cost of the other tags increase with their designation number; Class 5 tags offer much of the same capabilities as the current generation of interrogators.

While EPCGlobal™ has not outlined specific requirements for interrogators, much of their current capability is driven by the interfaces defined in the tag specification. Antennas have not been addressed, although transmission parameters and limits are set in the US by the Federal Communications Commission (FCC) and in other countries by similar entities. There are also other standards which EPCGlobal™ has defined that we will not be discussing.

One result of these hardware standards is that they reduce Product Manufacturers' and Distribution Chain Participants' dependence upon any single RFID Component Provider. The untimely demise of one startup would not imperil the initiatives of the overall value chain. The standards also serve to limit the power of these RFID Component Providers by removing most possibilities for proprietary solutions. The standards have in effect become a suitable answer to the challenges of working with an emerging technology described in section 2.5.2.2.

2.5.3.2. A single industry voice for RFID

There are already many companies working with RFID technologies and more are being added to this list every day. An important role of the EPCGlobal™ consortium is to provide a single voice for the industry. While there are challenges in gaining agreement from all the individual members within the consortium, managing conflicts internally grants the possibility of coherent and consistent external communication. When used appropriately, the full weight of some of the world's largest companies can provide solutions to problems that would otherwise be ignored and limit adoption.

One area in which this is important is in addressing wireless spectrum regulations across the world. Countries have different limitations on the amount of power that can be transmitted from an antenna, making communications performance and reliability in global supply chains difficult to predict. In addition, frequency ranges allowed for RFID communication can differ between countries. Antenna length and other parameters are tuned for specific frequencies, and this difference can adversely affect performance. EPCGlobal™ can provide a source of power in transforming these regulations, but it is unclear whether this will occur.

The consortium provides a forum for all the value chain actors to interact, and this can lead to additional advantages. Recently a member of the consortium requested large royalties for the intellectual property it had contributed to the next generation tag specification. While the request was made in compliance with EPCGlobal™'s intellectual property policy, furor over this request may result in the standard remaining royalty-free [27]. Without a formal forum in which to have these discussions, it is unlikely that royalty-free standards would be developed.

Finally, the consortium allows a single voice in responding to consumer concern regarding privacy in an RFID-enabled world. EPCGlobal™ has issued guidelines for use by all companies engaged in large-scale deployment of EPC [28]. These dictate that customers have the right to be notified if EPC is present in a product or its packaging, and how to disable the RFID. In general, the RFID tag will be on the product packaging, and so simply discarding the packaging is sufficient. The guidelines also address methods for informing the public on EPC and require consortium members to publish privacy policies regarding how information collected is used.

While the guidelines are commendable, it is not clear that EPCGlobal™ has succeeded in allaying the fears of the public and especially watchdog groups like CASPIAN and Electronic Privacy Information Center [29]. There is a need for a consistent and vocal public relations program if RFID adoption is to extend to the public consumer.

2.5.3.3. EPCGlobal™ and knowledge sharing

The final method in which EPCGlobal™ helps to meet the challenges posed by quick adoption of RFID is by providing a forum for sharing knowledge. A company seeking to integrate RFID into its supply chain must consider issues spanning manufacturing operations, information technology, finance, packaging design, facilities layout, and other topics. The formal knowledgebase made available to consortium members can help organizations up this steep learning curve. Frequent conferences are held, and action groups have formed in some industries to address with their specific concerns [30].

In addition, EPCGlobal™ maintains a relationship with the Auto-ID Labs at several universities worldwide [31]. The labs conduct research into various aspects of RFID systems, and continue to publish research. Through this relationship, EPCGlobal™ can help shape the direction of research in order to address obstacles adoption might face in the future.

2.5.4. The need for mandates

A challenge EPCGlobal™ does not specifically address is the lack of overlap between those who pay for RFID and those who accrue the benefits of this information. Only in some cases is the return on investment so spectacular to the manufacturer that it is feasible to implement RFID within its own organizational boundaries. On the other hand, retailers can see significant benefit if shipments arrive with RFID tags on them [32].

One example of this is Gillette's proposed use of RFID to counter shrinkage. Shrinkage is usually a euphemism for theft and loss, and occurs throughout Gillette's distribution chain. Gillette's razors are small, high-value items and easily resold once stolen. The company is currently researching methods of implementing RFID in order to reduce this shrinkage. However, this example of generating internal ROI is the exception, and usually limited to industries with high-value products [32].

The question is how does an industry drive RFID adoption? One option is to develop contracts stipulating the sharing of costs and benefits across multiple parties. This type of solution is used in a number of situations where organizations are seeking to achieve a global optimum in their supply chains. However, this would be difficult to do with RFID. There are a large number of suppliers and the number of contracts required would be prohibitive. In addition, RFID is still an emerging technology. There are many unknowns in any cost / benefit calculation, and organizations may find it difficult to come to an agreement.

A more likely option is for particularly powerful market participants to mandate that other members begin an investment in RFID. This is what is happening in the retail industry. Wal*Mart and other large global retailers will be requiring their suppliers to tag shipments with RFID and transmit this information to them. The retailers' market power allows them to issue such a policy with a high likelihood of compliance. This has driven adoption throughout the value chain.

2.5.5. The DoD RFID Policy

Seeing a similar situation, the DoD finalized an RFID policy to its 43,000 suppliers on July 30, 2004 [33]. The information in this section is sourced from this policy statement, and citations are only used for specific figures or quotes from the statement. In broad strokes it requires defense suppliers to tag their shipments with RFID tags. This will allow the shipments to be tracked as they travel through the Defense Logistics Agency's supply chain. This section describes the policy in detail. Although there are aspects which are specific to the defense

industry, the policy is similar in structure and intent to those issued by companies in retail and other industries.

While the specific business rules were issued on July 30, 2004, the general expectations were publicly outlined as early as October 2, 2003 [34]. The first part of the policy describes requirements for the tagging of oceangoing containers and international shipments with Active RFID tags. This is an extension of the network the DoD has deployed worldwide and was described in section 2.1. We will focus on the portion of the policy that considers passive RFID tags.

2.5.5.1. Three dimensions of the policy rollout

The scope of the policy expands over the next few years in three dimensions:

- The types of products which must be tagged,
- The shipment’s point of entry into the DoD’s brick and mortar distribution network, and
- The level at which shipments are tagged: individual items, cases or pallets.

On January 1 of 2005, 2006 and 2007, the next level of the requirement is mandated until nearly all shipments are tagged with RFID.

The DoD organizes the products it buys into ten different classifications as shown in Table 2.

Class	Material covered
I	Meals-Ready-To-Eat (MREs), food, sustenance, and commercially bottled water
II	Clothing, individual equipment, tools, toolkits, administrative and housekeeping supplies
III	Petroleum, oil & lubricants, bulk fuels
IV	Construction items
V	Ammunition and ordnance
VI	Personal demand items, health & comfort items
VII	Major end items and military equipment like tanks, vehicles and most Raytheon products
VIII	Medical supplies
IX	Repair parts and maintenance components
X	Material for non-military programs like economic development and disaster relief

Table 2: Classes of supply in the military [35]

Each year, the policy expands to cover a wider set of classifications as shown in Figure 8. Some products, like fuel in pipelines, cannot be physically tagged and are excluded from the policy’s requirements.

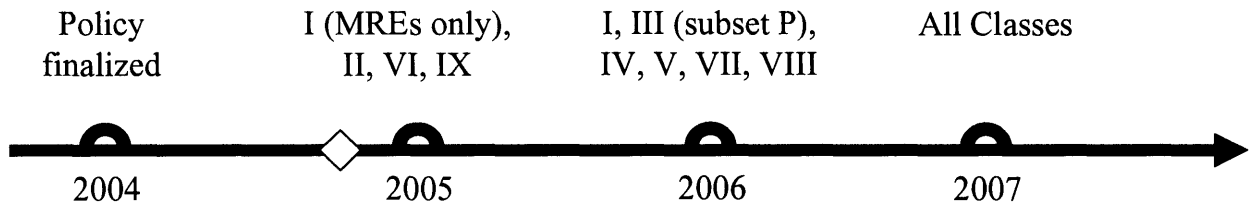


Figure 8: Commodities covered under the DoD RFID Policy

The DoD operates a large number of distribution depots in the continental U.S. and all over the world. Its contracts with suppliers stipulate that shipments are to be made to one or more of these depots. The RFID policy outlines an expanding set of depots whose shipments must be tagged, as shown in Figure 9. By 2007, all shipments to the DoD or its components (the armed forces) must have RFID tags.

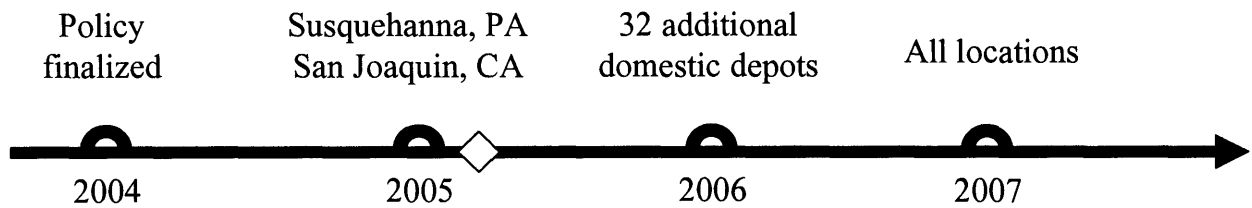


Figure 9: Depots requiring RFID tags

The third dimension along which the policy extends over time is the level of container which will require an RFID tag. Figure 10 shows how individual items are first combined into an exterior container and then loaded onto a pallet. The majority of Raytheon's shipments look like the example on the right side of the figure, where one or more shipping containers are placed on a pallet.

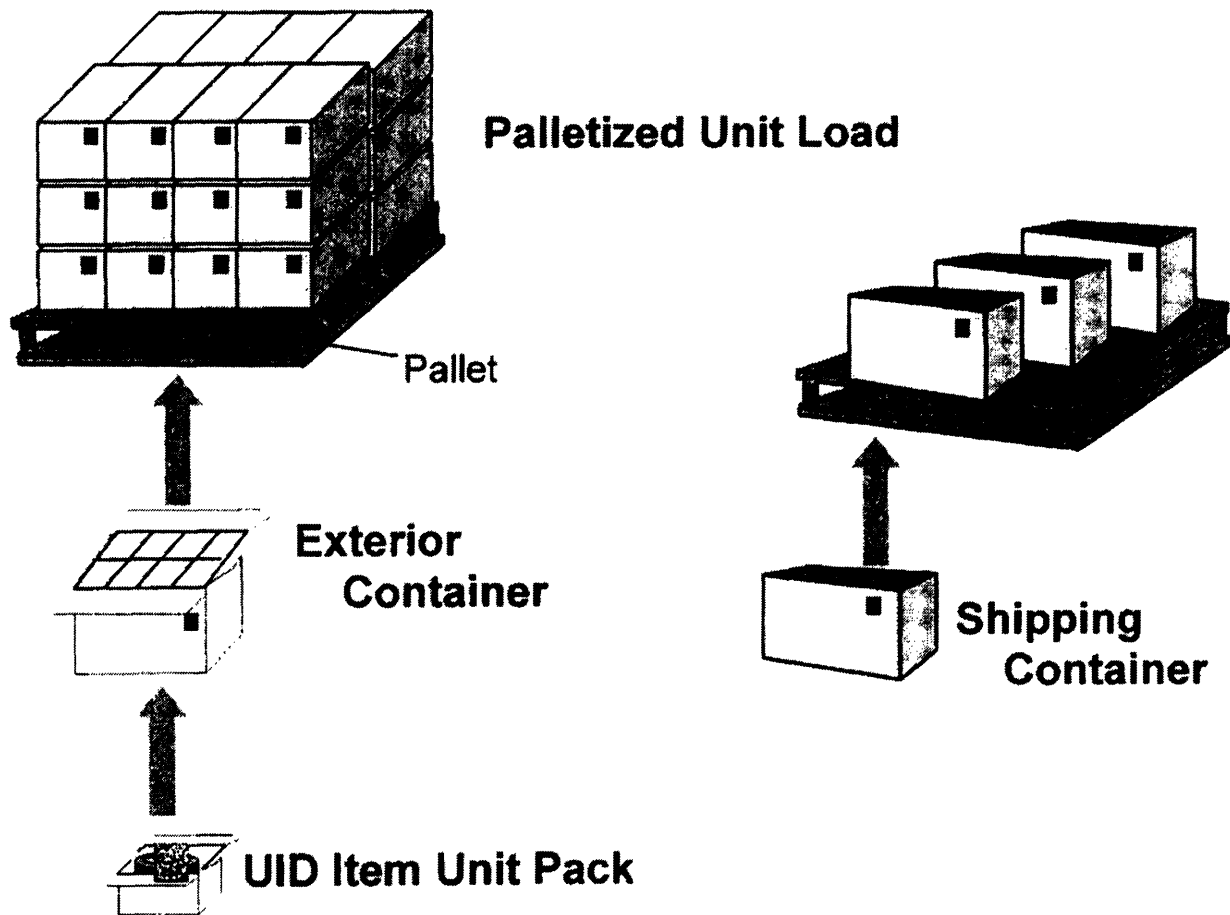


Figure 10: DoD Container Hierarchy [33]

Before 2007, only exterior containers, palletized unit loads and shipping containers require passive RFID tags. This level of tagging is consistent with the overall goal of the RFID policy: to give the DoD visibility on items on their initial journey to the warfighter.

In 2007, the policy expands to cover “UID Item Unit Packs”. UID, or Unique Identification, is a separate policy which requires permanent serialized designations on expensive end items and repairable parts. The goal of this policy is to simplify identification of product through the supply chain during the product’s entire lifecycle. The 2007 extension of the RFID policy may be the first of future attempts to reconcile these two policies.

The obvious question posed by many defense suppliers is “When will I need to be compliant?” Raytheon’s situation may be similar to others in the defense industry. The majority of shipments Raytheon makes are either spares and repair parts (Class IX) or major end items and weapon systems (Class VII). However, very few spares and repair parts are sent to either Susquehanna or San Joaquin, the commodity classifications and depots covered in the 2005 requirement. The 2006 expansion of the policy to include major end items and 32 additional depots means that nearly all Raytheon shipments will be impacted by the policy in that year.

2.5.5.2. Workflow requirements of the RFID policy

In addition to these physical requirements, the policy also stipulates aspects of the workflow to be used when transmitting RFID data. There are two components to this: The content structure of the tag's "license plate" and the transmission of data.

The policy specifies the use of EPCGlobal™ Class 0 or Class 1 passive tags. These provide either 64 or 96 bits of storage to be used for identifying the manufacturer, product SKU or Object Class, and unique serial number. The DoD accepts two formats for this information.

One is the Electronic Product Code described in section 2.5.3.1. EPCGlobal™ will make sure that manufacturers do not encroach on each others' namespaces through the assignment of globally unique EPC manager numbers. There is a membership fee associated with joining EPCGlobal™ and receiving a manager number. For many of the DoD's suppliers, this cost will be substantial in comparison with the rest of their RFID investment. It is likely that this cost would be directly or indirectly charged back to the DoD, especially if the supplier can show that it is not using RFID for other purposes.

For this reason and possibly others, the DoD has allowed the use of the "DoD Construct", an alternative namespace allocation nomenclature. It comes in several formats, but essentially allows the use of pre-existing manufacturing identifiers like the Commercial and Government Entity (CAGE) code instead of EPC manager numbers [36].

Regardless of which numbering scheme is used, the supplier is responsible for maintaining rational and unique object class and serial number data. For those suppliers who also conduct business outside of the defense industry, the Electronic Product Code might make sense by eliminating the possibility of duplicate numbering schemes. All but the largest Defense-only suppliers will probably choose the DoD Construct because of its use of existing and familiar manufacturer identifiers.

