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Innovating Continuous Review Policies with RFID

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INNOVATING CONTINUOUS REVIEW INVENTORY POLICIES WITH RFID

by

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INNOVATING CONTINUOUS REVIEW INVENTORY POLICIES WITH RFID

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Inventory accuracy is critical for NASA astronauts in space. In 2004, astronauts onboard the International Space Station (ISS) nearly had to de-man their outpost due to the fact the replenishment of consumables were uncertain. Automated Identification Technologies (AITs) such as Radio Frequency Identification (RFID) can be utilized to minimize the occurrence of situations like this one. RFID has been used to aid inventory management systems by providing real time availability of the item information including location and status. The benefit of RFID over barcodes is immense as it allows users to employ continuous review models. Barcodes are only capable of being used in conjunction with periodic review models as inventory is not able to be monitored continuously.

Although RFID has the ability to improve inventory control policies, one must note that it is not 100 percent accurate. Factors such as metal or poor orientation can limit the ability for a tag to be read; thus, reliability of tag reads must be accounted for to provide more accurate inventory policies. In this thesis, we seek to demonstrate how optimizing inventory policies with technologies such as RFID can improve inventory control. The goal of this thesis is to develop a continuous review inventory policy that accounts for the more accurate knowledge of the level of inventory located in a certain area due to the addition of RFID.

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CHAPTER 1 INTRODUCTION

In the information age, technological advancements such as computers have allowed users to process, analyze, and display information regarding daily processes. Entering information with regard to these processes requires manual data entry which has proven to be cumbersome, expensive, and error-prone. To minimize the errors of manual data entry, Automated Identification technologies (AITs) can be implemented within a system that deals with the movement of goods or people. Several AITs have been developed to transform the data entry issues. Applications of these AITs include product identification within consumer goods industries, Global Positioning Systems (GPS) which identifies the location of a product, and swipe cards which allow access to areas. The availability of such systems has revolutionized decision support and control systems.

The issue of inventory management, using policies and techniques to maintain the optimal amount of inventory, is a crucial problem faced by many organizations throughout the supply chain. Upper management fully recognizes the strategic importance of evaluating all costs related to inventory. Along with inventory control models, some organizations utilize vendor managed inventory where the supplier maintains an agreed upon inventory level for the buyer if they provide certain information. Several models exist to improve inventory control, and these models allow for a significant competitive advantage when developing inventory control systems. The advancement of information technology systems resulting from the use of AITs have led to the evolution of inventory control policies as the accuracy of the system has led to more efficient models. Improvements to the efficiency led by of the system have resulted in the reduction of the costs throughout the supply chain.

Oftentimes, the demand and supply of a system are each random variables that must be forecasted using historical data; these variables are best characterized using probability distributions. The variability in these numbers are problematic as most inventory control policies require values of parameters in order to determine the most cost-effective policy. Forecasts are necessary to construct inventory control policies, but they are often not correct. Mismatches between the forecasts and higher demands can be adjusted by using buffer inventory. Another method to improve inventory policies is to find a better way to reduce internal variability of product demand within a system. Sources of this variability include errors in determining the amount and location of inventory, errors in process yield or errors in predicting effort and time required for different operations. In addition to affecting stock holding and operational costs, these errors also hinder the ability to accurately determine whether demand can be satisfied, limiting the corrective capabilities of the organization. Two factors can be addressed by AITs: impact of internal variability and the ability to manage demand fluctuations.

The cornerstone of all inventory control systems is the capturing of data; inventory control systems are dependent on the availability of accurate and timely data from suppliers and service providers regarding the location of the shipments and the inventory levels. Data capture is the point at which AITs can add essential value to supply chain operations. Although they are not 100 % reliable, AITs can improve the data capture process, and ensure that variability within the system is captured earlier as well as in a more accurate manner that allows for a more complete representation of the actual system to where shipments are, what the current inventory level is, and where is it located. This newfound accuracy allows for top management to recognize a problem more quickly; thus, these technologies allow for a more accurate assessment of the problem and addressing the problem in a more expedient manner. Earlier detection of problems allows for more options for corrective responses. For example, early detection of critical food levels in a NASA space station allows for the option of expediting a flight that contains crucial supplies, while later detection would lead to the de-manning of the space station and millions of taxpayer dollars lost.

Radio Frequency Identification (RFID) is an AIT that has been used for a wide variety of applications such as highway tolls, cattle tracking, and transportation freight tracking. Until recently, the technologies were considered expensive and limited, but as the tags, readers and the associated equipment costs continue to decrease, a growing number of organizations have begun to explore the feasibility of using RFID systems. Hospitals, retail stores, and warehouses are seeking to implement this technology to reduce the amounts of lost inventory and supports tracking items. This is a technology that has recently gained acceptance due to its capabilities and functionalities.

There exist situations where the cost of transporting replenishments is extremely high and the limit of space provides a complexity to the amount of stored safety stock, the level of extra stock that is maintained to alleviate risk of stockouts due to uncertainties in supply and demand; thus, it is necessary to minimize ordering and find the optimal levels of safety stock. It is also necessary to consider the reliability of RFID when constructing these inventory policies. One such situation is the replenishment of food for the International Space Station. The NASA Constellation Program has identified the need for a system that tracks inventory without requiring astronauts to perform daily logging activities. Currently, NASA tracks items such as crew clothing, office supplies, and hygienic supplies with barcodes at the bag level and not at the item level. Recently, NASA chose to evaluate RFID Automatic Data Capture (ADC) at the item level. This thesis investigates RFID uncertainty in conjunction with inventory control theory in order to create a more optimal (Q,R) policy which can be utilized by several organizations including supporting better inventory control at NASA. Inventory control theory investigation includes traditional continuous review models with a focus on the Economic Order Quantity (EOQ).

The rest of the thesis is structured as follows. Chapter 2 provides a background on inventory control, RFID, and the effect of RFID on inventory control. Chapter 3 focuses on providing the motivation behind the study of this thesis along with the research question and objectives. NASA's method of managing inventory is described. Chapter 4 describes the proposed methodology. In this chapter, the method of collecting data for reliability of RFID is discussed. Also, the proposed model that incorporates the reliability of RFID in a (Q,R) policy is developed within this chapter. Finally, the empirical model that validates the theoretical model is described. Chapter 5 presents the results of the comparison of the model developed with current (Q,R) models. Finally, Chapter 6 presents the conclusions, as well as providing the limitations of the work and direction for future work.

CHAPTER 2 BACKGROUND

This chapter describes important background relevant to the research of the thesis, which includes: inventory control theories, the history of RFID, how RFID works, RFID vs. Barcode, using RFID at NASA, and how inventory control and RFID are being used for more effective policies. Inventory control theories provide a basis for the model that will be developed to improve current policies. The history of RFID is relevant to background for understanding. How RFID works is important because it provides a basis of understanding for the research. RFID's advantages over barcode technology are an important topic to focus on because it demonstrates the need for implementing RFID over barcodes. RFID readability is necessary to understand the importance of adding a reliability measure to current inventory management systems that deploy RFID. Using RFID at NASA demonstrates practical uses for the research. How RFID is used in current inventory control policies is relevant to show the benefit of RFID within inventory control.

2.1 Inventory Control Theory

To acquire a better understanding of the inventory policies, it is necessary to define the costs that pertain to inventory control models including holding costs, ordering or setup costs, shortage costs or service constraints, and other costs and assumptions. Holding costs can be viewed in layman's terms as rent on inventory; it is the money spent to store and maintain the stock of goods. Oftentimes, holding cost per unit is calculated as a percentage of the unit value, which is considerably higher than the interest rate charged by the bank (Axsater, 2006). This percentage usually varies according to the product.

Generally holding cost can be calculated based on their ability to become obsolete (Axsater 2006). Ordering and setup costs are fixed costs that are associated with replenishment. They may represent the cost of ordering a replenishment and include transportation costs as well administrative costs. Not all models allow for shortages, but for those that do, a shortage cost represents an item that is demanded and cannot be delivered due to a shortage of products available.