Since 1999, the DoD has offered a paperless workflow system for coordinating the shipping, receiving and payments processes. This system is called Wide Area Workflow, or WAWF for short [37]. WAWF provides a clearinghouse for storing supply chain workflow documents like contracts, invoices and advanced shipping notices (ASNs). It can be accessed by all participants in the supply chain.

The RFID policy states that suppliers will use the WAWF to send advanced shipping notices to the receiving DoD entity and that the RFID tag data will be included in this ASN. The ASN transaction template will allow for RFID-specific information to be entered, including data on container and tag nesting and UID / RFID cross-references.

2.6. Primer conclusion

This chapter should provide the reader with sufficient background to understand the remaining portions of this work. The citations provide a good source of additional information, and should be used as necessary to complement the reader's knowledge.

Chapter 3: Challenges identified in the current state

One aspect of the DoD RFID policy which is still uncertain is who will ultimately pay for the cost of achieving RFID compliance. The Department of Defense hopes that the policy will accelerate the adoption of RFID by companies seeking to identify cost savings opportunities. This expectation has been communicated to Raytheon and other major defense suppliers. If the return on investment for these business process improvement activities is sufficiently large, it should compensate for the costs of achieving compliance.

However, there are significant challenges to both achieving compliance and evaluating improvement opportunities. This chapter describes these challenges faced by companies evaluating RFID. In some cases, Raytheon's Integrated Air Defense Center is used as an example, but the challenges are applicable to any location.

3.1. Challenges in achieving compliance to the DoD RFID Policy

Several challenges await defense suppliers who are tasked with meeting the compliance requirements.

First is the labor force's reaction to introducing RFID into a facility or warehouse. The introduction of a new technology is often met with fear for job security and cynicism. In the case of RFID, job security fears are unlikely to be realized in the near term. In addition, management attention and significant communication are generally focused on reducing this fear.

Cynicism will be a more difficult emotion to counter, since early efforts at tagging material will be unsuccessful. Current performance levels do not allow tags to be attached to containers in just any orientation. Material in the containers is likely to prevent some tags from being read. Still, this performance challenge can be overcome relatively easily: the majority of containers used by Raytheon and other large suppliers are large wooden shipping crates which are RF transparent.

The differences between RFID and other automatic identification technologies also take time to become comfortable with. Operators' training with barcode readers leads them to expect RFID to work in a line-of-sight configuration and read only one tag at a time. An exercise we performed in our RFID training class has trainees try to identify specific tags which are mixed in with a large number of others. It generally takes some time before the students realize the implications of field-based identification and expose tags to the field one at a time. Again, experience reduces the impact of this difficulty.

Another challenge is in interfacing with Wide Area Workflow. The system is still new, and many suppliers have only recently integrated their shipping systems with WAWF. IT resources skilled in web-based data integration and EDI are often difficult to find within many defense suppliers. In many cases, experienced resources outside of the company are also difficult to acquire, since there is such high demand for this skill.

While the DoD RFID policy describes several requirements in depth, several aspects are not yet completed. For example, the payment method for tag expenses is not defined yet, nor are some of the specific data structures required for transmitting RFID data into WAWF [33]. This information will become available in advance of any non-compliance penalty decisions, of course. In the meantime, however, there is uncertainty which makes planning a compliance project more difficult.

Finally, the compliance project requires the coordination of many internal organizations. Generally, resources from shipping, information systems, finance, engineering, the union, and

RFID vendors are involved. Coordinating these organizations can be difficult, even if they are all committed to achieving compliance.

3.2. Challenges in achieving business process improvement

There are additional challenges inherent in leveraging RFID technology to achieve business process improvement. The bulk of this thesis focuses on these challenges and a set of tools, techniques and frameworks developed to understand and overcome them.

3.2.1. Developing a business case for using RFID

One of the first steps a company takes when evaluating RFID for business process improvement is to calculate the financial and other benefits of deploying the technology. However, any return on investment calculation assumes that a decision has been made on what business process improvements will be undertaken. An overview of the material distribution process at the Raytheon Integrated Air Defense Center (IADC) shows how this assumption cannot always be made. After identifying the root causes of this complication, a solution is proposed in Chapter 4: Developing a business case using systems optimization.

3.2.1.1. The materials distribution process at the IADC

The material flow for incoming shipments and raw materials at the IADC provides a good example for the complexities facing someone developing an RFID business case. The process described below is significantly simplified from the real-world flow and some aspects have been modified for competition reasons.

Even in its modified form, the process description is important for several reasons. First, it makes clear some of the differences between the raw material arrival process at a consumer goods company versus a defense supplier. The defense supplier must support a greater range of material sizes, usage rates and quality control requirements than its commercial counterparts. The materials process also provides a current state that we will attempt to improve upon using RFID. Finally, we will identify aspects of the process flow which will have implications on the RFID cost / benefit calculation. Examples of this are reader locations, cycle times and tag performance requirements.

Materials arrive into the IADC facility through one of four standard-sized dock doors. On average, 250 shipping "lots" arrive each day. In the real-world flow, a lot may be made up of several individual boxes from a single vendor, but in our example we will assume that each lot is comprised of just one box, crate, parcel or container. The majority of these arrive through global parcel services like UPS® or Federal Express®, although larger items will arrive in trailers or on delivery runs from other Raytheon facilities. Most deliveries occur in the morning, resulting in a backlog which is processed for the rest of the day.

When incoming shipments arrive, they are looked up in the receiving IT system, where they will be associated with a specific purchase order. Approximately 40% of the packages will have a Raytheon-format barcode attached which facilitates this lookup process. Operators will look at the packing slips of packages without barcodes to find this information. The IT system then prints a label which is applied to all the incoming shipments. This label becomes the identifier for this shipment container throughout the rest of the warehouse receiving process. This would also be the logical step at which an RFID tag would be applied to the box if this was deemed necessary. All packages go through this step and an RFID-enabled label printer would allow the application to occur without an effect on the overall cycle time.

After affixing the label, the operator places the product in one of 60 racks depending upon the next step in the process flow. The operator currently uses a handheld barcode scanner to scan both the box and rack in order to update the system with location information. Material will often move from rack to rack as it undergoes processing in the warehouse. RFID readers on the rack could make this scan unnecessary and perhaps reduce the number of items misplaced during this step in the process. The existing racks are made of metal, however, a material which negatively impacts RFID performance.

The next steps in the process depend upon the characteristics of the package and material inside. One of the first decisions made is whether the package contains material which will be going into an assembled product made on the manufacturing floor. This material is called "Product" in Raytheon parlance. "Non-product" encompasses all the other items. Non-product can include letters, desktop computers, MRO items, urgent deliveries and tools or fixtures.

Unlike many commercial facilities, these non-product deliveries come through the loading dock instead of delivery to a central mailroom. Facility security is one of the drivers behind this decision, as monitoring is easier with a single point of entry. Approximately 90 packages arrive each day and are placed into a rack depending upon their final destination. Five operators deliver these packages to the manufacturing floor or point-of-use destinations like offices and cubicles. Delivery is confirmed with a final barcode scan at the destination location. The shipping box is "detrashed" (opened and thrown away) at the final destination only by the recipient, and the flow of non-product material effectively ends here.

The remaining "Product" falls into one of two main categories. Some of the material comes from Raytheon's strategic partners. These suppliers have been able to meet quality guidelines to the extent that their shipments do not require inspection before proceeding to the manufacturing floor. This Vendor Qualified Product (VQP) accounts for 40-45 shipments per day.

The majority of "Product" will require some inspection before going to the floor. On average 120 packages per day are placed on one of the inspection racks. Using a priority system, operators take packages from the inspection racks into the inspection area in a room next to the warehouse. There the container is scanned, opened and the product inspected as per the defined protocol. The inspection process can be very in-depth, depending upon the type of material involved. After inspection, the material is returned to the box, which is resealed before being returned to one of the storage racks.

Some of the inspected product, however, will not immediately pass inspection and requires escalation to the engineering group. Inbound Engineering Services (IES) receives approximately 40 shipments per week, and this group is responsible for troubleshooting first-round failures. IES is located down the hall from the warehouse, and receives deliveries a few times a day. The material label is scanned when it arrives and leaves the IES area. For this simplified process, we'll assume that all material eventually passes inspection. Obviously, this is not the real-world situation as otherwise Raytheon would not need to inspect material at all.

Once all the material has passed or circumvented inspection (by virtue of being vendor-qualified), a decision is made on where it will be stored until needed by the manufacturing floor. Large items are considered "Bulk" and will be stored in 50 foot tall warehouse shelving racks. These include system controllers, structural components and everything else larger than 24" x 6" x 18". Bulk items will ultimately be delivered directly to the floor and bypass the main stores carousels described later in this section.

Smaller parts reach the manufacturing floor through a different process. Before the material is put into storage, it must be inducted into the Andover Warehouse Control System, or AWCS. The shipping container is scanned for a final time as it enters the AWCS induction area and the material is removed from its original shipping container. The shipping container is detashed at this time.

Generally the containers' contents are separated into individual items. For large quantities of very small items, however, the parts are grouped into quantities of 10, 20 or 50. Examples of these types of items are diodes, resistors and some connectors. The individual parts (or groups) are repackaged into small storage containers. These are usually electrostatic discharge (ESD) bags. These act as a Faraday shield protecting the components from electrical shock. These bags also ground the antennas of any RFID tags applied directly to them, rendering them inoperable.

Each of these small containers is bound for the main stores carousels, and for this reason we will refer to them as "carousel stock". The operator prints labels for each of carousel stock containers, which creates an entry for them in AWCS. The label is called a PID and has barcodes and human readable components which specify the part number and random carousel storage location it will reside in. The containers are then placed on a "To Stores" rack. Approximately 44,000 PIDs are created each year.

The full flow of the warehouse receiving process is shown in Figure 11.

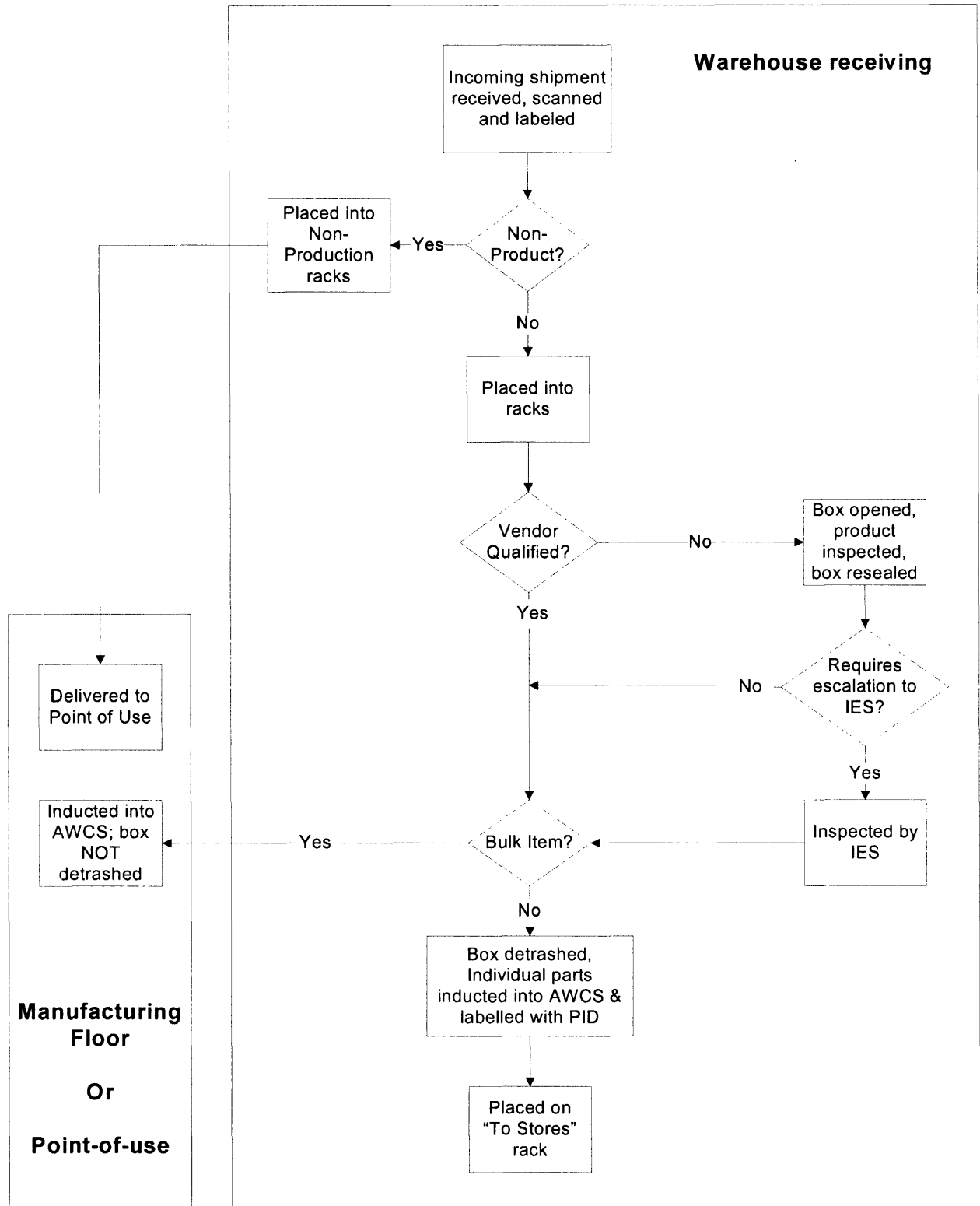


Figure 11: Warehouse receiving material flow

After the material is placed on the “To Stores” rack, control of the process and responsibility for the material is transitioned to the Main Stores department. The role of the receiving department was to sort, qualify and distribute material. Main Stores, on the other hand, is tasked with storing this material until it is needed by the manufacturing floor. It then delivers a consolidated set of several different parts in a kit to support manufacturing. The process flow through Main Stores is essentially linear, but dwell time for any specific item can vary considerably. This flow is shown in Figure 12.

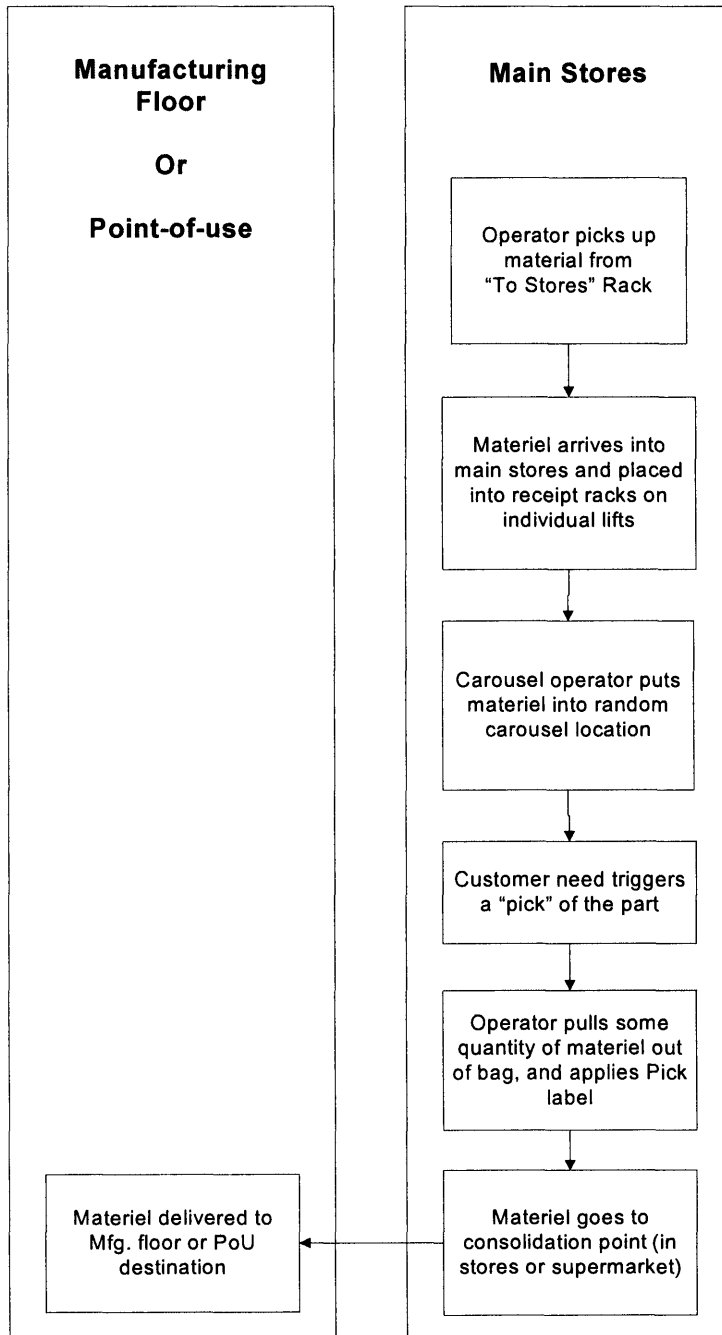


Figure 12: Main Stores material flow

The most obvious feature of the Main Stores area are the 27 carousels which take up most of the available floor space. Each is nearly 12 feet high, 6 feet wide and over 40 feet deep and contains thousands of wood or cardboard storage location bins. Seventeen lift stations service the carousels, with some placed so that the operator can run two carousels. The carousels are computer controlled, and entering a storage location number will rotate the carousel until that storage location is presented to the operator. The software which controls the carousels and lift stations is called Wavetrak, and has been developed relatively recently.

A carousel and lift station is shown in Figure 13.

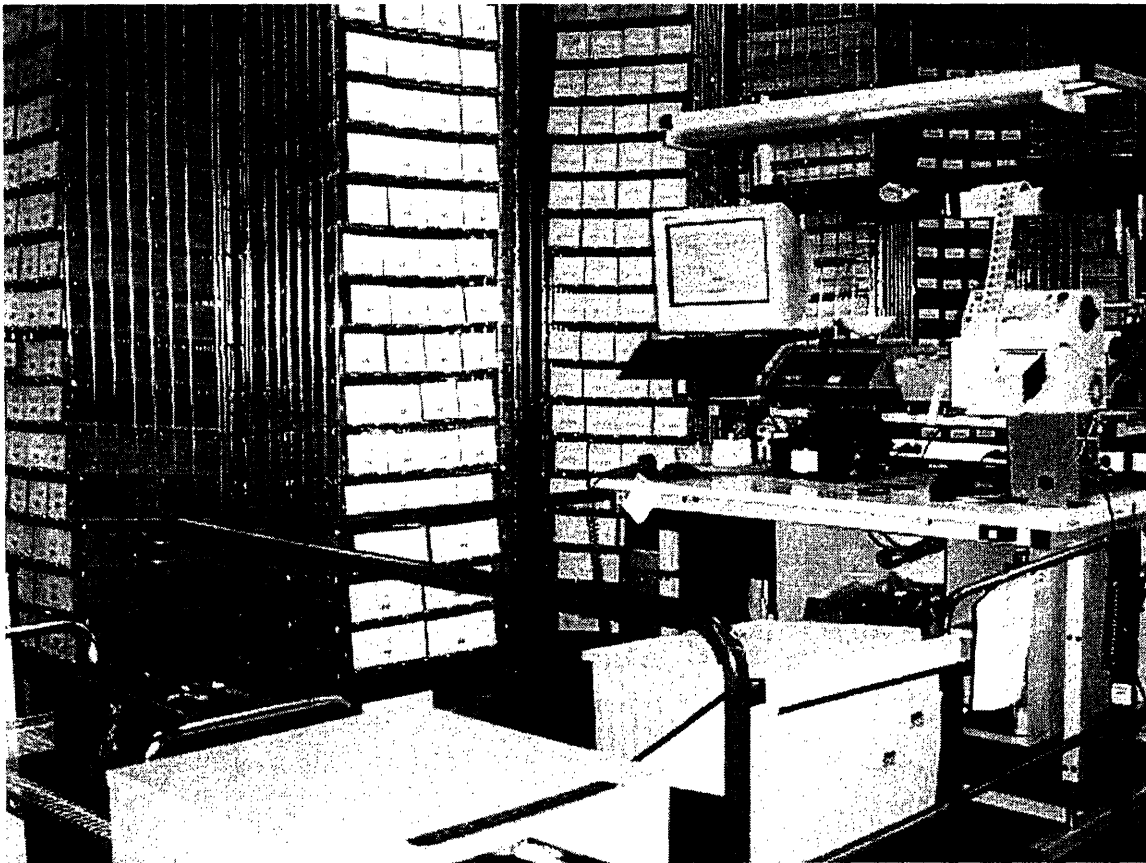


Figure 13: Main Stores carousel and lift station

The first step of the Main Stores process is to “put-away” the PID-labeled carousel stock into the carousels. An operator picks up recently inducted stock from the “To Stores” racks in the warehouse. As over 180 PIDs are created daily, this pickup happens several times a day. Once the operator arrives in Main Stores, he or she places the material into the receipt racks on the correct lift station. The receipt racks are the light blue bins shown in Figure 13.

The operator assigned to that carousel will scan the barcode on the package and place the material into the storage location. Note that the PID label was not scanned between AWCS

induction and the actual put-away action. Also note that there is no consolidation occurring: if the part number is already stored somewhere within the carousel, the two carousel stock containers are not combined nor are they necessarily put in the same storage location.

The material now awaits manufacturing floor area (customer) need to trigger a “pick” of the part. At anytime, this need is transmitted through several MRP systems, but the information ultimately enters WaveTrak and is prioritized. The customer usually requests a kit of parts, sufficient to support the complete manufacture of one or more end items or subassemblies. Depending upon the part number and customer need, the carousel stock may be resident in the carousel for anywhere from a few days to years.

Remember that the PID label may be affixed to a carousel stock container with one or more items inside. The kit may not require all the pieces within the carousel stock container, and so the remaining carousel stock is returned to storage location (the quantity remaining is updated in AWCS). Another possibility is that the kit requires more than the quantity of a part stored in any one carousel stock container. In this case, more than one carousel stock container will be opened and emptied.

When a part is requested, an operator pulls the correct quantity from the carousel stock and applies a new identifying label, the “pick label”, to a new ESD bag container. In addition, more than one pick label might be printed since the carousel stock containers might be at different lift stations and therefore not easily put into the same pick label bag. In any case, emptied carousel stock containers are detashed, and we will call the new container the picked parts. Approximately 1700 Pick Labels are printed each day, implying that an even greater number of individual pieces are requested.

The picked parts are carried to the consolidation area, which is past the end of the long aisle of carousel lift stations. The pick label is scanned here, and once all the components of the kit arrive into the consolidation area, the kit is sent to the manufacturing floor. This effectively ends the incoming material process flow.

There are dozens of internal customers for the materials distribution process. Defense companies are characterized by a large number of long-term programs, and the IADC is no exception. There are a few key manufacturing lines within the plant, and these comprise the bulk of incoming packages and request the majority of kits from main stores. It's possible that a complete analysis of material flow through the IADC (incoming, manufacturing and outbound delivery) might be worthwhile. Evaluating the first part of this flow, however, became the focus of analysis in this thesis.

3.2.1.2. Systems interactions in RFID evaluation

When developing a business case based on the above process, several questions are usually asked by the analyst. Among other things, they will want to know:

- What RFID benefits could be found in a future state process?
- Which of these usage scenarios should be implemented, and which should be ignored?
- Where should one install interrogators in order to support the chosen usage scenarios?
- What items should be tagged, and which should be ignored?
- Will expected tag performance impact the usage scenario benefits achieved?

- What IT investment will be necessary, and what functionality should be developed in these systems?

The analyst will quickly realize that the answer to any one of these questions is predicated upon the answer to one or more of the others.

For example, if the analyst decides to place interrogators at each of the lift stations in order to reduce the cycle times associated with putaway, could those same interrogators be used to find material misplaced within the carousels? There would be an incremental cost in doing so, but also an incremental benefit. In fact, there may not be a return on investment with any one usage scenario, but a significant return on the right set of usage scenarios.

The evaluation of an emerging technology is very difficult due to the significant unknowns that come with a lack of experience and technological maturity and reliability. These system-level interactions make developing a business case even more difficult. The choice of a future state and the financial impact of that choice requires joint optimization.

These difficulties became apparent during the evaluation of RFID-driven business process improvement at the IADC, and are likely to be present at other facilities as well.

3.3. Hardware performance and tag read reliability

Privacy advocates often credit RFID with having nearly unlimited read range, but the reality of current technology is quite different. Many manufacturers are struggling with methods of affixing tags to their product in a way that optimizes the performance of tag / interrogator communication. As described in section 2.2, the communication method between a tag and an interrogator is governed by the laws of physics.

The ability to improve this performance and therefore be able to read tags with a greater reliability is often a necessary step towards achieving a return on investment. Consider a usage scenario often discussed at defense suppliers: carousel cycle counting. For auditing purposes, defense suppliers must ensure that inventory quantities listed in their IT systems are accurate and correspond to the quantity actually available in the carousels. One method of doing this is to perform complete inventory counts at regular intervals. This has the significant disadvantage of effectively shutting down the materials distribution flow while inventory is counted.

A more often used solution is to perform counts on randomly selected part numbers each day. Over the course of a year, any particular part number will be counted several times, but main stores can operate as normal while cycle counting is performed. Consider what might be possible if all the parts were individually tagged with RFID and interrogators and antennas were set up near the carousels. Simply rotating the carousel would cause all the tagged parts to pass through the interrogator fields, and a count could be done automatically. The thousands of labor hours spent each year in performing cycle counts could be reduced to a few minutes of circulating the carousels.

But what if one of the tags is not working properly, is oriented improperly or blocked from the field by metal? The short count on that part number would require a manual verification, removing any advantage gained by RFID. Now consider if 20 items of a particular part number are stored within the carousels, and our read reliability is at 95%. We are defining tag read reliability as the likelihood of a tag being read in a particular process step. Making an independence assumption, the chances of correctly counting all 20 items is as follows:

$$P(\text{correct}) = (.95)^{20} \approx 36\%$$

The count will be incorrect nearly 2 times out of 3! Any expected benefit from RFID will be reduced by this substantial amount.

However, consider the difference if we are able to improve our performance to 99% reliability:

$$P(\text{correct}) = (.99)^{20} \approx 82\%$$

The RFID system now reduces the number of cycle counts performed by a factor of 5. With this level of performance, the RFID-enabled count will be correct most of the time, and remove the need for a resource-consuming manual cycle count.

The effect of RFID performance on the financial viability of any proposed implementation can be substantial, as this example clearly shows. In complex systems, micro-level factors, like RFID performance in a specific scenario, can have a substantial effect on the macro-level viability of the entire system.

Chapter 4: Developing a business case using systems optimization

Chapter 3 described the system-level interactions which complicate the evaluation of RFID. In this chapter, we formulate a model we can optimize in order to achieve the highest return on investment. This chapter outlines a framework for defining this model which will be the basis of a software tool described in Chapter 5 and used to evaluate a deployment at the Integrated Air Defense Center in Chapter 6.

4.1. Background

In order to discuss the evaluation of RFID, several definitions are required. In addition, a general review of possible RFID opportunities gives us an understanding of how to evaluate the financial benefits.

4.1.1. Definitions

Several terms are used in this chapter which may not be familiar. These terms are defined below.

Term	Definition
Usage scenario	A usage scenario is a specific benefit gained from using RFID. It may be cost savings from replacing a time-consuming barcode scan with an automatic tag read or shrinkage reduction resulting from the ability to track lost product.
Material type	Also called "Materiel Type", this is a specific type of item which may be tagged with an RFID tag. Examples include incoming shipment containers, A-parts inventory, and reusable storage bins.
Reader sets	Also called "Interrogator sets", this is an array of RFID interrogators which cover the same general area. A bank of dock doors may have several individual interrogators in a single interrogator set, while the sole exit from a warehouse would have one interrogator in its set.
IT module	A discrete set of IT functionality which supports a specific capability in an RFID system. For example, an IT module may be built for supporting carousel cycle counts or searching for lost items.

Table 3: Business case definitions

4.1.2. Usage scenario types

As described in section 2.1, organizations have used RFID in a variety of ways since World War II. While the variety of usage scenarios is almost limitless, several specific usage scenario types are most common at defense suppliers. This chapter describes these in detail, as they are the available usage scenario templates in the Excel™ RFID Calculator.

Any substantial investigation of RFID for efficiency improvement should review all the ways in which RFID might be used to improve upon existing business processes. The final list of possible usage scenarios will usually include most of the types below, and some may be used in several different instances.

4.1.2.1. Receiving identification

Product often arrives on the shipping dock with multiple cases on a pallet, each of which needs to be inducted into local business processes and IT systems. If the containers were individually tagged with RFID prior to their being inducted, manual scans could be replaced by passing the pallet through an RFID chokepoint. This usage scenario can also apply within the four walls of a facility where product is transported in pallets between departments.

Generally, this usage scenario works best if an enforceable and wide-ranging mandate is in place. The expectation is that a company's suppliers will tag their outgoing product and electronically submit advance shipping notices (ASNs). The ability to match incoming shipments with ASNs makes induction time essentially nil.

Of course, there is no assumption of 100% compliance. As long as compliance is sufficiently high, however, it can make sense to run two processes. Those shipments that arrive w/o RFID tags and advance shipping notices may have a tag applied upon induction.

This is the key usage scenario that the Department of Defense expects to take advantage of once its RFID policy has been fully implemented. There are direct benefits from labor savings and indirect benefits that result from being able to more effectively handle peak loads. The calculations used to determine this benefit will be different for each organization.

4.1.2.2. Identification speed

This usage scenario type encompasses most scenarios in which a barcode scan or keyboard entry is being replaced with an automatic RFID tag identification. In real-world RFID installations, many of the usage scenarios will be of this type. In some cases, the benefits can be very large.

Consider an example in which a pallet is broken down and each individual case barcode scanned to verify the shipment's contents. Depending upon the material inside, the pallet could be scanned with an RFID interrogator and all the verification data transmitted by individual passive tags on each container. This could easily save 2-5 minutes per pallet.

Unfortunately, not every tag will be read successfully. In these cases, a backup manual process will need to be used. The problem is exacerbated by the fact that if one tag fails within a particular conveyance, all the parts in that storage bin or on that forklift will probably need to be scanned manually. This difficulty can be minimized by using a conveyor or other process which enables single-piece flow instead of large consolidated shipments.

4.1.2.3. Carousel cycle counting

Warehouse carousels provide automated access to large numbers of storage locations without requiring operators to walk around shelving systems. They can come in both horizontal and vertical configurations and are of various sizes. In the case of RFID-tagged material, carousels can make it easier to perform cycle counts: Spin the carousel a few times and a fixed interrogator can irradiate the entire contents of the carousel. We discussed the requirement for cycle counting in section 3.3, and for many organizations it can be a huge investment in time even if it is preferable to taking complete inventories every year or quarter.