Inventory control methods can be categorized into two types: periodic review or continuous review. A continuous review system is one in which inventory is monitored at a continuous rate whereas a periodic review system is one in which inventory is checked at certain points in time over a period of time (Winston 2004). Unlike continuous review policies, periodic review policies do not allow for the possibility of a replenishment order to be triggered when the inventory level declines to any previous value. Since continuous review policies monitor their inventory at every point, the policy is able to send a trigger at a preset value (Axsater 2006). To use continuous review policies, one must have access to a system that allows for the capture of a large amount of data. Using a continuous review policy is necessary especially if a stockout of the item being review is especially costly to the organization (Carrillo, Carrillo, & Paul, 2006). A summary of inventory policies is seen in Table 1 (Carrillo, Carrillo, & Paul, 2006).

Table 1: Inventory Models (Carrillo, Carrillo, & Paul, 2006)

INVENTORY MODEL	DETERMINES	APPROPRIATE FOR	SIGNIFICANT FACTORS
Continuous review	Order frequency	Critical items with costly stock-outs	Information intensive
Periodic review	Order frequency	General purpose items	
Economic order quantity	Order quantity (inventory level)	Stable demand	Monthly demand Holding cost Fixed order cost Lead time
Reorder point	Order quantity (inventory level)	Uncertain demand	Average demand Standard deviation demand Customer service level
Min–max	Order quantity (inventory level)	Uncertain demand	Min stock level Max stock level
Order up-to	Order quantity (inventory level)	Uncertain demand	Max stock level

2.2 History of RFID

Automated identification technologies (AITs) include a variety of technologies such as RFID and barcodes that are used to identify objects. Some aims of AITs are to increase efficiency and reduce data entry errors. RFID is an AIT that uses radio waves to automatically identify objects. There are several aims of RFID but two of the most important ones are to reduce administrative errors and labor costs associated with lack of an efficient means to capture data.

Radio Frequency Identification (RFID) technologies originated from radar theories that were discovered by the Allied forces during World War II and have been commercially available since the early 1980 (Landt, 2001). One of the earliest papers exploring RFID was written by Harry Stockman titled “Communication by Means of Reflected Power” and was published in 1948 (Association for Automatic Identification and Data Capture Technologies, 2001).

The 1950's resulted in more theoretical exploration of RFID techniques characterized by several scientific papers published on the subject. Prototype systems enter developmental stage in the 1960's. Some commercial systems developed a 1 bit tag that could be used as an antitheft device that could detect the presence or absence of a tag (Association for Automatic Identification and Data Capture Technologies, 2001). Some argue this was the first and most widespread commercial use of RFID.

In the 1970s resulted with increased interest in RFID from researchers, developers and academic institutions. In the 1980s, RFID applications extended into a number of areas. In Europe animal tracking systems and toll roads became widespread. The 1990s were significant with the widespread adoption of electronic toll collection in the United States. In Europe there was also considerable interest in RFID applications including toll collections, rail applications and access control (Landt 2001). RFID tolling and rail applications began to appear in many countries. Developments of RFID technology continued in the 1990s as the size of tags reduced and an integrated circuit was developed (Association for Automatic Identification and Data Capture Technologies, 2001).

Over the last two decades, RFID has been used for a wide variety of applications such as highway tolls, cattle tracking, and transportation freight tracking. Until recently, the technologies were considered expensive and limited, but as the tags, readers and the associated equipment costs continue to decrease, a growing number of organizations have begun to explore the feasibility of using RFID systems. Hospitals, retail stores, and warehouses are seeking to implement this technology to reduce the amounts of lost inventory and supports tracking items. This is a technology that has recently gained acceptance due to its capabilities and functionalities.

The history of RFID can be summarized by decades as seen in Table 2 (Association for Automatic Identification and Data Capture Technologies, 2001).

Table 2: The Decades of RFID (Association for Automatic Identification and Data Capture Technologies, 2001)

Decade	**Event**
1940-1950	Radar refined and used, major World War II development effort. RFID invented in 1948
1950-1960	Early explorations of RFID technology, laboratory experiments
1960-1970	Development of the theory of RFID. Start of applications field trials.
1970-1980	Explosion of RFID development. Tests of RFID accelerate. Very early adopter implementations of RFID.
1980-1990	Commercial applications of RFID enter mainstream.
1990-2000	Emergence of standards. RFID widely deployed. RFID becomes a part of everyday life

2.3 How RFID Works

RFID systems consist of three main components: readers, antennas, and tags. The antenna emits radio signals that the tags respond to with their own unique code. The reader then receives and decodes the tag information and sends it to a computer through standard interfaces. There are three types of RFID tags: active, passive, and semi-passive (Angeles, 2005). There are several differences between the types of tags. Active tags are battery powered which allows for longer read ranges and a greater memory capacity. One disadvantage of active tags is that they are typically more expensive than their counterparts (Want, 2006). Passive tags have no battery and are much less expensive than active tags, but their read ranges are significantly lower than their counterparts (Want, 2006). Semi-passive tags are similar to active tags in that they have long read ranges and they are more expensive than passive tags. These tags utilize a battery to run the chip's circuitry, but draw power from the reader in order to communicate.

RFID operates on several frequencies: low-frequency (125 KHz), high-frequency (13.56 MHz), ultra-high-frequency (UHF) (860-960 MHz), and microwave (2.45 GHz). Each frequency has different characteristics, which in turn allows different frequencies to be useful in different applications. For example, low-frequency tags use less power and have the best ability to penetrate non-metallic substances in comparison with the other frequencies while high-frequency tags work better than the others on objects made of metal. The frequency bands and applications can be summarized in Table 3 (Roberts 2006).

Table 3: Frequency Bands and Applications (Roberts 2006).

Frequency Band	Characteristics	Typical Applications
Low 100-500 kHz	Short to medium read range Inexpensive Low reading speed	Access control Animal identification Inventory control Car immobilizer
Intermediate 10-15 MHz	Short to medium read range Potentially inexpensive Medium reading speed	Access control Smart cards Library control
High 850-950 MHz 2.4-5.8 GHz	Long read range High reading speed Line of sight required Expensive	Railway vehicle monitoring Toll collection systems Pallet & container tracking Vehicle tracking

The RFID technology can also be integrated with Real Time Location Systems (RTLS) to both identify and locate items. Companies are taking advantage of this technology because it provides the most accurate measure and has the ability to pin point where items are located. The way RFID technology works is through electromagnetic communication between a reader (interrogator) and a tag (transponder) (Ranky, 2006). A tag is attached to an object with internal memory storage, which contains critical information pertaining to the object, such as a serial number, manufacture date, or information that aid in the identification of the object. An interrogator emits an electromagnetic field and when a tag enters the field, the information stored on the tag is transmitted back to the interrogator (Ranky, 2006). In general, when the reader emits a radio frequency signal, any corresponding tag within range of the reader will detect the signal. Once a tag has verified the signal, it replies to the reader indicating its presence. RFID has the ability to locate misplaced items at a reduced cost.

2.4 RFID vs. Barcode

There are two main AITs that are being used for inventory control: barcode and RFID. Barcode technology until recently has been the main AIT used in inventory control. As the price of RFID has decreased and general acceptance of RFID has increased, the use of RFID has slowly replaced barcode technology. There are many benefits of using RFID over traditional methods of inventory control. Table 4 details some advantages of using RFID versus using barcode technology. (Juban and Wyld, 2004).

Table 4: RFID versus Barcode Technology (Juban and Wyld, 2004)

RFID tags can be read or updated without line of sight	Barcodes require line of sight to be read
Multiple RFID tags can be read simultaneously	Barcodes can only be read individually
RFID tags are able to cope with harsh and dirty environments	Barcodes cannot be read if they become dirty or damaged
RFID tags are ultra thins, and they can be read even when concealed within an item	Barcodes must be visible to be logged
RFID tags can identify a specific item	Barcodes can only identify the type of item
Electronic information can be over-written repeatable on RFID tags	Barcodes information cannot be updated
RFID tags can be automatically tracked eliminating human error	Barcodes must be manually tracked for item identification, make human error an issue
RFID allows for real-time information	Barcodes must be manually scanned to obtain information

Other literature suggests that there are two advantages that RFID has over barcodes: RFID can be readily scanned automatically without human involvement and RFID does not require line of sight (McFarlane 2003). The use of RFID over barcodes adds another dimension to inventory control by allowing the ability for continuous review versus as oppose to barcodes which can only be used with periodic review models.

2.6 RFID Readability

Although tag reliability has improved immensely since early adopters, RFID tag manufacturers continue to produce tags that are not 100% reliable (Shutzberg, 2004). In early RFID pilots, failure rates were as high as 20% to 30% (Shutzberg, 2004). Poor performing tags differs depend on many factors, including what materials are adjacent to each tag and environmental conditions such as temperature and humidity (Shutzberg, 2004).

One challenge found within the design of RFID tags is that tags are not resilient to all types of materials (Want, 2006). Metal has long been an issue for the readability of RFID tags. RF waves are unable to penetrate metal; instead, metal reflects these waves, which makes it difficult to read the tags placed on metal surfaces. Research has shown that when RFID tags are directly attached to a metal surface, they are often undetected (Floerkemeier, & Lampe, 2004). Most liquids absorb RF waves which again reduces the read range. Highly dielectric materials (liquids) and conductors (metal), even in small amounts, can drastically change the properties of a tag antenna, reducing efficiency, and shortening the read distance, sometimes to the point of becoming completely unreadable at any distance (Singh, Vorst, & Tripp, 2009).

Recent research in the field of RFID reliability has pointed out weaknesses with achieving 100% read rates. Lack of 100% reliability is mainly attributed to the fact that radio frequency operates differently depending on the environment. The effect of various materials on read rates was highlighted in several recent studies. The effects on RF field of different materials is summarized in the Table 5 below (Singh, Vorst, & Tripp, 2009):

Table 5: Effects of Different Materials on RF Field

Material	Effect on RF field
• Cardboard	Absorption (moisture), detuning (dielectric)
• Conductive liquids	Absorption
• Plastics	Detuning (dielectric)
• Metals	Reflection
• Groups of cans	Complex effects (lenses, filters), reflection
• Human body/animals	Absorption, detuning (dielectric), reflection

In the research, RFID alien "higgs" tags were used to analyze specific variables that may affect the read accuracy of multiple RFID tags on a pallet when driving a pallet through an RFID portal. The study found that there is a significant relationship between the read rate and forklift speed. The best read rate (100%) was achieved for paper towels; this is because of the papers transparency to RF signals (Singh, Vorst, & Tripp, 2009) . Carbonated beverages in aluminum cans had the greatest difficulty in achieving 100% read rate, they achieved a read rate of little over 25% (Singh, McCarney, Singh, & Clarke, 2008) (Singh, Holtz, Singh, & Saha, 2008) . The lowest speed used to move the palletized load through a portal increased the probability of reading the tags applied to the cases. The rice – filled jars had a higher read rate. Presence of air gaps created in secondary packaging (trays and shippers) configurations between the locations and positioning of RFID tags and primary packages or products (bottles and cans) allows RFID readers to get more effective reads and reduce interferences and reflectance or blockage by water and metal. The research also showed that reducing the number of cases in a palletized load does not always guarantee a more efficient read rate. It was demonstrated that fewer cases provided better readability of case level tags for bottled water, but not for beverage cans (Singh, Vorst, & Tripp, 2009).

Previous research conducted at the University of Nebraska – Lincoln's Radio Frequency Identification (RFID) and Supply Chain Lab on Cargo Transport Bags (CTBs) demonstrated that various factors affect the readability of NASA items tagged with RFID (Jones 2005). Design of Experiments was used to determine which factors affect the read rate: test type, distance, number and placement of antennas, and movement of items. The experiment was performed using both the CTB and cardboard container. The goal of the data collection was to identify problems with item level tagging and determine the factors that have the most significant effect on the read rate. The results in this study present the data at the item level only. The performance metric was the percent of tags within the CTB or cardboard containers that are read within 15 seconds using a fixed or mobile reader. Read rates are shown in Table 6 (Jones 2005).

Table 6: Results of Item Level Testing Using CTB (Jones 2005)

Results of Item Level Testing Using CTB

Trial Number	Distance (feet)	Number and Placement of Antennas	Movement of Items	Percentage of Tags Read B1 (Clothing)	B2 (Hygiene)	B3 (Office)	Total
1	1	4 (2 per side)	None	100%	85%	75%	87%
2	1	4 (2 per side)	None	75%	92%	75%	86%
3	1	4 (2 per side)	None	100%	92%	75%	91%
4	1	4 (2 per side)	Rotating	100%	100%	100%	100%
5	1	4 (2 per side)	None	100%	100%	100%	100%
6	3	4 (2 per side)	None	75%	92%	75%	86%
7	3	4 (2 per side)	Rotating	75%	100%	75%	91%
8	3	2 (same side)	None	75%	69%	25%	64%
9	3	2 (same side)	None	75%	100%	75%	91%
10	3	2 (same side)	None	100%	69%	0%	64%
11	3	2 (same side)	None	100%	100%	50%	91%
12	3	2 (1 per side)	Rotating	100%	100%	75%	95%
13	1	2 (1 per side)	None	100%	92%	75%	91%
14	1	2 (1 per side)	Rotating	100%	100%	75%	95%
15	1	1 (one side)	None	100%	54%	75%	68%
16	1	1 (one side)	Rotating	100%	100%	75%	95%
17	3	1 (one side)	Rotating	100%	100%	50%	91%

As can be seen by Table 6, tags are not always read with 100% reliability. Different factors affect whether they are read by an RFID reader or not. The results of the experiment found that as distance from the tags to the reader antenna increase, the reliability of the readings decreased. A decrease in number of antennas led to a decrease in read rate; thus, there was an increase in the chances of a tag being missed due to orientation issues. Placement of antennas was found to increase read rate when placed at opposite sides. Movement of items (orientation) was found to be the most significant factor. When the CTB was held in a static position, an average of 84% of the tags was read, however, when movement was introduced and the CTB was rotated, the read rate increased to 95% (Jones 2005). Results of this paper show that it is highly unlikely to achieve 100% read rates because several factors interfere with read rates.

2.7 RFID at NASA

Currently, the inventory management system on the ISS is primarily based on barcodes and a database called the Inventory Management System (ISS). All items that enter the ISS are labeled with a barcode which is inputted into IMS. To update the location or status of an item, one must scan the barcode and enter the appropriate changes into the database. Every day, each ISS crew member must take 20 minutes to update the IMS. Currently, there are approximately 130000 items on the ISS and NASA has designated 3% as lost. Using this knowledge, they are working to implement an RFID system that would allow for crew-free inventory management (Jones 2005).

2.8 Inventory Control Policies and RFID

Information regarding the status of supply chain systems has become increasingly important. The reliability of this data has a profound impact on supply chain management. Liu, So, and Zhang developed a modeling framework to quantify the value of improving supply reliability (2009). Their findings showed that as supply reliability becomes higher, the firm has the ability to earn a higher profit (Liu, So, & Zhang, 2009). RFID added to the supply chain adds another level to inventory management. Gaukler analyzes the item-level RFID in the retail supply chain and developed a model that captures the most important benefits of RFID at the retailer (2007). With his model, he shows that sharing costs of RFID does not hinder the supplier or retailer cost-wise (2007). Wong and McFarlane describe possible benefits of using RFID data capture in the improvement of Shelf replenishment (2005). They concluded that current shelf replenishment policies would improve with the introduction of RFID because it allows for accurate information to be available immediately. Other models exist that incorporate RFID, but all fail to address the reliability of RFID.

Below is a summary of inventory models that have been developed incorporating RFID. As seen in the Table 7, no models have been created based on the reliability of RFID.