Depending upon hardware performance and the robustness of the RFID cycle counting process, the number of part numbers which will require manual cycle counts might be reduced considerably. Defining the following variables:

<i>p</i>	Probability that any given tag will be read successfully
<i>N</i>	Number of individual part numbers which require cycle counting
<i>Q</i>	Average inventory level of each of these part numbers
<i>t</i>	Time in seconds required to perform a manual cycle count of a part number

We can determine that the time saved per cycle counting period is equal to:

$$N \times t \times p^Q$$

Most defense suppliers categorize their raw materials into A, B and C parts in order of decreasing cost. It is often true that **Q** will be lower for A parts than B parts, and lower for B parts than for C parts. Finally, government agreements often stipulate more frequent cycle counts on A parts as well. Because this all has a significant effect on the benefit achieved, it's often worthwhile to evaluate these different material types separately.

4.1.2.4. Asset visibility

While individual interrogators can result in benefits from identification speed and injury prevention, their existence also allows better visibility of material and other assets within the four walls of a factory. Without RFID, the high cost of manually tracking the movement of material means that product cannot be located with a great deal of precision.

RFID provides more granular visibility with relative ease. For example, instead of just knowing that a product is "To Stores", the system would know whether the product is in the receiving area, between the warehouse and stores, or sitting in stores waiting to be put away. The benefit of this usage scenario increases with the number of unique zones which are created by the RFID interrogators. With ***N-1*** interrogators, an RFID system could differentiate ***N*** discrete zones at a theoretical maximum.

One benefit of having a large number of interrogators is a reduction in time spent looking for misplaced material. The ability to know that the misplaced material is within a small physical area bounded by two or more interrogators can reduce search time significantly. In cases where material would have been marked as lost, this results in even larger cost savings.

The difficulty with calculating the benefit from asset visibility usage scenarios is that a judgment call must be made regarding how much less time will be spent or how much less material will be lost. An analyst can only estimate the benefit, and no rules of thumb exist to help make the calculation.

One possible calculation method is to assume that the amount of time spent searching for material is proportional to the physical size of the zone it is lost within. With the high cost of manual product identification through barcode scans or keyboard entry, it's likely that there would be fewer zones prior to an RFID installation than afterwards. Given these assumptions and defining variables as

<i>M</i>	Number of zones in previous, manual identification scenario
<i>N</i>	Number of zones with RFID-enabled asset visibility
<i>t_m</i>	Amount of time spent searching for material in manual identification scenario
<i>t_n</i>	Amount of time spent searching for material with RFID-enabled asset visibility

Then one might expect that the resulting benefit would follow in the form:

$$t_n \approx \frac{M}{N} t_m$$

In practice business analysts are more comfortable with simply agreeing to an arbitrary, but conservative, percentage decrease as the benefit from this scenario. However, this calculation can help focus the discussion.

4.1.2.5. Injury prevention

The repetitive motions required in firing a handheld barcode gun or in keying information into an IT system can lead to repetitive strain injuries and carpal tunnel problems. Back problems can result from lifting larger boxes in order to orient them properly for barcode scanning or visual label inspection. The direct cost of these injuries can be several tens of thousands of dollars, and the indirect costs of having an unsafe workplace and negatively affecting an employee's quality of life are difficult to quantify.

The hands-free aspect of an RFID tracking system removes much of the requirement to perform these actions, and can improve workplace safety. Many companies, including Raytheon, provide a figure for the fully loaded cost of an OSHA Recordable Injury [38]. However, the expected reduction in this rate can only be estimated at this time. In the future, benchmarks made available by other organizations will better guide RFID investment decisions.

4.2. Process diagramming RFID material flows

Before developing a model with which to optimize RFID investment decisions, one must fully understand the process to be improved. Current methods used to understand processes are not always appropriate for guiding RFID decisions. In this section, a new process mapping technique is proposed which best highlights the impact of decisions made when evaluating RFID.

4.2.1. Advantages and disadvantages of existing diagramming techniques

During the process of understanding the material flow at the Integrated Air Defense Center, it became clear that existing process diagramming techniques were not appropriate for illustrating a future-state RFID material flow. Three different diagramming techniques were used, and each had advantages and disadvantages.

Process mapping is the most obvious starting point for visualizing the material flow in any facility. The flowcharts in Figure 11 and Figure 12 are both diagrammed using a variant of this technique primarily because a layperson can understand the diagram quite easily. It also effectively illustrates the divergent nature of material flow in some parts of the facility. It is not, however, a good tool for identifying the divergent flows to begin with. Process mapping also provides little basis for intuiting possible RFID usage scenarios and ignores many of the physical constraints which are so important in the future state.

Spaghetti maps trace the physical travel of material as it undergoes processing by overlaying transit line paper or electronic floor plan. This diagramming method is very useful when it is used to track the movement of several types of material through the plant. Chokepoints and portals at which RFID interrogators could be deployed quickly become obvious. Spaghetti maps are also useful for checking whether all possible product flows have been identified: If the traces ignore a part of the facility where material obviously travels, it's a clear indication that something has been missed. While useful for understanding the current state, spaghetti maps provide little to illustrate the decisions required to develop a future state.

As one would expect from the use of the terms “current state” and “future state”, value stream mapping is another diagramming tool used to understand the process flow. Value stream mapping is very useful for displaying the cycle time data used in usage scenario benefit calculations and it also illustrates information flows much better than alternative techniques. Most importantly, it can help identify process improvements that do not require RFID. This can help ensure that RFID becomes an enabler for efficiency instead of a distraction within a lean project.

The key disadvantage of value stream mapping is that it focuses on a linear process flow for one particular product or material type. Practitioners often exhort that one should “follow the product” when developing a current state map. However, RFID systems are defined by the forks and tributaries of material flow, not a linear process. Value stream mapping is also geared towards assisting continuous flow improvements and reducing dwell time. RFID may be best used to manage the “non-value-added” steps necessary in push production industries like defense.

4.2.2. RFID swim lanes

In section 4.3.1 it will be shown that the two key decisions facing an analyst are “What should be tagged?” and “What usage scenarios should be implemented”. A future state diagramming method has been developed to illustrate this decision. The method, called “RFID swim lanes”, is built around the concept of material flowing through RFID usage scenarios. This section describes the building blocks used to develop a diagram, while Chapter 6 shows a real-world application of this based on the Integrated Air Defense Center.

In its simplest form, vertical swim lanes describe the coverage of usage scenarios, while material types flow from left to right through them, as shown in Figure 14. The circles indicate that the usage scenarios in question can act upon the material type and therefore some benefit might be achieved.

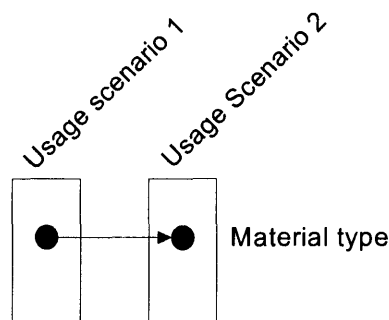


Figure 14: RFID swim lanes building blocks

In many real-world cases, however, material types may flow through different usage scenarios. For example, a subset of materials may require inspection, but otherwise go through the same process steps as the other materials. This would be diagrammed as shown below in Figure 15. Material type 1 goes through two usage scenarios (numbers 3 and 5), while Material type 2 also passes through usage scenario 4.

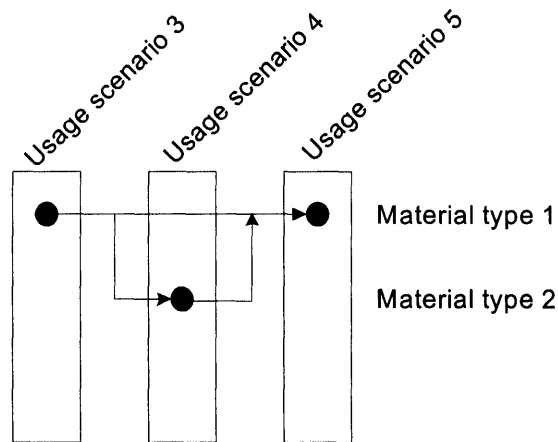


Figure 15: RFID swim lanes with diverging and converging flow

Another reality in material process flows are the physical actions that may be performed on a particular type of material or container. In some cases, boxes are opened and the contents are separated and possibly repackaged. This occurs often in inbound material flows. The opposite action occurs in outbound material flows, where products are consolidated into new containers. In each of these cases, containers may be detashed, or thrown away, if they are no longer useful. This also occurs at the point-of-use on a manufacturing floor or at the final customer. Figure 16 below shows how this might be diagrammed.

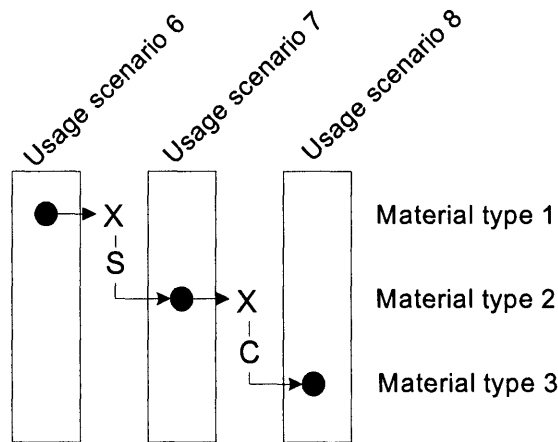


Figure 16: RFID swim lanes with container actions

The “X” indicates that the container has been disposed of, ending the flow for that material type. “S” indicates that the contents have been ‘S’eparated and possibly tagged with individual RFID tags. Finally, “C” indicates an action where multiple items have been ‘C’onsolidated into larger containers. In the figure, it is important to note that material types 1 and 3 are not the same container, and that the contents, size and features of one might be significantly different than the other.

RFID swim lane diagrams have some significant benefits in process illustration. The technique explicitly outlines the flow of each material type through the possible RFID usage scenarios. Its ability to show divergence and convergence in material flows is particularly useful when used in conjunction with spaghetti diagrams since chokepoints can be easily identified.

These diagrams also explicitly identify container actions that are key inputs into any RFID evaluation. Separation results in a loss of RFID tracking capability unless new tags are applied, while consolidation often provides an opportunity for cost reduction. Finally, it is easier to recognize the concept of physical zones using a RFID swim lane diagram.

The key disadvantage of the diagramming method is that the act of creating the diagram is not actually a useful step in the process of intuiting a future state. One of the key advantages of Value Stream Mapping is the fact that diagramming actually helps to generate new ideas of the future state. RFID swim lanes are often too unwieldy to help in the creativity process, and the analyst must rely on experience to identify possible usage scenarios.

4.3. System optimization framework

The development of an optimization model requires identification of decision variables, constraints and the calculation of an objective function. For this model, we also discuss the benefits of various optimization algorithms.

4.3.1. Decision variables

Several factors drive the resulting cost and benefits in an RFID system. Many of these are environmental factors which one can measure and sometimes control. Examples of these are RFID tag performance, process cycle times and imposed business rules. These will be important in determining the final cost and benefit, but each has a clear optimal value which maximizes financial return. The better the tag performance and slower the initial cycle times, the better an RFID investment will look.

Another set of factors do not have the same obvious relationship to the final financial model. There are four sets of dependent and independent variables whose values have a large effect on the final result of the model optimization. We will describe each of these in turn.

4.3.1.1. Usage scenarios

The first set of binary variables corresponds to the possible usage scenarios. Each can be individually implemented or not. We will use the notation as follows:

$$U_i \in U_1, U_2, \dots, U_a$$

With our knowledge of RFID, we can see that these are all independent variables and no member of set U affects the value of another member. In addition, no member of the other three binary variable sets will drive the value of U . This does not mean that every possible value of U will be financially viable, but that every one is possible.

4.3.1.2. Material types

The second set of binary variables corresponds to the discrete material types we might tag with RFID. Instances of each material type will be notated as follows:

$$M_j \in M_1, M_2, \dots, M_b$$

Like usage scenarios, members of the set M are independent variables. Each type of material can be tagged regardless of whether the other material types are tagged. In addition, the choice of usage scenarios, reader sets and IT modules do not drive the decision of which material types are tagged. As with usage scenarios, some combinations of material types will not make sense or be financially viable, but each is possible.

4.3.1.3. Reader sets

In section 4.1.1, we describe a reader set as one or more interrogators which work towards the same purpose. A reader set of several interrogators may be set up at a bank of dock doors, while a separate reader set consisting of just one interrogator may be placed at the single door between two departments. The dock door reader set will require multiple interrogators since there are several dock doors. But these are still in the same interrogator set since a truck might show up at any one of the doors. Put another way, interrogators in a reader set support the same business process step or steps.

Reader sets are notated as:

$$R_k \in R_1, R_2, \dots R_c$$

The fact that reader sets support a business process helps to explain why members of the set R are not independent variables. The choice of usage scenarios in fact drives the selection of specific reader sets. The value of U will determine the values of R . This can be notated as:

$$R_k = f(U_1, U_2, \dots U_a)$$

For example, a usage scenario to track items as they enter through the dock door will require that readers be set up at the dock doors.

4.3.1.4. IT modules

IT modules are discrete building blocks of software technology which support either general RFID functionality or a specific capability. The role of RFID information technology development usually falls into these two groups. Some amount of training, research, software development and testing will be required in order to do anything with RFID. This is the cost of getting the resources up the learning curve, buying RFID middleware and deploying servers to host the software.

Each actual usage of RFID might require that a new IT module be created in order to support this functionality. On the other hand, the usage scenario might also be able to leverage an existing IT module to provide this functionality, and in this case no additional IT development may be necessary. The optimization model will have a number of individual IT modules which may or may not be implemented:

$$I_l \in I_1, I_2, \dots I_d$$

I is a dependent variable, like R . I is driven by the choice of usage scenarios. Making the choice to implement a particular set of usage scenarios requires that certain IT modules must be written in order to support that level of functionality. In notational form:

$$I_l = g(U_1, U_2, \dots U_a)$$

For example, if a usage scenario is needed for tracking shipping containers, this may require both an initial investment by information services and a specific module created to track RFID-tagged items. An additional usage scenario to replace barcodes scans with automatic RFID reads would require an entirely new IT module to be created to support this functionality.

4.3.1.5. Independent decision variables

This analysis shows that the optimization will only focus on two sets of independent decision variables, U and M . Our final model will have 2^{U+M} possible solutions, which is a manageable number for most types of optimizations. Based on users' experiences with the calculator at several Raytheon facilities, U usually contains between 5 and 20 members, while the number of members in M has ranged from 3 to 15. An analysis which attempts to optimize RFID decisions across multiple firms would have many more possible usage scenarios and several more material types.

4.3.2. Constants and constraints

We know that the objective function will be a function of benefits and cost, and in section 4.3.1 we mentioned several environmental factors which would ultimately affect this. The table below outlines several of the constants which may be used in a specific model formulation. Models in different industries or even different organizations may use a different set of constants.

Constant	Description
Operator cost / hr	The fully loaded cost of how much financial savings an hour of operator time is worth.
Hurdle rate (cost of capital)	Most objective functions use some notion of present value and discounted cash flows, which requires a discount rate.
Interrogator cost	This should be the full cost of purchasing and installing an interrogator. For many facilities, the cost of power drops and network connectivity may be substantial. This constant is often subdivided so that different types of interrogators (fixed, handheld, label printers) can be accommodated.
Tag cost	This is the cost of an affixed RFID tag. In most cases, this is the marginal cost of a label with an RFID inlay compared to a standard label.
Tag Dead-on-Arrival (DOA) (%)	Some percentage of tags cannot be written to successfully. This may be due to physical damage or other reasons.
Hardware maintenance cost (%)	There will be a cost to maintaining the physical RFID infrastructure year-to-year. This may include service contract costs, replacing damaged interrogators and other maintenance.
Software maintenance cost (%)	The costs of maintaining and performing necessary upgrades of the software infrastructure. This includes hardware rentals, on-call fees and service contracts.