Table 7: Inventory Models with RFID

Model Type	**Description**	**Inclusion of RFID Reliability Factor**
Shelf Replenishment (Wong and McFarlane 2009)	Improved information data capture allows for better shelf-replenishment	No
Item-Level (Gaukler, 2007)	RFID improves supplier and retailer relationship at no added cost to either	No
Emergent Reorder (Gaukler, 2007)	Use of RFID allows for an emergent order policy	No

CHAPTER 3 RATIONALE

This chapter discusses the motivation behind the research of this thesis, a situation that occurred in NASA's ISS in 2004. The research question is also introduced to demonstrate the purpose of the study. Finally, the objectives are stated to show how the research question was answered.

3.1 Motivation

Inventory control affects several industries and requires strategic management to ensure an optimal policy. NASA's operations demonstrate a critical need for an accurate inventory control policy due to the drastic measures that must be taken if any mistakes are made. The astronauts on the International Space Station (ISS) have no option other than to abandon their outpost if their food inventory diminishes to minimal levels. It is very difficult to replenish inventory levels in space. One such situation that motivated this study occurred in 2004 when astronauts aboard the ISS were instructed to cut daily food intake by 5 to 10 percent to compensate for the food shortage aboard the space station. During this five-week period, crewmembers aboard the station rationed food inventory until a Russian cargo ship arrived with 440 pounds of food (Mather 2004). To exacerbate the situation, an unsuccessful launch of the cargo ship would have left the crew with only fourteen days of food (Mather 2004).

Currently, NASA utilizes barcode technology to monitor their inventory. Use of this technology requires manual audits and searches for lost items. Each crew member performs at least four hours per year of manual audits plus any "personal time" they wish to use on this chore. Time assigned to this chore takes away from the time that astronauts could be conducting experiments. Implementation of an effective inventory management system is necessary to not only diminish this time on a non-value added task but also to improve the accuracy of the inventory levels. Inaccurate measures of inventory would have forced the astronauts in 2004 to abandon the outpost and return to earth unsuccessfully completing the mission had cargo ships not reached them. When you consider that building a space shuttle for launch is an estimated 1.7 billion, and the actual launching is estimated as $450 million (Grinter 2000), the combined cost of a space shuttle launch along with an unsuccessful completion of the planned mission is extremely high. Also, the costs to the taxpayers are not the only things to consider; the actual stress the decrease in caloric consumption takes on the astronaut's body must be considered as well. As the crew members' bodies adapt to weightlessness, many physiological changes occur, which can affect be affected by the nutrition of the crew member. Some changes include loss of bone and muscles, changes in the blood, changes in the amount of fluid in different areas of the body, and changes in heart and blood vessel function. Consuming a certain amount of nutrients may not be able to stop the changes, but consuming too few can intensify these problems. To prevent this type of situation, investigating an improved inventory control system that is automated is justifiable.

3.2 Research Question

The purpose of this thesis is to investigate continuous review policies that can be evaluated due to RFID's ability to continuously monitor inventory levels. The following research question will be answered:

Can an improved inventory policy be developed that accounts for the reliability of RFID?

To investigate this research question, continuous review policies will need to be altered with the introduction of a reliability factor that represents the average number of tags read divided by the total number of tags. Comparing previous models with new models using NASA data will allow for validation of the new model.

3.3. Objectives

To investigate the research question, several objectives must be met. The first objective is to develop a (Q,R) policy that includes a reliability factor to account for tags on inventory that are not read. By adding the reliability factor into a total cost function and reoptimizing the optimal quantity Q and the reorder point R, a new model can be found that includes the reliability factor. The second objective is to compare the costs of a system without RFID, with RFID and reliability not taken into account, and with RFID and reliability taken into account. These objectives helped investigate the hypothesis that adding a reliability factor into RFID provided a more accurate view of the total cost and reduce the total cost of the system compared to the cost of a system with no RFID.

CHAPTER 4 METHODS

In this chapter, a theoretical model was developed to based on the previous EOQ model used and a (Q, R) policy that allows for shortages. The model takes into account the reliability of RFID by adding an alpha value and reoptimizing the total cost function. Finally it presents the problem description and the assumptions of an empirical model that will be used to validate the model developed.

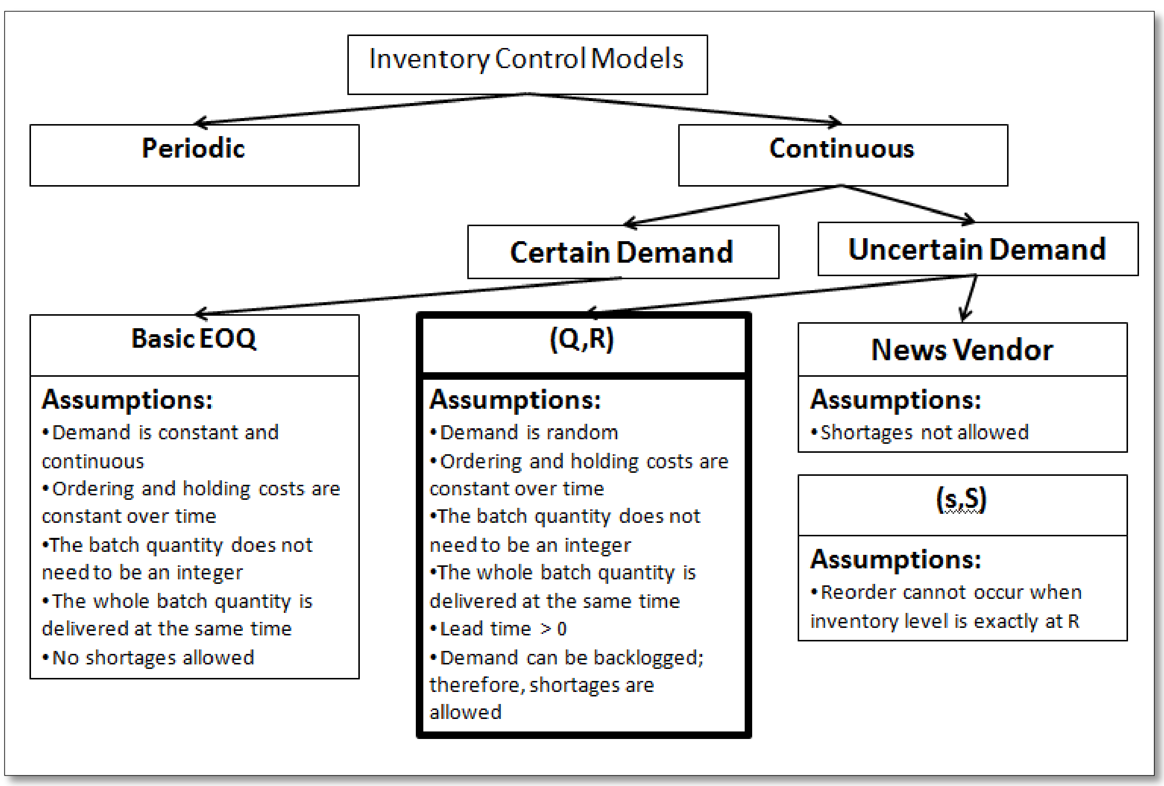
4.1 Overview

Developing a model that included the reliability of RFID required several steps. To begin with, the theoretical model was developed by evaluating different known inventory control theories. To validate the theoretical model, an empirical model was developed with known NASA data. Finally, two comparisons were made: a comparison of the current NASA model, the continuous review model, and the continuous review model with reliability based on total cost and a comparison of reorder points of the continuous review model with reliability based on measured and actual inventory.

4.2 Theoretical Model Development

When developing the theoretical model, several models were considered, but two models in particular aided in the design on the proposed model. As stated before, models are classified as periodic or continuous. Utilization of RFID allows for the use of RFID because RFID can monitor inventory levels continuously. The demand was the second parameter to consider when developing the model. Demand can either be certain or uncertain. Since we are dealing with a real word situation and most times demand is uncertain, we decided the model should take into account uncertain demand. There are three main models that deal with uncertain demand: News Vendor, (Q, R), and (s, S). The three models have several assumptions. The News Vendor model was not used because shortages are not allowed and most inventory situations have shortages that must be considered. The (s, S) model does not allow reordering to occur when the inventory level is exactly at R. The (Q, R) model with shortages allowed was the best model because the assumptions were most like the real world issues faced by inventory managers. Currently, NASA is using the EOQ model which does not consider shortages or have a reorder point. Figure 1 shows the algorithm of developing the model.

Figure 1: Algorithm of Model Development



The notations used throughout the thesis are summarized below.

- Q = quantity
- R = reorder point
- H = holding cost
- K = ordering cost
- c_B = shortage cost
- P = purchase cost
- L = lead time
- E[D] = expected demand
- $E[B_r]$ = expected shortage at reorder point
- E[X] = expected demand during lead time

4.2. EOQ Model

EOQ can be categorized in two ways: periodic review system or a continuous review inventory system. Which system is utilized depends on how often you monitor the inventory levels and at what point you can order more inventory. Previously, continuous models have been theoretical but with technologies such as the RFID, use of these continuous models has become more of a reality. This automation will allow for the costs of replenishing inventory to be reduced by minimizing costs such as transportation and manual inventories.

The EOQ determines the number of units a company should add to inventory with each order to minimize the total costs of inventory (Accounting Financial and Tax, 2008). The costs are associated into three different categories; holding costs, order costs, and shortage costs. The EOQ is utilized as part of a continuous review inventory system. The system inventory status is monitored at all times with a fixed quantity that is ordered each time inventory levels reaches a unique reorder point.

The EOQ provides a model for calculating the appropriate reorder point and the optimal reorder quantity to ensure the instantaneous replenishment of inventory with no shortages. The EOQ model assumes certain measures, which the demand considers as being constant; also, inventory is decreased at a static rate until the value of zero is meant. At this point, a specific number of items return the inventory to its beginning level (Accounting Financial and Tax, 2008).

The EOQ model assumes instantaneous replenishment; there are no inventory deficiencies or no costs. Inventory cost, under the EOQ model utilizes a tradeoff between inventory holding costs (the cost of storage, as well as the cost of tying up capital in inventory rather than investing it or using it for other purposes) and order costs (any fees associated with placing orders, such as delivery charges).

Prior research suggests that ordering a large amount at a given time increases holding costs, while implementing more frequent orders of fewer items minimizes holding costs but increase order costs (Winston 2004). The EOQ model has the ability to find the quantity that minimizes the sum of these costs. The EOQ formula is as follows:

$$TC = PD + \frac{HQ}{2} + \frac{KD}{Q}$$

Where,

TC = total inventory cost per year,

PD = inventory purchase cost per year (P multiplied by D in units per year),

H = Holding cost,

Q = Order Quantity, and

K = Order cost.

The yearly holding cost of inventory can be determined by multiplying H by the average number of units in inventory. The model assumes that inventory is reduced at a uniform rate, with the average number of units equal to Q/2. The total order cost per year is distinguished by *K* and multiplied by the number of orders per year. This is also equal to annual demand divided by the number of orders or also known as D/Q [4]. Lastly, PD is constant and the order quantity has no effect on it. Equation 2 shows how the optimal order quantity is found:

$$\frac{HQ}{2} = \frac{KD}{Q} \; or \; Q^* = \sqrt{\frac{2KD}{H}}$$

The holding costs are calculated by the loss of money incurred by holding the inventory, so it is generally calculated as cost of one item(C) x the cost of money (i) in the form of interest to store it (generally 15 to 35% interest).

Summary of Assumptions for EOQ:

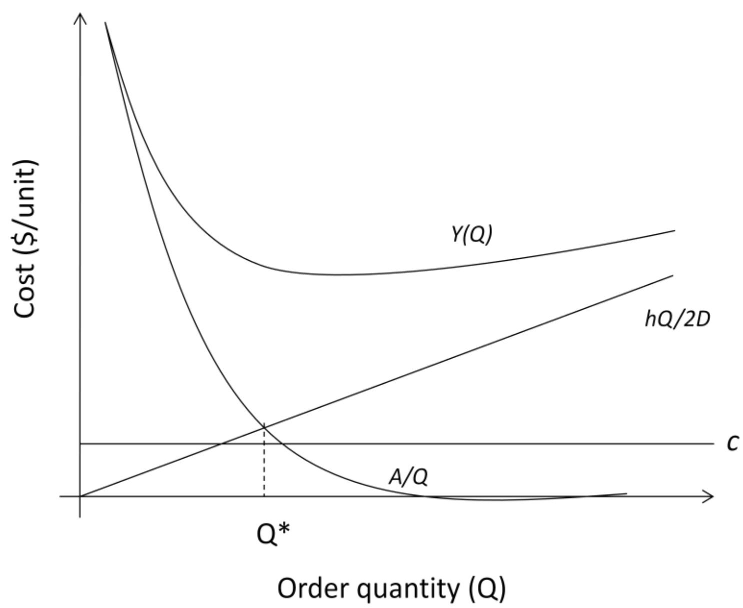
- Demand is constant and continuous,
- Ordering and holding costs are constant over time,
- The batch quantity does not need to be an integer,

- The whole batch quantity is delivered at the same time, and
- No shortages allowed.

A visual representation of the cost and ordering quantity can be seen in Figure 2.

Q* represents where the optimal ordering quantity occurs.

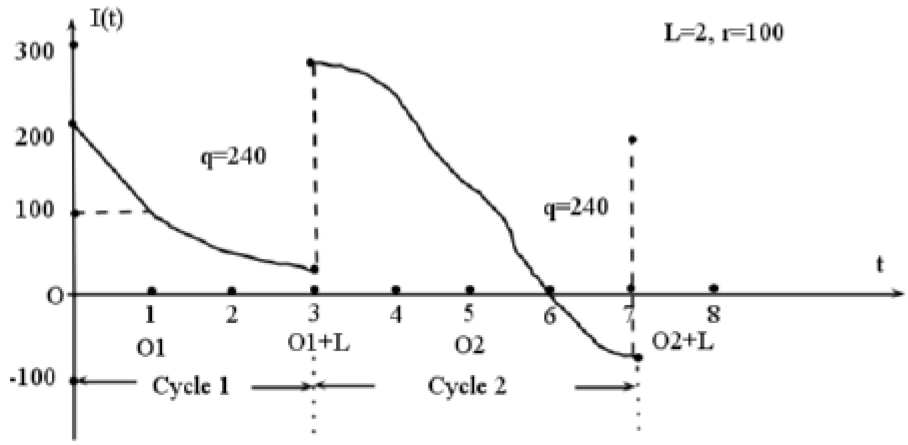
Figure 2: Optimal Order Quantity



4.2.2 (Q, R) Policy with Shortages

By utilizing a (Q, R) policy, we can continually track the inventory level, and place an order of size Q at any point over the time horizon when the on-hand inventory is at or below R. When shortages are allowed, we can utilize a model that includes shortage costs. Figure 3 shows a typical situation where shortages are involved.

Figure 3: (Q,R) with Shortages (Winston, 2004)



The first assumption is that the inventory policy follows a continuous review model. The second assumption is that demand, *D*, is stochastic and is random continuous variable of annual demand (E[*D*], σ_d). The on-hand inventory at time *t* is represented by O(*t*). The third assumption is that $I_A(t)$ the actual inventory at time *t* follows a uniform distribution. We can assume uniformity because the demand at t is constant.

A total cost of the model is represented as

TC(Q,R) = expected values of (holding cost + shortage cost + order cost).