Table 4: RFID optimization model constants

The only constraint within the model is the binary integer constraints on the decision variables. The value of each variable indicates whether or not a usage scenario is implemented or a particular material type tagged. The analyst may choose to add a constraint which limits the initial capital investment to some maximum value.

4.3.3. Objective function

The most logical objective function candidates are financial metrics. These are what will be expected by project sponsors and executives and allow comparison to other business process improvements the company may be considering. Any strategic or core competency benefits will generally be qualitative considerations, and the model does not attempt to consider these. These qualitative factors are nonetheless important, and should be discussed in any overall RFID improvement strategy.

The two main components to the objective function are benefits and costs. These two are certainly linked, as both are dependent upon the values of the decision variables M and U . The two together create a stream of cash flows, and these can be evaluated in several ways. Very few organizations evaluate opportunities on the basis of income statement components: accrued benefits and depreciated investment are generally eschewed in favor of cash flow considerations.

A stream of cash flows can be evaluated in several ways. Some examples are enterprise value added (EVA), net present value (NPV), payback period and undiscounted cash flows. Each has its advantages and disadvantages, and the optimal solution under each method may result in different decision variable values. For this section, we will assume that net present value is used.

The time period between cash flow streams is also a consideration. This is often driven by financial policy within the organization. The most common periods are monthly, quarterly or annually. The structure of the problem is such that the time period selection does not usually affect the results significantly.

4.3.3.1. Financial benefits

In calculating the benefits, two key assumptions are made. The first assumption is that the total benefit resulting from the implementation of an RFID system is the sum of benefits achieved from each implemented usage scenario. Any aspects of the problem which suggest that the whole is greater than the sum of its parts should be encapsulated into a formal usage scenario. Second, an assumption is made that the benefit achieved from implementing any one usage scenario is independent of the decision to implement any of the other usage scenarios.

Asset visibility usage scenarios illustrate the invalidity of the second assumption. The ability to find RFID-tagged material is dependent upon how many zones are created. These zones, however, are usually created in order to support other usage scenarios. In general, the more usage scenarios that get implemented, the greater the benefit achieved from asset visibility usage scenarios. Future modifications to the model may incorporate this highly non-linear behavior.

Based on these assumptions, in any given time period t , the total benefit achieved is

$$B_t = \sum_{i=1}^a U_i B_i$$

where B_t is the benefit during time period t from implementing usage scenario U_i . Calculating the benefit from any specific U_i is more difficult, however. First, it is highly dependent upon the type of usage scenario and a number of environmental and usage-specific factors. Among these are:

- Reductions in cycle time
- Reduction in lost material or time spent looking for misplaced material
- Reduction in injury rates
- Reduced inventory levels

Not all of these factors will apply to every usage scenario. One factor that is almost always applicable is the actual tag read reliability. Examining the benefit calculation in the extreme condition of zero reliability shows that RFID performance is critical.

Some usage scenarios are more sensitive than others to small changes in expected tag reliability. Scenarios which rely on several tags to be successfully read are included in this group. Carousel cycle counting, for example, requires all instances of a particular part number to be read in order to be useful. In cycle counting scenarios with many instances of the same part number, minor reductions in performance can easily remove much of the anticipated benefit. This was described in section 4.1.2.3.

The benefit resulting from nearly every type of usage scenario is dependent upon the volume of material passing through the usage scenario. In many cases, this is a direct and linear relationship. For example, doubling the volume of material usually doubles the cycle time savings. Of course, costs may also increase, but these are accounted for in section 4.3.3.2.

The volume of material that passes through the usage scenario will be dependent upon the values of the decision variables \mathbf{M} . In general terms, the benefit from any usage scenario U_i is

$$B_i = U_i h_i(M_1, M_2, \dots, M_b)$$

where $h_i(\cdot)$ is specific to the usage scenario U_i . It is immediately apparent that this formulation is non-linear, and this will have several implications on our optimization algorithm described in 4.3.3.4.

While the inputs to $h_i(\cdot)$ implies a complex internal formulation based on the values of \mathbf{M} , this is not the case. In fact, most benefit functions are directly correlated to the volume of material passing through the usage scenario. Defining the following variables:

- W_{ij} binary integer constant indicating whether material type M_j passes through usage scenario U_i .
- n_{M_j} : Volume of material type M_j flowing in each time period

In this case, our formulation for $h_i(\cdot)$ becomes:

$$h_i(M_1, M_2, \dots, M_b) = \bar{h}_i \left(\sum_{j=1}^b n_{M_j} W_{i,j} \right)$$

The final equation for the total benefit achieved during time period t is

$$B_t = \sum_{i=1}^a U_i B_i = \sum_{i=1}^a U_i \bar{h}_i \left(\sum_{j=1}^b n_{M_j} W_{i,j} \right)$$

4.3.3.2. Initial costs

As with most capital projects, there can be substantial startup costs to any RFID system implementation. These initial costs are generally in three main categories: hardware, software, and business processes. The model divides the initial cost along the same lines as the components of an RFID system described in section 2.4. Doing so helps to ensure that all possible costs are accounted for.

The most obvious initial cost in an RFID system is in purchasing and installing the interrogator network. In many cases, it will not be the largest component of total cost, but it is certainly the most visible physical manifestation of the system. The hardware costs will include not only purchasing the interrogators but also the additional costs associated with installation. Power drops, network connectivity, additional housing materials and asset tagging costs should all be considered.

The hardware cost depends upon which reader sets are included in the RFID system. As explained in section 4.3.1.3, the choice of reader sets is in turn solely dependent upon which usage scenarios are implemented. Most usage scenarios will require just one reader set. One reader set, however, may support multiple usage scenarios. Consider a reader set comprised of interrogators installed at the dock doors of a facility. These could be used for scanning material as it arrives into the facility and for identifying material that is departing the facility. The implementation of either usage scenario would require the installation of the reader set.

This relationship between a reader set and usage scenarios which require them was notated as

$$R_k = f(U_1, U_2, \dots, U_a)$$

This function can be made more explicit using a set of constants, \mathbf{X} . Let $X_{i,k}$ be a binary constant indicating whether usage scenario U_i requires the installation of reader set R_k . Then

$$R_k = \text{Min}\left(1, \sum_{i=1}^a X_{i,k} U_i\right)$$

From this, we can determine the total initial cost of hardware. Defining the following variables and constants

$C_{t=0,R}$: Total initial cost of all hardware components

c_{R_k} : Installed cost of reader set R_k

We see that

$$\begin{aligned} C_{t=0,R} &= \sum_{k=1}^c c_{R_k} R_k \\ &= \sum_{k=1}^c c_{R_k} \left[\text{Min}\left(1, \sum_{i=1}^a X_{i,k} U_i\right) \right] \end{aligned}$$

Software development, middleware licenses, and integration costs can be a substantial contributor to the total cost of deploying an RFID system. The large number of system integrators and software companies currently serving the RFID market confirms this.

Unlike reader sets, IT costs are not easy to estimate. Obtaining accurate estimates on IT projects takes considerable time and skill. It also requires detailed knowledge of the functional requirements to be programmed. This is difficult with RFID due to the immaturity of the technology and software and the lack of detailed information during the evaluation phase. In addition, the full cost of these components includes a wide range of activities. Requirements definition, prototyping, software development, middleware licenses, server hardware, testing, deployment and training all must be considered.

Another difference between reader sets and IT modules is that the latter are not easy to individually identify and separate. Many internal IT departments and external system integrators do not separate the cost of IT projects based on functionality. Nonetheless, software investment in an RFID system can be estimated, evaluated and implemented modularly. There is usually a core level of investment associated with doing anything with RFID. This includes computer servers, software licenses and training developers up the learning curve. In addition to this, functionality can be divided into modules which support similar usage scenarios.

For example, consider the activities required to support an asset visibility usage scenario on inbound shipping containers. A certain amount of purchasing, server setup, middleware installation and learning would be required in order to support this scenario. In addition, material search functionality would need to be built and tested.

We would model this as two different IT modules. The first would be a base module, and would be a cost incurred when implementing any usage scenario in this facility. All the generic costs would be included in this IT module. The incremental costs of developing and deploying the material search functionality would be modeled as a second IT module. This functionality would probably not be required for most other usage scenarios. However, if the organization decides to track parts within its manufacturing facility, the same two IT modules would probably suffice. In other words, the marginal cost of adding the second usage scenario would be nil, at least from an IT perspective.

Like reader sets, the necessity of IT modules is solely dependent upon the selection of usage scenarios. We use a binary constant $Y_{i,l}$ to indicate whether IT module I_l is necessary for the implementation of usage scenario U_i . Likewise, we define the following variables:

- $C_{l=0,I}$: Total initial cost of all IT modules
 c_{I_l} : Installed cost of IT module I_l

Our equations to determine total cost follow:

$$\begin{aligned}
 I_l &= g(U_1, U_2, \dots, U_a) \\
 &= \text{Min} \left(1, \sum_{i=1}^a Y_{i,l} U_i \right) \\
 C_{l=0,I} &= \sum_{l=1}^d c_{I_l} I_l \\
 &= \sum_{l=1}^d c_{I_l} \left[\text{Min} \left(1, \sum_{i=1}^a Y_{i,l} U_i \right) \right]
 \end{aligned}$$

The final component of initial cost is in migrating to new business processes. These can include several types of cost:

- New equipment required in order to support the usage scenario. This would include automated conveyors, plastic racks to replace metal ones, and other long-term investments
- Plant layout changes to allow the installation of RFID hardware
- Training operators on how to use the RFID equipment in place of or in addition to existing technologies

In general, these costs are related to the implementation of a specific usage scenario. As business processes are inextricably tied to usage scenarios, this is not surprising. Defining the following variables,

$C_{t=0,U}$: Total initial cost of all business process migration

$c_{U_i, initial}$: Additional initial cost associated specifically with implementing U_i

we see that the cost of business process migration is

$$C_{t=0,U} = \sum_{i=1}^a c_{U_i, initial} U_i$$

So our final initial cost function for $C_{t=0}$ is then

$$C_{t=0} = \sum_{k=1}^c c_{R_k} \left[\text{Min} \left(1, \sum_{i=1}^a X_{i,k} U_i \right) \right] + \sum_{l=1}^d c_{I_l} \left[\text{Min} \left(1, \sum_{i=1}^a Y_{i,l} U_i \right) \right] + \sum_{i=1}^a c_{U_i, initial} U_i$$

4.3.3.3. Recurring costs

In each time period t , there are several types of recurring costs which figure into the optimization model. The importance of these to the final outcome of the model depends upon the facility and situation.

In most situations, the largest recurring cost in RFID systems is in the cost of the tags. While benefits associated with RFID may be correlated to both the volume and cost of material flowing through the system, tagging cost is usually directly proportional to the volume of material.

This cost is straightforward to calculate. Defining the following variables and constants:

$C_{t, tags}$: Total cost in time period t of tagging material

c_{tag} : Marginal cost of a single tag

P_{DOA} : Probability of a paid-for tag being dead-on-arrival

We can then calculate

$$C_{t, tags} = \frac{c_{tag} \sum_{j=1}^b n_{M_j} M_j}{(1 - p_{DOA})}$$

In addition to the cost of the tags, each time period may have a recurring cost in each of the component categories: hardware, software and business processes. For hardware and software, these costs are modeled as percentages of the initial investment. The logic for this simplification is that the main contributors to these recurring costs are annual support fees levied by the component providers. In addition, IT departments will sometimes allocate support costs as a percentage of the initial investment.

The recurring costs which are required for maintaining business processes include, but are not limited to the following:

- Additional RFID-related training for new employees
- Charges for increased floor space utilization
- Maintenance of new equipment installed to support the RFID system

Defining the following variables and constants:

- $C_{t, comp}$: Total recurring cost in time period t attributable to components
 $p_{hardware}$: Recurring hardware maintenance cost (percentage of initial investment)
 $p_{software}$: Recurring IT maintenance cost (percentage of initial investment)
 $C_{U_i, recurring}$: Recurring cost associated specifically with implementing U_i

We can calculate the recurring cost in the RFID system associated with the components as:

$$C_{t, comp} = p_{hardware} C_{t=0, R} + p_{software} C_{t=0, I} + \sum_{i=1}^a C_{U_i, recurring} U_i$$

So our total recurring cost C_t is:

$$C_t = C_{t, tags} + C_{t, comp}$$

$$= \frac{c_{tag} \sum_{j=1}^b n_{M_j} M_j}{1 - p_{DOA}} + p_{hardware} C_{t=0, R} + p_{software} C_{t=0, I} + \sum_{i=1}^a C_{U_i, recurring} U_i$$

4.3.3.4. Evaluation functions

With these components, we can now consider a single objective function which integrates benefits, initial and recurring costs. The main selection mechanism for this will be driven by the expectations of the business. Most organizations use some form of net present value or payback period, but some may use enterprise value added or other assessment techniques. The example that follows uses NPV.

We will assume that a discount (or hurdle) rate r is used per time period. In addition, an overall time window is generally designated for evaluation of benefits. This can range anywhere from thirty days to several years. If n time periods exist in this window, our final objective function will be of the form:

$$ObjFn = -C_{t=0} + \frac{1}{(1+r)}(B_{t=1} - C_{t=1}) + \frac{1}{(1+r)^2}(B_{t=2} - C_{t=2}) + \dots + \frac{1}{(1+r)^n}(B_{t=n} - C_{t=n})$$

4.3.4. Optimization algorithm

The choice of optimization algorithm is especially important given the nature of the program. The formulation is clearly a binary integer problem: all the decision variables correspond to Yes / No decisions. There exist a number of high performance algorithms for solving linear integer programs, but there are several aspects which break the linearity requirement:

- The benefit B_i gained from implementing usage scenario U_i is a function $h_i()$ of another set of decision variables M .
- The precise formulation of $h_i()$ can include non-linear terms. This is especially true when tag read reliability probabilities affect the benefit.
- The initial cost $C_{t=0}$ uses the $Min()$ function, which is not linear.

The last of the non-linear aspects can be overcome with a less intuitive formulation, but the final objective function will remain a non-linear binary integer program. Experience in developing several models has shown that the problem is non-convex and that there are many local optima. In many cases, the behavior of the model defies straightforward explanation due to the many system interactions. Finding the global optimum can be very difficult.

Using several different models, a number of candidate optimization algorithms were tested. The solution presented by each was compared to the global optimum identified through a simple binary enumeration of all possible decision variable values. The evolutionary solver algorithms generally performed the best, especially when a large number of initial starting points were specified. Even so, it could not be relied upon to find the global optimum.

Real-world usage of the model involves using the evolutionary solver to first get an understanding of magnitude of the benefit. Running the binary enumeration is then used to ensure that the global optimum is not being ignored. This optimum is then entered as a possible starting point into the algorithm while sensitivity analysis is performed. In many cases, the global optimum corresponds to an NPV of 0: the best course of action is to not implement RFID.

Chapter 5: Excel™ RFID Calculator

Many RFID project leaders and business analysts will encounter the challenges described in section 3.2.1.2 as they evaluate ROI for their organizations. Most will not develop an optimization model to help them determine the best course of action. A software tool was developed in Microsoft Excel™ in order to assist these leaders and analysts. This section describes the tool, which is available on the Leaders for Manufacturing Virtual Community website at <http://lfmsdm.mit.edu/>.

5.1. Ubiquity, usability and extensibility

The model formulation is non-convex, non-linear and does not always yield a global optimum even when evaluated with very sophisticated algorithms. Dozens of independent decision variables are involved. In this situation, one would not expect Microsoft Excel™ to be the most appropriate tool in which to formulate and evaluate the model.