The new (Q, R) policy requires the calculation of each value and the inclusion of the reliability factor. To calculate the cost attributed to holding inventory, one must determine the average inventory on hand O(*t*). The I(*t*) is approximately equal to O(*t*) since determining the optimal reorder point and order quantity minimizes the average number of back orders relative to the average inventory on hand (Winston, 2004). Since I(*t*) follows a uniform distribution, the expected value can be determined using the following formula

$$\mathrm{E}[\mathrm{I_A}(t)] = \frac{[I(t)\ at\ the\ beginning\ \ of\ a\ cycle\ + I(t)\ at\ the\ end\ of\ a\ cycle\ ]}{2}.$$

$$\mathrm{E}[\mathrm{I}(t)] = \frac{[(R-E[X]+q)+(r-E[X]]}{2}$$

$$= R - E[X] + \ q/2$$

Substituting the equation of (R-$E[X]$+Q) is allowed because the initial inventory level is at or below r so we have ordered Q units demonstrating that the initial inventory is at R + Q, but we also must account for the demand so we subtract E[X] (Winston, 2004). We account for this value because the lead time L is greater than 0, so we have a positive demand value arriving between the time we place an order and the time we actually receive the order (Winston, 2004).

Finally the holding cost can be calculated by multiplying H*E[$\mathrm{I_A}(t)$].

Expected holding cost = H*($R - E[X] + \frac{Q}{2}$).

The expected annual shortage cost is equal to the expected shortage cost per cycle times the expected number of cycles per year (Winston, 2004).

Expected shortage cost = c_BE[B_r]*$\frac{E[D]}{Q}$

where c_B is the cost incurred for each unit short.

Finally the expected annual order cost is calculated in the following manner.

Expected order cost = K(E[D]/Q).

Combining all the costs, we can get the total cost.

$$\text{TC(Q, R)} = H^* \left(R - E[X] + \frac{Q}{2}\right) + c_B \text{E}[B_r]^* \frac{E[D]}{Q} + K(\text{E}[D]/Q).$$

This cost must be minimized to find the optimal Q and R values. To do this, we must take the derivative with respect to and the derivative with respect to r such that

$$\frac{dTC(Q,R)}{dQ} = \frac{dTC(Q,R)}{dR} = 0$$

The derivative with respect to Q is difficult to calculate because the E[B_r] is challenging to determine. Winston (2004) states that in most cases this value is so small that

$$Q^* \approx \sqrt{\frac{2KE[D]}{H}}.$$

Determining the optimal value of r is a little more difficult. Marginal analysis will be used to determine the reorder point. If we assume a given value of Q, the expected annual ordering cost is independent of r; therefore, by determining a value of r that minimizes the total cost, we can concentrate on minimizing the sum of the expected annual holding and shortage costs. Suppose we increase the reorder point from r to $r + \Delta$, the expected annual holding cost will increase by

$$H^* \left(R + \Delta - E[X] + \frac{Q}{2}\right) - H^* \left(R - E[X] + \frac{Q}{2}\right) = H\Delta.$$

If we increase the reorder point by a small amount, the expected annual stockout costs will be reduced. Since the lead time demand is at least r during any cycle, the number of stockouts during the cycle will be reduced by Δ units. Increasing the reoproder point results in the reduction of stockout costs by c_B during a fraction P(X >= r) of all cycles.

Since there are an average of E[D]/Q cycles per year, increasing the reorder point from r to r + Δ will reduce the expected annual stockout cost by

$$\frac{\Delta E[D]c_B P(X \geq r)}{q}.$$

The optimal r is the value of r which marginal benefit equals marginal cost

$$\frac{\Delta E[D]c_B P(X \geq R)}{Q} = H\Delta.$$

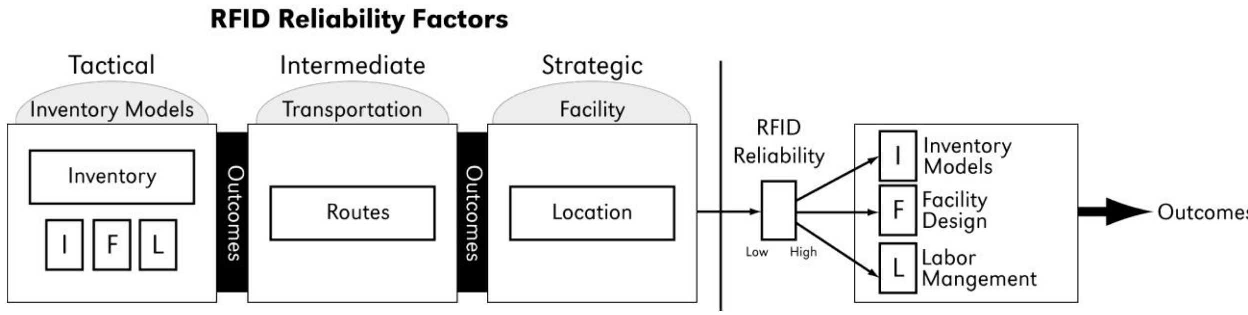
Therefore,

$$P(X >= R) = \frac{Hq}{E[D]c_B}.$$

4.2.3 Proposed Model with Reliability

Introducing RFID technology into the inventory management system, adds a level of uncertainty to the previous model and a model to be used by NASA must take into account this uncertainty when creating an inventory policy for the ISS. The reliability of the RFID technology has an effect on these inventory models, and must be taken into account when creating a new inventory management policy. This research added another element to provide a more accurate inventory policy for the NASA space station when compared to the (Q,R) models. This transmission probability can be described as the reliability of the RFID tag. Figure 4 depicts the effect reliability has on inventory control.

Figure 4: RFID Reliability Factors



The introduction of the reliability constant within a common (Q, R) model may lead to more accurate inventory policies in comparison to a simple EOQ model or a common (Q, R) model. Using the reliability information from previous research, we can build upon the previous current (Q, R) policies. This research introduces the influence of RFID technologies and their associated RFID reliability factors into the cost function, and evaluates their impacts on inventory, lead time, and customer service levels. Using a (Q, R) policy and the RFID reading point status, a multi-level inventory policy can be created. This model can utilize previous research and can be evaluated against other (Q, R) models without RFID, with RFID, and no technology factors for performance to determine the most accurate inventory management system. This new model can be used to help organizations such as NASA determine the proper inventory policy which will minimize shortages and surpluses at the ISS.

In order to take into the accounts the reliability of RFID technology, new values for the (Q, R) policy must be determined based on the accuracy of the inventory measured. Reliability of RFID did only affect reorder points, the optimal quantity, but it also affected the total cost and levels of safety stock. By utilizing a (Q, R) policy, we can continually track the inventory level, and place an order of size Q at any point over the time horizon when the on-hand inventory is at or below R. By acknowledging the fact that the measured inventory may not be an actual depiction of the true levels, a policy can be adapted that reduces the total cost. Developing a new model requires assumptions that must be met for the model to work successfully. The first assumption is that the policy is a continuous review policy. The introduction of RFID allows for a real time view of the inventory levels that can be monitored continuously throughout the time horizon. The second assumption is that demand *D* is stochastic and is random continuous variable of annual demand (E[*D*], σ_d). The on-hand inventory at time *t* is represented by O(*t*). The third assumption is that $I_A(t)$ the actual inventory at time *t* follows a uniform distribution. We can assume uniformity because the demand at t is constant.

A total cost of the model is represented as

TC(Q,R) = expected values of (holding cost + shortage cost + order cost).

The new (Q, R) policy requires the calculation of each value and the inclusion of the reliability factor. To calculate the cost attributed to holding inventory, one must determine the average inventory on hand. Since $I_A(t)$ follows a uniform distribution, the expected value can be determined using the following formula

$$E[I_A(t)] = \frac{[I_A(t)\ at\ the\ beginn\ ing\ of\ a\ cycle\ + I_A(t)\ at\ the\ end\ of\ a\ cycle\ ]}{2}.$$

Since $I_M(t)$ represents the measured inventory, these values must be adjusted to account for the reliability of the RFID tags. A tag can either be read or not read, where reading a tag can be seen as a success while not reading a tag can be seen as a failure. Given that *X* is a random variable of the number of tags read, we know that X follows a binomial distribution where the n equals the number of tags and p equals the probability that a tag will be read; thus the expected value of inventory read at t is $p*I(t)$. Let us assume that p is equal to $\propto$ where $0 \leq \propto \leq 1$. The measured inventory value is $\propto * I_A(t)$ where $I_A(t)$ is the actual inventory level at t. To convert to the measured value to the actual inventory level, you must divide by α; therefore the following relationship holds

$$I_A(t) = I_M(t)/ \propto.$$

Using this relationship, we can substitute and get the following equation

$$E[I_A(t)] \qquad = \frac{[I_M(t) \text{ at the beginning of a cycle } /\propto + I_M(t) \text{ at the end of a cycle } /\propto]}{2}.$$

Since α is a constant, we can pull the value out of the equation

$$E[I_A(t)] \qquad = \frac{[I_M(t) \text{ at the beginning of a cycle } + I_M(t) \text{ at the end of a cycle }]}{2\propto}.$$

$$= \frac{[(R-E[X]+Q)+(R-E[X]]}{2\propto}$$

Substituting the equation of (r-$E[X]$+Q) is allowed because the initial inventory level is at or below r so we have ordered Q units demonstrating that the initial inventory is at $r + Q$, but we also must account for the demand so we subtract $E[X]$. We account for this value because L is greater than 0, so we have a positive demand value arriving between the time we place an order and the time we actually receive the order. The final inventory does not have a replenishment order so it is just $r - E[X]$.

Simplifying this equation yields the following calculation

$$E[I_A(t)] \quad = \frac{[(R - E[X] + Q/2)]}{\propto}$$

Finally the holding cost can be calculated by multiplying H*$E[I_A(t)]$.

$$\text{Expected holding cost} = H * \frac{[(R - E[X] + q/2)]}{\propto}.$$

The expected shortage cost is calculated in the same manner as before as the inventory level does not affect the cost.

$$\text{Expected shortage cost} = c_B E[B_r] * \frac{E[D]}{q}.$$

The expected order cost is again calculated in the same manner as before as the inventory level does not affect the cost.

$$\text{Expected order cost} = K(E[D]/Q).$$

Combining all the costs, we can get the total cost.

$$TC(Q,R) = H * \frac{[(R - E[X] + Q/2)]}{\propto} + c_B E[B_r] * \frac{E[D]}{Q} + K(E[D]/Q).$$

This cost must be minimized to find the optimal Q and r values. To do this, we must take the derivative with respect to and the derivative with respect to r such that

$$\frac{dTC(Q,R)}{dQ} = \frac{dTC(Q,R)}{dR} = 0$$

The derivative with respect to Q is difficult to calculate because the $E[B_r]$ is challenging to determine. Winston (2004) states that in most cases this value is so small that

$$Q^* \approx \sqrt{\frac{2 \propto K E[D]}{H}}.$$

Determining the optimal value of *R* is done in a similar manner as before. Marginal analysis was again used to determine the reorder point. If we assume a given value of *Q*, the expected annual ordering cost is independent of *R*; therefore, by determining a value of *R* that minimizes the total cost, we can concentrate on minimizing the sum of the expected annual holding and shortage costs with the reliability data included. Suppose we increase the reorder point from *r* to *r* + Δ, the expected annual holding cost increased by

$$H/\propto * \left(R + \Delta - E[X] + \frac{Q}{2}\right) - H/\propto *(R - E[X] + \frac{Q}{2}) = H\Delta/\propto.$$

If we increased the reorder point by a small amount, the expected annual stockout costs reduced. Since the lead time demand was at least *R* during any cycle, the number of stockouts during the cycle reduced by Δ units. Increasing the reoproder point results in the reduction of stockout costs by c_B during a fraction P(X >= *R*) of all cycles. Again assuming an average of E[D]/Q cycles per year, increasing the reorder point from *R* to *R* + Δ again reduced the expected annual stockout cost by

$$\frac{\Delta E[D] c_B P(X \geq R)}{q}.$$

The optimal *r* was the value of *r* when marginal benefit equals marginal cost

$$\frac{\Delta E[D] c_B P(X \geq R)}{q} = H\Delta/\propto.$$

Therefore,

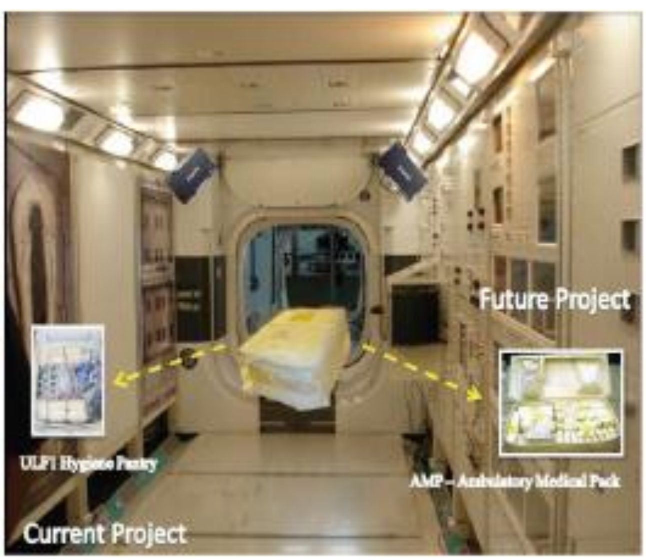
$$\text{P(X >= } R) = \frac{HQ}{\propto E[D] c_B}.$$

4.3 Empirical Model

4.3.1 Problem Definition

Although launches are critical for astronauts' survival, the cost of a space launch is difficult to ignore. The cost of a space flight is estimated to be $450 million. The high cost of launches demonstrates that the de-manning of an outpost due to food shortages would be detrimental to NASA's budget. Astronauts onboard the ISS currently utilize manual auditing and barcode scanning to track perishable inventory (consumables), this presents a challenge because periodic inventory audits are very labor intensive, time consuming, and may provide inaccurate measures. Currently, researchers are investigating "automated inventories" which allow for inventory audits to occur remotely and without the need of human intervention. Figure 5 represents how a CTB would be read with RFID.

Figure 5: RFID used at NASA



This study was aligned with NASA procedural requirements which states ‘Stock replenishment shall be in accordance with FPMR requirements and shall use EOQ principles”. Moreover the requirements provides the parameters for the EOQ model by stating “a review point for each stocked item shall be established, using a formula that provides at least 90-percent assurance that an out-of-stock condition shall not occur”. These guidelines support NASA’s use of the EOQ policies but unfortunately, errors still occur. Currently, NASA utilizes manual counting and barcode technologies to track items such as crew clothing, office supplies, and hygienic supplies at the bag level but not at the item level.

Our research team investigated the use of RFID technologies to eliminate the manual tasks associated with the aforementioned techniques. An RFID system will allow for “crew free” automated inventories that require astronauts minimal time and labor and will reduce excessive inventory weight for the space payloads. According to NASA public documents, menu planning for shuttle flights begins 8 to 9 months before the launch date of the cargo shuttles. Varieties of American and Russian foods go through a series of investigations before packaging and installation for space missions. These investigations include sampling, evaluating, and subjective ranking according to preference by the astronauts. Through these investigations, necessary improvements can be made. At the conclusion of this phase, NASA personnel do not have an effective system that measures quantity of assets packaged for usage. The research led to the elimination of the daily logging of inventory while maintaining high inventory accuracy.

4.3.2 Assumptions

According to NASA public documents, the ISS normally has a crew size of three, which annually consumes food at normal distribution with mean 15,972 pounds and standard deviation 5 pounds. The cost of placing each order is $450,000,000 (the cost of launching a shuttle) and the annual unit holding cost can be estimated as $5550 per pound (35% of the purchasing cost which is $15,000). The per unit stockout cost is $450,000,000 because the cost of a shortage is demanning the flight and equal to a loss of the cost of launch. The reliability of the RFID tag ranges from 0 to 100%.