Excel™ was chosen for three reasons: its ubiquity, usability and extensibility. Every member of an RFID evaluation team in any organization will have access to Excel™, and this is one of its key advantages. Most other tools would require installation and possibly even purchase of run-time software. The Excel™ RFID Calculator can be emailed to anyone with the knowledge that the recipient will be able to open, run and even modify the business case.

Over time, Excel™ has become a very powerful and user-friendly software package. To tool developers, Excel™ VBA offers a powerful and easy-to-learn programming language with which to guide workflows and simplify data entry. The Excel™ RFID Calculator contains over 1000 lines of VBA code, but this complexity is invisible to the user. Finally, many users are able to develop complex financial models and even rudimentary optimization models using Excel. These users can modify the financial results which are outputted by the model in whatever way they choose. This improves the chances of the tool being used.

Of course, organizations will have their own idiosyncrasies which require some modification or extension to the calculator. The Excel™ RFID Calculator has been designed with this in mind. Organizations can easily add new usage scenario types to the ones described in section 4.1.2. Benefit calculations can be changed simply by editing formulas in cells.

5.2. Stage 1: Entering system-wide parameters

Several of the variables and constants used in the model formulation require a creative user interface if they are to be understood by the analyst. For example, constant sets $X_{i,k}$ and $Y_{i,l}$ define whether reader sets and IT modules are required for specific usage scenarios. In addition, each of the decision variables U_i and M_j have associated constants which need to be explained and collected before costs and benefits can be calculated.

The first stage of the Excel™ RFID Calculator contains six steps which facilitate identifying and entering this information. These steps are:

1. Entering and naming usage scenarios (U)
2. Entering, naming and collecting volume data on material types (M, n_M)
3. Entering, naming and collecting cost data on reader sets (R_k, c_R)
4. Identifying the material types which pass through specific usage scenarios ($W_{i,j}$)

5. Identifying the reader sets which are required for specific usage scenarios ($X_{i,k}$)
6. Entering, naming and collecting cost data on IT modules as well as identifying which IT modules are required for specific usage scenarios ($I_i, c_{i,j}, Y_{i,j}$)

Several usability features were incorporated into the screens for this stage. In order to navigate through the various screens which facilitate data entry, a Microsoft Wizard style interface was used. This used "Previous" and "Next" buttons to help transition between the various steps. This can be seen in Figure 17.

	A	B	C	D	E	F	G	H
1	<p>Value stream mapping can be a difficult tool to use when diagramming material process flow. This is because a material flow often branches into many sub-flows, like inspection or PO search, before returning to the main flow through the facility. Some of this material may be more expensive than others, and some may even come into your facility "pre-tagged".</p> <p>For these reasons, the calculator needs to know the different types of material which will match up to the specific usage scenarios you've just selected. A good rule of thumb when defining this is to split materials up when one usage scenario applies to just a subset of the material. Another important reason to add material types is when a package is opened or broken down, and one can no longer ensure correspondence between the tag and the individual item.</p> <p>Add material types using the "Add Material" button, and make sure that you don't duplicate names. Select whether the material is already pre-tagged when it arrives for each type; generally this will be false, unless you are receiving it from another Raytheon facility.</p>							
2								
3								
4	ID	Material Name	Units / year	Pre-tagged?				
5	1	Container - VQP	10382	FALSE	<input type="text"/>			
6	2	Container - Inspect	26942	FALSE				
7	3	Container - IES	2000	FALSE				
8	4	Container - NonProduct	22000	FALSE				
9	5	Carousel stock	44000	FALSE				
10	6	Picked parts	408000	FALSE				
11								
12	<input type="button" value="Add Material"/>			<input type="button" value=" < Previous"/> <input type="button" value=" Next >"/>				
13								
14								

Figure 17: Wizard interface for Excel™ RFID Calculator

The row and column headers in each step are pre-populated with information entered in previous steps. In addition, a clickable interface was used to help collect the binary constants $W_{i,j}$, $X_{i,k}$, and $Y_{i,j}$. Simply clicking on one of the matrix cells toggles the binary constant between

an empty cell and an "X". This proved to be more user-friendly than entering 1s and 0s into the cells. This can be seen in Figure 18.

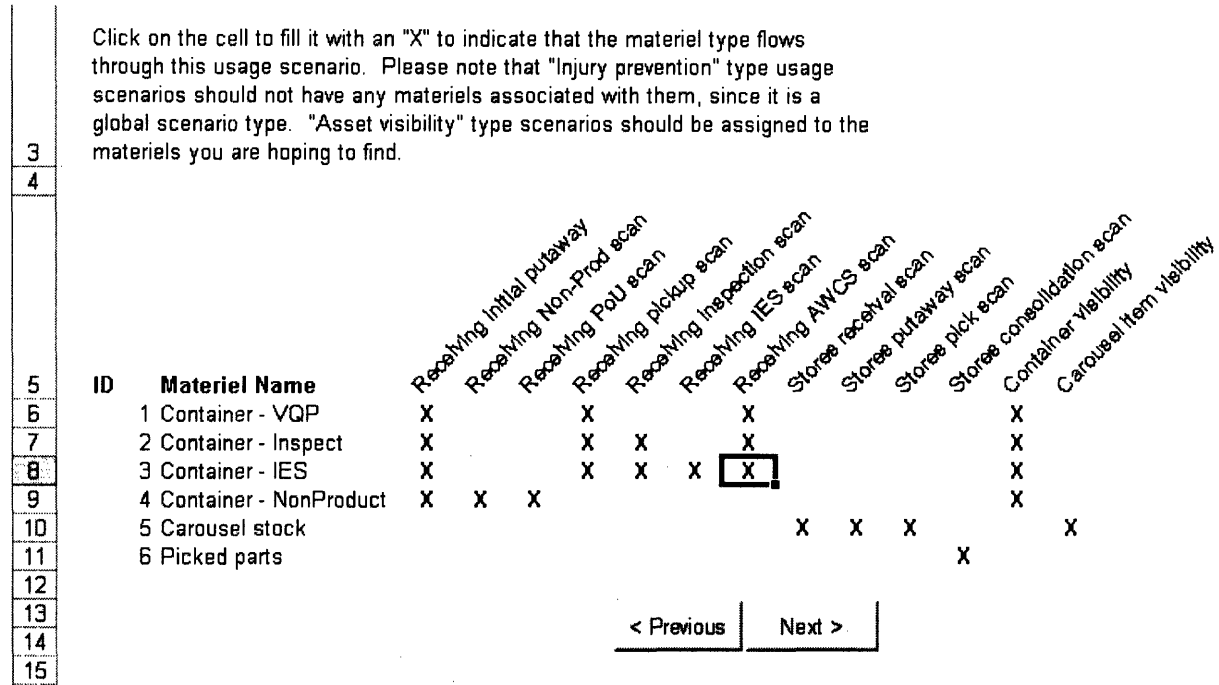


Figure 18: Clickable cells for collecting binary constants

These usability features greatly reduced the complexity of collecting data on system-wide operating parameters.

Once all six steps of the wizard are completed, the user saves the file and moves on to the next stage of the calculator. Because the system-wide parameters are fundamental to the generation of usage scenario benefits and financial analysis, there is no way to return to stage 1 after moving to stage 2 other than opening the previously saved file.

5.3. Stage 2: Constants and Usage scenario detail

Stage 2 of the Excel™ RFID Calculator serves two main functions. First, it allows the user to set values for the constants used throughout the cost and benefit calculations. This is primarily an usability feature, allowing the usage scenario sheets to reference agreed-to values. Examples of these are shown in Figure 19 below.

	A	B	C	D	E	F	G	H
1								
2		Item		Value		Notes		
3		Financial Constants						
4		Fully-loaded Salaried employee cost / hour		\$ 36.08				
5		Fully-loaded Operator cost / hour		\$ 20.05				
6		Interest Rate		13.4%	Hurdle rate			
7								
8		Hardware Cost Constants						
9		Portal interrogator		\$ 3,000	Inclusive of antennas, ruggedized housing, etc.			
10		Carousel interrogator		\$ 2,500	Inclusive of antennas, ruggedized housing, etc.			
12		Marginal cost of 4x6 label with EPC Class 1 tag		\$ 0.59	How much more a smartlabel costs than a p			
13		Percentage of tags / labels which will be DOA		0%	Generally, 10% of tags are dead-on-arrival.			
16		Yearly HW maintenance costs (percentage)		15%	As a percentage of initial spending.			
17								
18		IT Constants						
19		Yearly IT maintenance costs (percentage)		15%	As a percentage of initial spending.			
23								
<div style="border: 1px solid black; padding: 2px;"> Summary / Constants / Receiving initial putaway / Receiving Non-Prod scan / Receiving PoU scan / Receiving pickup </div>								
Ready								

Figure 19: Entering constants into the RFID Calculator

The majority of user activity in Stage 2 is to enter benefit and business process cost data for each of the usage scenarios U_i . An Excel™ sheet is created for each of the usage scenarios. These sheets are pre-formatted and populated with data from a template based on the generic type of usage scenario selected. Predefined cells on this sheet contain placeholder formulas for B_i , $C_{U_i, initial}$, and $C_{U_i, recurring}$. An example of this is shown in Figure 20.

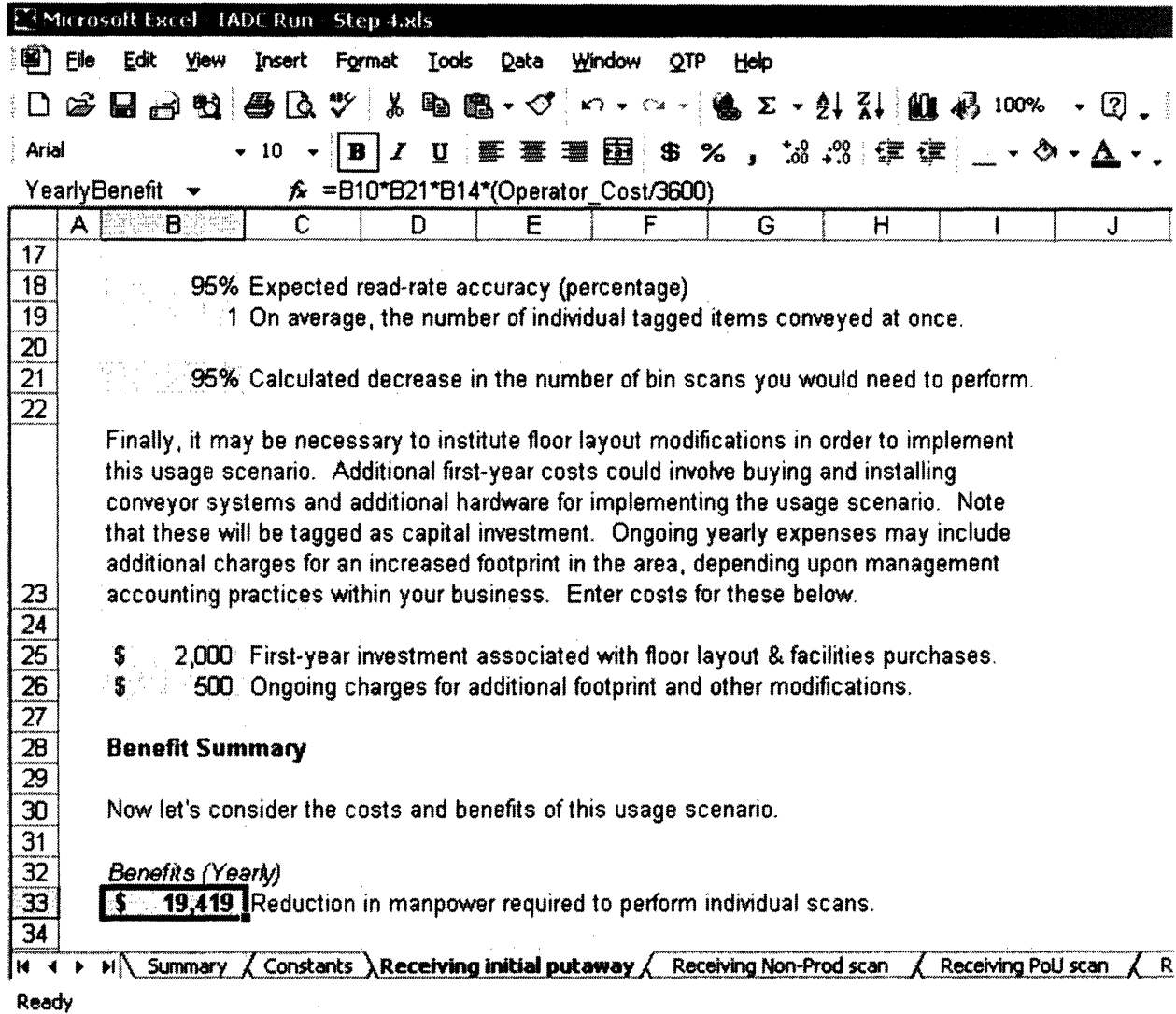


Figure 20: Usage scenario sheet in Stage 2

This process can become very involved since the data for benefit calculations may need to be collected from a number of separate IT systems. The calculations can be modified as necessary, since only the three final values (B_i , $c_{U_i, initial}$, and $c_{U_i, recurring}$) are used from the sheet. This allows users to calculate benefits in completely different ways for otherwise similar usage scenarios, depending upon the data available.

5.4. Stage 3: Optimization and sensitivity analysis of financial results

The default values for the decision variables U and M are 1, meaning that each usage scenario is implemented and every material type tagged. This may not be the most economically advantageous solution, however, and Stage 3 is when optimization and sensitivity analysis occurs.

The decision variables are listed in the calculator, and the user can easily modify any of the variables by changing the values in the cell. See Figure 21 for an example of this.

	A	B	C	D	E	F	G	H
1								
2		Usage Scenarios	Selected (0,1)	Benefit				
3		Receiving initial putaway	1	\$ 19,419				
4		Receiving Non-Prod scan	1	\$ 6,967				
5		Receiving PoU scan	1	\$ 6,967				
6		Receiving pickup scan	1	\$ 12,453				
7		Receiving inspection scan	1	\$ 9,165				
8		Receiving IES scan	1	\$ 633				
9		Receiving AWCS scan	1	\$ 12,453				
10		Stores receival scan	1	\$ 17,649				
11		Stores putaway scan	1	\$ 9,289				
12		Stores pick scan	1	\$ 9,289				
13		Stores consolidation scan	1	\$ 110,773				
14		Container visibility	1	\$ 32,950				
15		Carousel item visibility	1	\$ 29,700				
16								
17								
18		Material Types	Selected (0,1)					
19		Container - VQP	1					
20		Container - Inspect	1					
21		Container - IES	1					
22		Container - NonProduct	1					
23		Carousel stock	1					
24		Picked parts	1					
25								
26								
27		What should we optimize for?	5-Year NPV					
28								
29		Optimize RFID Decisions	Click the button to have Excel identify the best RFID scenario. You can also change the yellow cells yourself to try different scenarios.					
30								

Figure 21: RFID calculator Stage 3 decision variables

The “Optimize RFID Decisions” button optimizes the decision variables for the maximum objective function value. Several different objective functions are available with the tool, including payback period, net present value over several time periods, and undiscounted cash flows over several periods. The optimization algorithm included in the tool is a simple binary enumeration. The guarantee of a global optimum compensates for a much slower execution speed. In addition, the tool can be used on any computer, and a separate license for solver algorithms is unnecessary.

Whether the user is automatically optimizing decisions or manually modifying decision variables for sensitivity analysis, the results are displayed in financial format as shown in Figure 22.

Financial Summary Data						
Quarter	[Initial]	YEAR 1				
		1	2	3	4	5
Discount Factor	100.00%	97.60%	95.26%	92.97%	90.74%	88.57%
Savings / Benefit	\$ -	\$ 61,246	\$ 61,246	\$ 61,246	\$ 61,246	\$ 61,246
Initial Capital Investment						
Reader cost	\$ (204,500)	\$ -	\$ -	\$ -	\$ -	\$ -
IT development	\$ (100,000)	\$ -	\$ -	\$ -	\$ -	\$ -
Additional initial costs	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Total	\$ (304,500)	\$ -	\$ -	\$ -	\$ -	\$ -
Cash Expenditures						
Tagging Cost	\$ -	\$ (76,285)	\$ (76,285)	\$ (76,285)	\$ (76,285)	\$ (76,285)
Reader maintenance	\$ (30,675)	\$ -	\$ -	\$ -	\$ -	\$ (30,675)
IT maintenance	\$ -	\$ (3,750)	\$ (3,750)	\$ (3,750)	\$ (3,750)	\$ (3,750)
Additional yearly costs	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
Total	\$ (30,675)	\$ (80,035)	\$ (80,035)	\$ (80,035)	\$ (80,035)	\$ (110,710)
Cash Flow Analysis						
Quarterly cash flow	\$ (335,175)	\$ (18,788)	\$ (18,788)	\$ (18,788)	\$ (18,788)	\$ (49,463)
Cumulative cash flow	\$ (335,175)	\$ (353,963)	\$ (372,752)	\$ (391,540)	\$ (410,328)	\$ (459,792)
Quarterly PV cash flow	\$ (335,175)	\$ (18,338)	\$ (17,898)	\$ (17,468)	\$ (17,049)	\$ (43,808)
Cumulative PV cash flow	\$ (335,175)	\$ (353,513)	\$ (371,410)	\$ (388,879)	\$ (405,928)	\$ (449,736)
Financial Summary						
Payback period (in quarters)	20					
2-Year NPV	\$ (497,300)					
3-Year NPV	\$ (580,215)					
4-Year NPV	\$ (655,455)					
5-Year NPV	\$ (723,731.21)					

Figure 22: Financial results summary in calculator step 3

The decision variables are on the same sheet as the financial summary, which allows the user to quickly evaluate the effect of modifying the optimal solution. The user can also change the value of constants in order to evaluate whether decreasing hardware costs might affect the final outcome.

At any point, the user can return to the usage scenario detail sheets and modify benefit calculations. This final stage of the process is usually iterative, in which different possible implementation plans might be considered.

Chapter 6: IADC business case evaluation

The evaluation of RFID for business process improvement was undertaken at the Integrated Air Defense Center in 2004. The evaluation was limited to the inbound materials process flow. There were three goals for the project:

1. Validate the Excel™ RFID Calculator as a tool to determine whether it should be added to the supply chain toolbox as a best practice for internal Raytheon use;
2. Evaluate whether any RFID investment was appropriate for the IADC, and if so, ensure that a rough-order-of-magnitude budget was established for the next fiscal year; and
3. Determine the sensitivity of the financial results to a variety of industry trend scenarios in order to determine the robustness of the decision proposed by the tool.

The Excel™ RFID calculator was used for this evaluation, and the three stages are described in this section.

6.1. Stage 1: System parameters

The first step of the process was to use the RFID swim lanes diagramming method to describe the inbound materials process flow and to brainstorm possible usage scenarios. Thirteen usage scenarios were identified, and are detailed in Table 5.

<i>i</i>	Name	Description
1	Receiving initial putaway	Replaces the manual barcode scan which associates an inbound container with the temporary storage rack into which it is placed. This would be implemented using RFID readers on the 60 individual racks to automatically recognize when a container is placed into the rack.
2	Receiving Non-Prod scan	Replaces the manual barcode scan which disassociates the inbound container from its temporary storage rack when the delivery operator puts the container onto the delivery cart. This would be implemented using a combination of the rack-mounted interrogators in U_1 and handheld readers used by the five delivery operators.
3	Receiving PoU scan	Replaces the manual barcode scan taken at the point of use location which confirms that the non-product delivery has been made. This would be done using the same handheld readers described in U_2 .
4	Receiving pickup scan	Replaces the manual barcode scan which disassociates the inbound container from its temporary storage rack when it is transferred to its next processing location. This would be implemented using the rack-mounted interrogators.
5	Receiving inspection scan	Replaces the manual barcode scan which confirms that a container has arrived into the inspection area. This would be implemented using an interrogator around the entrance to the inspection area.
6	Receiving IES scan	Replaces the manual barcode scan which confirms that a container has arrived into IES. This would be implemented using an interrogator around the entrance to IES.
7	Receiving AWCS scan	Replaces the manual barcode scan which confirms that the material is about to be entered into AWCS. This requires a reader at the AWCS induction station.
8	Stores receipt scan	Replaces the manual barcode scan of the PID label which confirms that carousel stock has been dropped off at main stores. This would

		require an interrogator at each of the 17 lift stations.
9	Stores putaway scan	Replaces the manual barcode scan of the PID label which confirms that the carousel stock has been put into a carousel storage location. This would require the same 17 interrogators as U_8 .
10	Stores pick scan	Replaces the manual barcode scan of the PID label which confirms that the carousel stock has been picked from its storage location. It may also be returned to the same carousel location if some parts remain in the carousel stock container.
11	Stores consolidation scan	Replaces the manual barcode scan of the picked parts label which indicates that it has been placed into a kit (with other picked parts).
12	Container visibility	Searches for misplaced inbound shipping containers in order to identify the physical area it is either in or most recently left. Uses existing interrogator networks in the warehouse area.
13	Carousel item visibility	Searches for misplaced carousel stock in order to identify where it is currently located. Uses the lift station interrogators, and will require all the carousels to “spin” during a search.

Table 5: Candidate usage scenarios at the IADC

The majority of the usage scenarios are “Identification speed” scenarios as described in section 4.1.2.2. Usage scenarios U_{12} and U_{13} are “Asset visibility” scenarios, and are listed separately since they are searching for different types of material.

It is interesting to note the usage scenario types which were not evaluated in this example. “Receiving identification” scenarios do not apply since no products arrive at the IADC with RFID tags already on them. This may change if intra-company shipments are tracked with RFID, and later if Raytheon’s suppliers embrace RFID. “Carousel cycle counting” scenarios are not applicable since carousel stock has multiple parts in each container, and these are not individually tagged. A future project may look at individually bagging & tagging high-value parts in the carousels. Finally, the IADC has not experienced any repetitive stress injuries which RFID could have prevented, and so the “Injury prevention” usage scenarios were removed from the model.

In addition to these 13 usage scenarios, the process also identified 6 material types which might or might not be tagged with RFID. These are numbered, named and described, and the volume of these per year listed in Table 6 below.

<i>j</i>	Name	Description	# / yr
1	Container – VQP	Vendor-qualified inbound containers and packages whose contents will not require inspection.	10,382
2	Container – Inspect	Inbound containers and packages whose contents will require inspection, but not escalation to IES.	26,942
3	Container – IES	Inbound containers and packages whose contents will require inspection and escalation to IES before they are ultimately pass inspection.	2,000
4	Container – Non-Product	Inbound containers and packages whose contents are not parts for a subassembly or final product produced by the plant; Container – Non-Product is delivered to the point-of-use.	22,000
5	Carousel	ESD storage bags containing one or more of the same part	44,000

	stock	number; usually resides in the carousels until needed.	
6	Picked parts	One or more of the same part in a new container which will be delivered to the manufacturing floor as part of a kit.	408,000

Table 6: Candidate material types at the IADC

It is important to note that M_2 , and M_3 , cannot be distinguished from each other when they are inducted into the facility. Whether an inspected part requires IES escalation cannot be known until a first round inspection is actually performed. While we make this subdivision based on historical volumes, any solution which tagged one and not the other may not be feasible.

Unlike the brainstorming and experience-based method used to identify candidate usage scenarios, material types were determined by tracking the flow of items through the process diagrams. The walkthrough method has the advantage of being easy to follow and is certain to identify all possible material types so long as the process is completely understood.

The method may actually result in a larger list of material types than is actually necessary for the model, however. If two material types flow through the same set of usage scenarios, and do not have differences which will affect the benefit calculations in those usage scenarios, one can combine the two types. For example, the initial list of material types included three separate material types for carousel stock because of differences in the frequency of cycle counting. As it became apparent that we would not include any carousel cycle counting usage scenarios, the three were combined into M_5 .

The entire process flow is easier to see using RFID swim lanes, as shown in Figure 23 below.

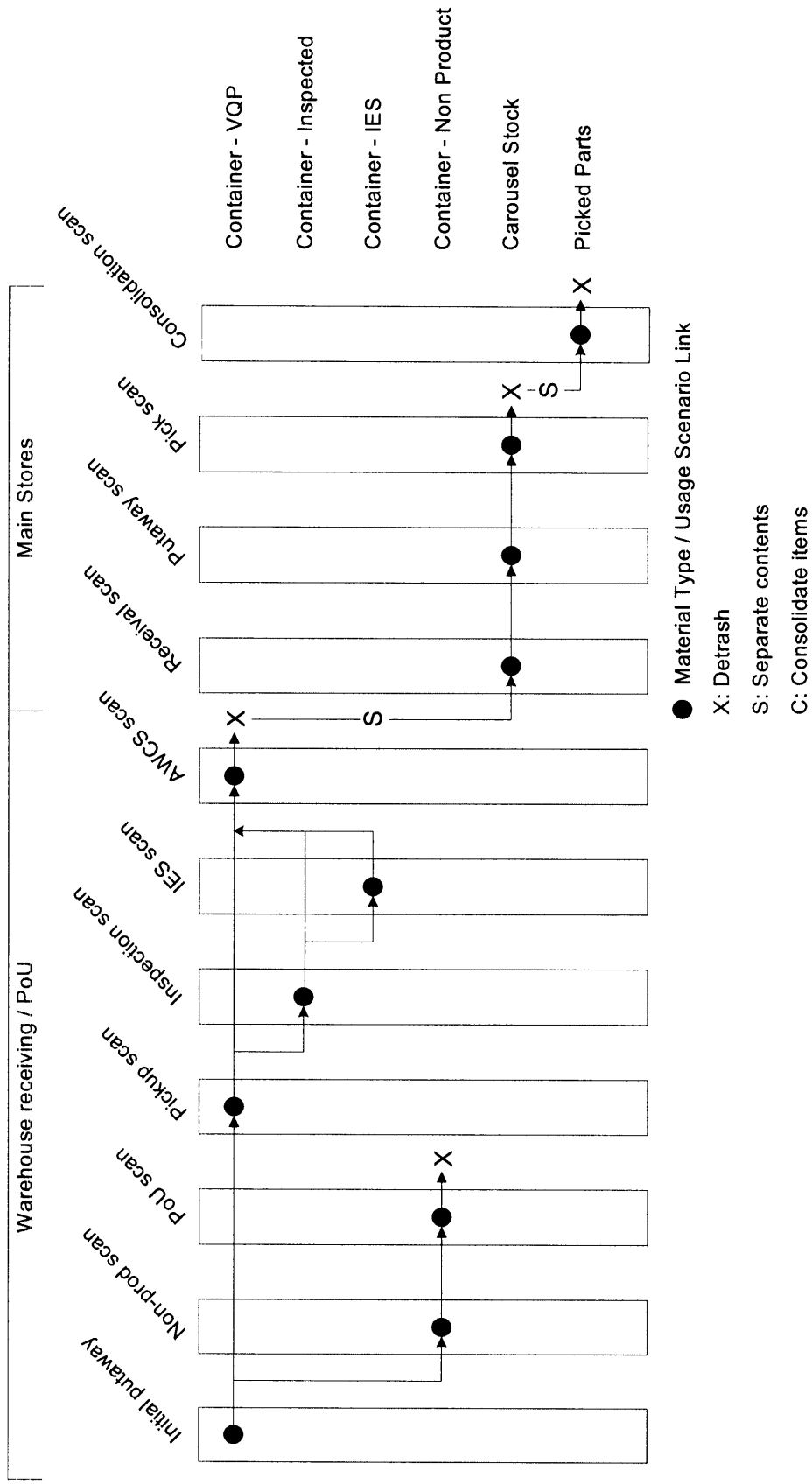


Figure 23: RFID swim lanes representation of IADC inbound material flow

It's important to note that some usage scenarios types do not appear on an RFID swim lane diagram. The asset visibility usage scenarios U_{12} and U_{13} apply to material types $M_1 - M_4$ and M_5 respectively.

The RFID swim lanes diagram also helps generate the matrix W . $W_{i,j}$ is a binary constant which indicates whether material type M_j flows through the usage scenario U_i . A tributary junction in the swim lanes indicates that the new material type inherits the usage scenarios of its parent. For example, while M_3 , "Container-IES" only has one circle shown on the diagram (U_6), it inherits U_1 , U_4 , U_5 , and U_7 from its parents M_1 and M_2 .

The reader sets are referenced in Table 5, but need to be described further. They differ in several ways: the type of interrogator used, the number required for the set, and which usage scenarios they support. Table 7 below describes the first two dimensions.

k	Name	Description	# req.	Cost
1	Racks and cages	These readers will be fixed to the racks and cages which contain in-process material in the warehouse.	60	\$150,000
2	PoU deliveries	Handheld readers attached to delivery carts which transport point-of-use material to locations within the factory.	5	\$12,500
3	Inspection area	A portal reader at the entrance/exit of the inspection area.	1	\$3,000
4	IES	A portal reader at the entrance/exit of IES.	1	\$3,000
5	AWCS station	A tabletop reader installed at the AWCS induction station.	1	\$3,000
6	Carousel lifts	An array of readers on the main stores carousel lifts. The installation should allow the field to cover both the workstation desk and carousel bins.	17	\$42,500
7	Consolidation	A portal reader at the entrance of the main stores consolidation area.	1	\$3,000

Table 7: Required reader sets for IADC RFID evaluation

Other ideas for reader sets were proposed, but a quick analysis indicated that the marginal benefit they added was so insignificant as to not merit significant consideration. For example, readers could be mounted on forklifts to track material between the warehouse and main stores, but a nearly equivalent capability could be achieved by inferring location based on events from R_5 and R_6 .

These 7 reader sets support all 13 usage scenarios. The matrix $X_{i,k}$ indicates which reader sets R_k are required to support usage scenario U_i . The easiest way to show the values of this matrix is its representation in the Excel™ RFID Calculator itself. This is shown in Figure 24.

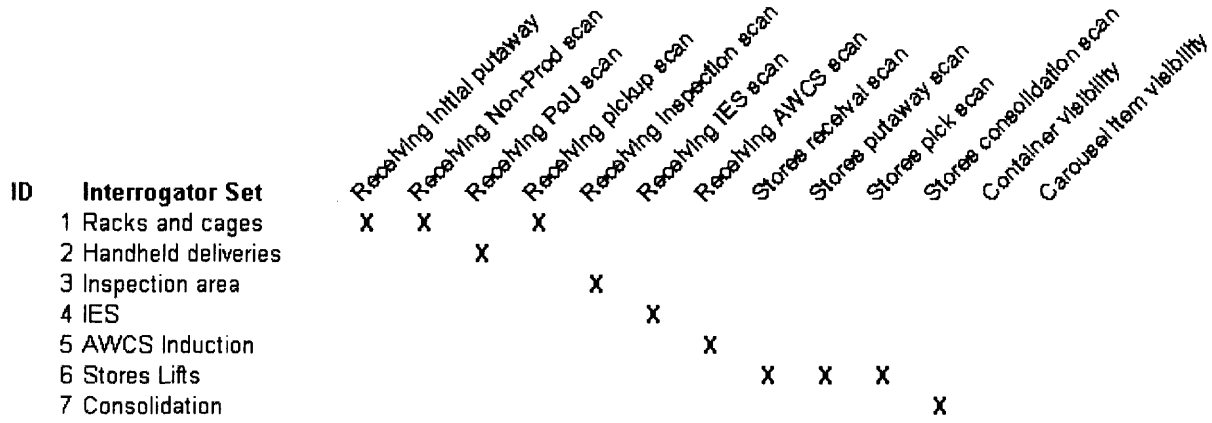


Figure 24: Reader sets required for usage scenarios (X_{ij})

Several of the reader sets support multiple usage scenarios, while others reader sets apply to just one usage scenario. This complexity underlines the importance of a systems approach to RFID evaluation, as the costs and benefits are not easily understood without in-depth analysis.

Finally, there are several IT modules that may need to be created. This is the last step of Stage 1, in which we define the system-level parameters for the IADC. This component of the cost equation is less exact, since software development costs are notoriously difficult to estimate. The list of proposed IT modules is shown below in Table 8.

I	Name	Description	Cost
1	Base project	Purchasing middleware, training programmers and framework development required for any usage scenario.	\$50,000
2	Barcode replacement	Supports all "Identification speed" scenarios, allowing RFID reads to replace manual barcode scans.	\$20,000
3	Wavetrak integration	Supports all main stores operations involving the carousels.	\$20,000
4	Material search	Supports searching for misplaced items within the RFID interrogator network.	\$10,000

Table 8: Candidate IT modules for the IADC evaluation

In developing a list of IT modules, a good strategy is to consider the requirements of each of the usage scenario types being proposed. I_2 and I_4 were developed to support two different very different groups of usage scenarios. Other possible IT modules might result from the legacy IT systems which will need to be modified or interfaced with. At the IADC, the Wavetrak system is used to control the carousels, and this required a separate IT module. Finally, the use of a "base" IT module is often a requirement for any RFID work to be done.

The matrix Y is shown as it is entered into the Excel™ RFID calculator in Figure 25 below. The "Base project" is required by every one of the usage scenarios, and each usage scenario requires an additional functionality-driven IT module as well.

ID	IT Modules	Receiving Initial putaway	Receiving Non-Prod scan	Receiving PoU scan	Receiving pickup scan	Receiving inspection scan	Receiving IES scan	Stores receipt scan	Stores receipt scan	Stores putaway scan	Stores pick scan	Container consolidation scan	Carousel item visibility
1	Base Project	X	X	X	X	X	X	X	X	X	X	X	X
2	Barcode replacement	X	X	X	X	X	X	X			X		
3	Wavetrak integration								X	X			
4	Material search											X	X

Figure 25: IT modules required for usage scenarios ($Y_{i,j}$)

Once the IT modules have been entered and the binary matrix Y populated, stage 1 of the RFID calculator is complete.

6.2. Stage 2: Usage scenario benefit calculations

In Stage 2, benefits are calculated using current and future state expectations of the business processes. In addition, constants are modified to represent current vendor pricing, operator wages, and discount rates. Most of these values are competition-sensitive, and so cannot be publicly shared. Of course, the information entered on these Excel™ sheets have a large impact on the final objective function.

Three general observations can be made from the calculation of usage scenario benefits. First, the benefits attained from identification speed scenarios are much higher when material conveyance occurs one item at a time. In consolidated conveyances like pallets or multi-item bins, the failure of any one tag requires use of the slower, pre-existing barcode or manual entry process.

Second, asset visibility scenarios can be very promising in terms of the benefits they might provide. A large, high-value manufacturing facility like the IADC spends a lot of money and time searching for misplaced product and duplicating orders if the material cannot be found in time. It is difficult to reliably predict the impact of RFID in this situation. Most benefit calculations on loss reduction are based on a good faith estimate agreed to by all the stakeholders. Benchmarking data will become available as more companies adopt RFID and this will help guide future benefit estimates.

Third, it is difficult to separate benefits facilitated by RFID from those which could be achieved through non-RFID improvement projects. One example is in U_{13} , carousel item visibility. The ability to achieve a return on investment from an RFID implementation is highly sensitive to the assumptions made in this calculation. In the final version of the calculator, it was agreed that the benefits from reducing material search time and loss reduction would be relatively small.

This is not surprising by itself, but the explanation for this low estimate was. A separate non-RFID improvement project had recently been approved based on a loss-reduction business case. This project would provide an integrated view into all the materials handling IT systems, facilitating the search for misplaced material. Even though all the stakeholders agreed RFID might provide substantial benefit, this could not be stated without impacting the business case of the already approved project. Finally, a small incremental benefit was assigned for this usage scenario.

6.3. Stage 3: Financial results optimization

Once all the usage scenario data is inputted into the calculator, the actual optimization can be performed. There are 13 usage scenarios and 6 material types, resulting in a total of 19 binary decision variables. This means that there are $2^{19} = 524,288$ possible values for the objective function. For this optimization, an exhaustive search algorithm was used to ensure the reliability of the conclusions contained in this section.

The financial results in this section are based on 5-year net present value of quarterly cash flows. The data is normalized in the following manner: The 5-year NPV of “doing nothing” is assigned the value of 0, which is in fact its non-normalized NPV. The 5 year NPV associated with the worst-possible RFID decision is assigned a normalized NPV of -1. This worst-possible decision is an implementation which makes little common sense, but that helps to explain why its NPV is so negative! All other decision value arrays will therefore have a normalized NPV greater than -1, but not necessary greater than 0.

The maximum normalized NPV found in this optimization was 0.03, which corresponds to a payback period of 14 quarters. Obviously, this is very close to 0, and the figure is not risk-adjusted. In addition, the solution is not robust: changing any one of 12 decision variables results in a non-negative NPV. For the majority of its supply chain projects, Raytheon expects an ROI in much less than 14 quarters. Finally, this is based on a simplified process, and the real-world complexities will reduce any overall benefit.

For these reasons, Raytheon chose not to implement RFID in its inbound materials process at this time. The experience of using the calculator and the systems optimization approach did result in analysts at other sites gaining a better understanding of which situations might most benefit from RFID. It is likely that another Raytheon site will discover a more lucrative result from implementing RFID.

Chapter 7: Conclusion

There are many difficulties to evaluating RFID in any complex, real-world process flow. The system-level interactions between the cost and benefits of an RFID system suggest that an optimization model may be the appropriate method for choosing usage scenarios and deciding what to tag. The Excel™ RFID Calculator provides a usable and extensible tool for formulating a specific model for any single facility or multi-site supply chain. Finally, the evaluation of the Integrated Air Defense Center's inbound materials flow validated the usefulness of optimization as a method and the calculator as a tool.

Future research in this area could occur in a number of areas:

Model and calculator extension: The model used in this evaluation is static and provides no guidance on when a project should be undertaken or suggestions on phased implementations. The nominal cost of RFID system components is falling, and this may make a previously infeasible project worthwhile several years from now. An optimization model framework and new version of the Excel™ RFID Calculator would help organizations understand the implications of this.

Improving RFID performance: Section 2.2 began a discussion on the factors which affect RFID performance and suggested Design of Experiments as a tool with which to achieve better reliability. A much more in-depth analysis of performance in real-world situations would be of great use to the RFID community.

Implications of actively driving technology adoption: Wal*Mart™ and the DoD are driving the adoption of RFID at rates which would not be achieved through organic growth. This could be highly successful or accelerate an expensive disaster. A cross-disciplinary view integrating technology strategy, product roadmap expectations, and financial analysis might shed some light on the future.

Improving inbound material process flow at the IADC: RFID is not the silver-bullet solution for the problems faced by the Integrated Air Defense Center. Ways to improve operational efficiency might result from further analysis of the current state and creative development of a future state. Implementing this change will take time, but some changes need to be made soon.

Citations

- [1] Raytheon Company: About Us. Raytheon Company. 30 Mar. 2005
<<http://www.raytheon.com> (Home > About Us)>.
- [2] Raytheon Company: Businesses: About IDS. Raytheon Company. 30 Mar. 2005
<<http://www.raytheon.com> (Home > Businesses > Integrated Defense Systems > About IDS)>.
- [3] Eagle, Jim. 27 2002. RFID: The Early Years. The Eagle's Nest. 28 Dec. 2004
<<http://members.surfbest.net/eaglesnest/rfidhist.htm>>.
- [4] Landt, Jerry. "Shrouds of Time - The History of RFID." AIM Global RFID Connections Feb 2002. 28 Dec 2004
<<http://www.aimglobal.org/technologies/rfid/newsletter/RFIDnews02.zip>>.
- [5] Overby, Stephanie. "Inside an Agile Transformation." CIO Magazine 15 Aug 2004. 29 Dec 2004
<<http://www.cio.com/archive/081504/profile.html>>.
- [6] Savi Technology Company History. Savi Technology. 29 Dec. 2004
<<http://www.savi.com/company/ov.company.shtml>>.
- [7] Joint Total Asset Visibility Office Charter. Joint Total Asset Visibility Office. 29 Dec. 2004
<<http://www.dla.mil/j-6/jtav/newcharter.html>>.
- [8] Estevez, Alan. "RFID Goes to War." CNet News.com. 22 Mar 2004
<http://news.com.com/RFID+goes+to+war/2008-1006_3-5176246.html>
- [9] Coyle, Edward. "DoD RFID Policy: Leading the Way in Two Worlds: Active and Passive RFID." Raytheon Enterprise RFID Kick-Off. , Waltham Woods, Massachusetts. 21 July 2004.
- [10] Cole, Peter. "A Study of Factors Affecting the Design of EPC Antennas and Readers for Supermarket Shelves." 1 Jun. 2002. Auto-ID Centre, University of Adelaide. 29 Dec. 2004
<<http://archive.epcglobalinc.org/publishedresearch/ADE-AUTOID-WH-001.pdf>>.
- [11] Scharfeld, Thomas, "An Analysis of the Fundamental Constraints on Low Cost Passive Radio-Frequency Identification System Design" (M.S. thesis, Massachusetts Institute of Technology, 2001), pp. 27 - 34.
- [12] Finkenzeller, Klaus. RFID Handbook. 1st ed. : John Wiley & Son, Ltd., 1999, pp. 108 - 109
- [13] "SaviTag ST-654 High Performance Tag." 02 Mar. 2004. Savi Technology. 16 Feb. 2005
<<http://www.savi.com/products/ds.st654.pdf>>.
- [14] Alien Technology - RFID Tags. Alien Technology. 16 Feb. 2005
<<http://www.alientechnology.com/products/rfid-tags/>>.
- [15] Alien Technology. 16 Feb. 2005
<<http://www.alientechnology.com/ftp/Products/9780reader.pdf>>.

-
- [16] Symbol. 16 Feb. 2005
<ftp://symstore.longisland.com/Symstore/pdf/RFID/RFIDAntennas_0105.pdf>.
- [17] Chappell, Gavin, Lyle Ginsburg, Paul Schmidt, Jeff Smith, and Joseph Tobolski. "Auto-ID on the Line: The Value of Auto-ID Technology in Manufacturing." 01 Feb 2003. 03 Feb 2005 <<http://www.autoidlabs.org/whitepapers/ACN-AUTOID-BC005.pdf>>.
- [18] Byrnes, Jonathan. "Are You Aiming Too Low with RFID?." Harvard Business School Working Knowledge 03 May 2004. 06 Feb 2005
<<http://hbswk.hbs.edu/item.jhtml?id=4107&t=dispatch>>
- [19] Cantwell, Brian. "Why Technical Breakthroughs Fail: A History of Public Concern with Emerging Technologies." 01 Nov 2002. 08 Feb 2005 <<http://www.autoidlabs.org/whitepapers/MIT-AUTOID-WH-016.pdf>>.
- [20] Spychips: RFID Privacy Website. Consumers Against Supermarket Privacy Invasion and Numbering. 08 Feb. 2005 <<http://www.spychips.com/>>.
- [21] Kantor, Andrew. "Tiny transmitters give retailers, privacy advocates goosebumps." USA Today 19 Dec 2003. 08 Feb 2005
<http://www.usatoday.com/tech/columnist/andrewkantor/2003-12-19-kantor_x.htm>
- [22] History of EPCglobal US. EPCGlobal. 08 Feb. 2005
<<http://www.epcglobalus.org/About/history.html>>.
- [23] Frequently Asked Questions about EPCGlobal. EPCGlobal. 09 Feb. 2005
<<http://www.epcglobalinc.com/about/faqs.html#1>>.
- [24] Frequently Asked Questions about EPCGlobal. EPCGlobal. 09 Feb. 2005
<<http://www.epcglobalinc.com/about/faqs.html#7>>.
- [25] Floerkemeier, Christian, Dipan Anarkat, Ted Osinski, and Mark Harrison. "PML Core Specifications." 15 Sep 2003. 09 Feb 2005
<http://www.epcglobalinc.com/standards_technology/Secure/v1.0/PML_Core_Specification_v1.0.pdf>.
- [26] Mealling, Michael. "EPCGlobal Object Name Service (ONS) 1.0." 15 Apr 2004. 09 Feb 2005 <http://www.epcglobalinc.com/EPCglobal_ONS_1.0.pdf>.
- [27] Roberti, Mark. "Intermec Withdraws IP Licensing Plan." RFID Journal 03 Feb 2005. 09 Feb 2005 <<http://www.rfidjournal.com/article/articleview/1387/1/1/>>
- [28] Guidelines on EPC for Consumer Products. EPCGlobal. 09 Feb. 2005
<http://www.epcglobalinc.com/public_policy/public_policy_guidelines.html>.
- [29] EPIC RFID Privacy Page. 08 Feb. 2005. Electronic Privacy Information Center. 09 Feb. 2005 <<http://www.epic.org/privacy/rfid>>.
- [30] Action Groups. EPCGlobal. 09 Feb. 2005
<http://www.epcglobalinc.com/action_groups/action_groups.html>.

-
- [31] Auto-ID Labs - About the Labs. Auto-ID Labs. 09 Feb. 2005
<<http://www.autoidlabs.org/aboutthelabs.html>>.
- [32] Byrnes, Jonathan. "Who Will Profit From Auto-ID?." Harvard Business School Working Knowledge 01 Sep 2003. 15 Feb 2005
<<http://hbswk.hbs.edu/item.jhtml?id=3651&t=dispatch>>
- [33] Wynne, Michael W. Radio Frequency Identification (RFID) Policy. 30 Jul. 2004. Department of Defense Automatic Identification Technology Office. 15 Feb. 2005
<[http://www.dodait.com/rfid/RFID%20Frequency%20Identification%20\(RFID\)%20Policy.pdf](http://www.dodait.com/rfid/RFID%20Frequency%20Identification%20(RFID)%20Policy.pdf)>.
- [34] Wynne, Michael W. Radio Frequency Identification (RFID) Policy. 2 Oct. 2003. Department of Defense Automatic Identification Technology Office. 15 Feb. 2005
<<http://www.dodait.com/docs/Wynne%20Policy%20Memo.pdf>>.
- [35] Lai, Elaine M., "An Analysis of the Department of Defense Supply Chain: Potential Applications of the Auto-ID Center Technology to Improve Effectiveness" (B.S. thesis, Massachusetts Institute of Technology, May 2003), p. 18.
- [36] CAGE FAQ. 16 Aug. 2004. Defense Logistics Information Service. 15 Feb. 2005
<http://www.dlis.dla.mil/CAGESearch/cage_faq.htm>.
- [37] WAWF Functional Information. Wide Area Workflow. 16 Feb. 2005
<<https://wawf.eb.mil/FuncInfo.html>>.
- [38] "Cost Savings Calculation Methods." Raytheon Environmental Health and Safety. 04 Oct. 2004 <Company Private Intranet>.