Summary of Assumptions is given below:

Holding Cost	$5250 per pound per year
Ordering Cost	$450,000,000
Shortage Cost	$450,000,000 per pound
Purchasing Cost	$15,000 per pound
Expected Annual Demand	15972 pounds
Standard Deviation of Demand	5 pounds
Lead Time	0.5 year
Expected Lead Time Demand	7986 pounds
Standard Deviation of Lead Time Demand	3.54 pounds

4.4 Comparison

To validate the model a comparison between the current EOQ model, the model with shortages with RFID, and the model with shortages with RFID and reliability considered. A comparison of the total annual cost was conducted for each model. Also, a comparison of the actual and measured inventories and their effects on reorder points was completed.

CHAPTER 5 RESULTS

5.1 Empirical Model Results

To see which policy resulted in the smallest total cost, the three policies were compared. By doing this, we are able to determine that by introducing RFID and allowing for continuous review policies, the total cost of the policy was reduced.

Table 8: Model Comparisons

Model	**Q**	**R**	**TC**
EOQ	52326 pounds	N/A	$514,293,851
(Q, R) with RFID	52326 pounds	8000 pounds	$274,787,294
(Q, R) with RFID and 100 % Reliability	52326 pounds	8000 pounds	$274,787,294

As can be seen by Table 8, the use of RFID significantly decreases the annual total cost. The cost is of the policy with continuous review is almost half the total cost using EOQ policies. Although all three policies require the same optimal quantity, the EOQ model would lead to more frequent launches as the inventory is not monitored continuously. The holding cost would increase because the amount of food would increase significantly requiring more room for storage. The total cost was calculated in the following manner:

EOQ:

$$TC = 15000 * 15972 + \frac{5250 * 15972}{2} + \frac{450000000 * 15972}{52326}$$

Continuous review:

$$TC(Q,R) = 5250*(8000 - 7926 + 52326/2) + 450{,}000{,}000(15972/52326).$$

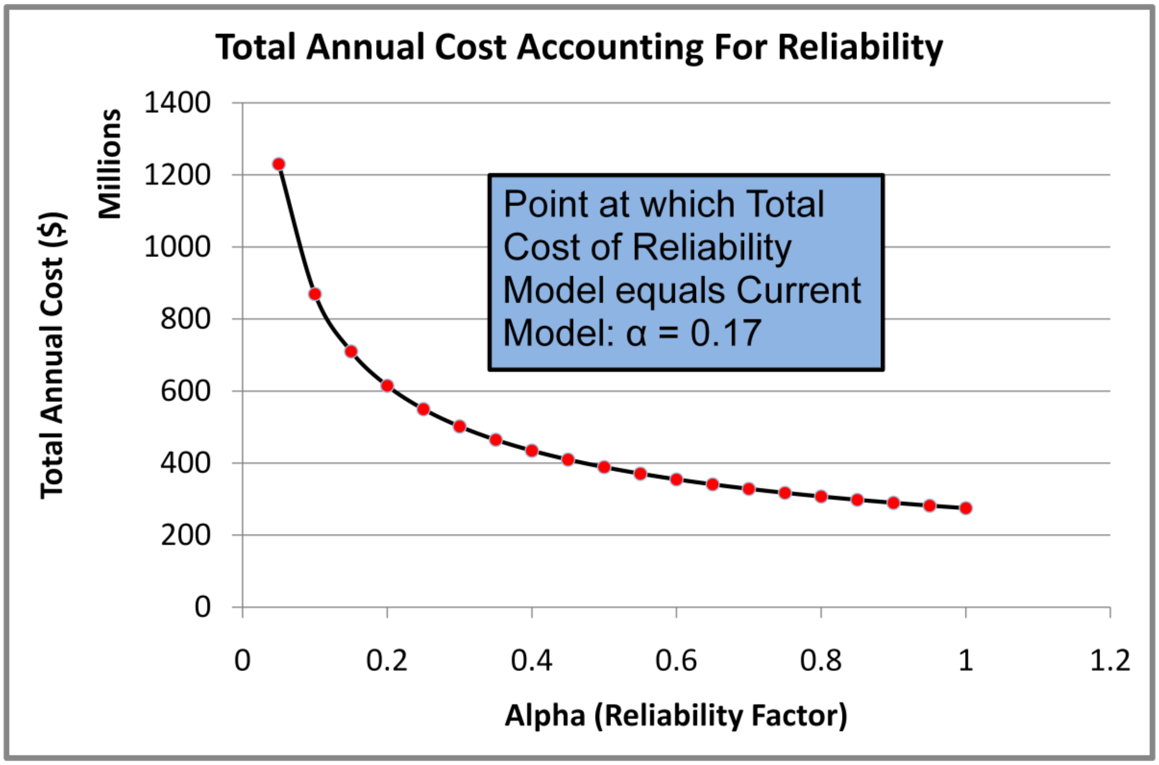
Continuous review with reliability:

$$TC(Q,R) = 5250*\frac{[(8000\ -7926+52326\,/2)]}{1} + 450{,}000{,}000(15972/52326).$$

The annual cost of the (Q, R) policy with RFID and no reliability and the (Q, R) policy with RFID and reliability are the same because the original policy assumes 100% reliability.

When accounting for reliability, the reliability of the RFID tag has a profound effect on the total cost. As the RFID tag becomes more reliable, the total annual cost decreases, demonstrating that more accurate information leads to cost reduction. The point at with the developed model equals the EOQ model is at a reliability of 17%, which as stated before would never occur because prior research shows that most reliability factors are 64% to 100%. Figure 6 demonstrates the effect that as the reliability of the RFID system increases the total annual cost decreases.

Figure 6: Total Annual Cost in Function of Reliability



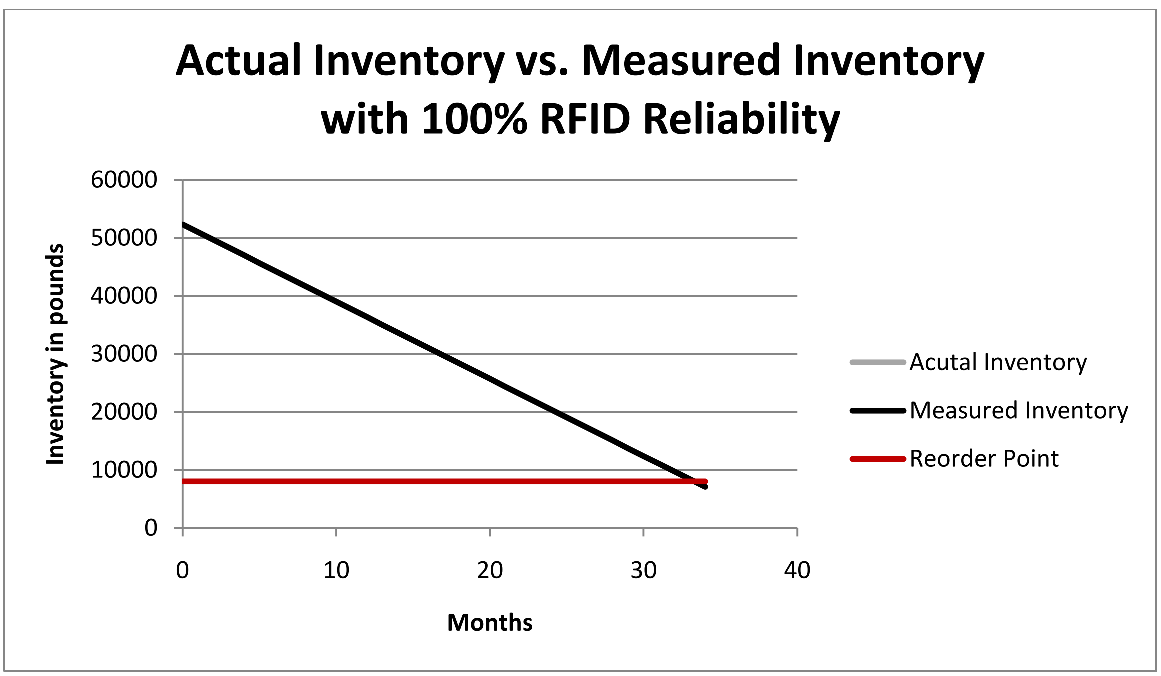
Next a comparison between the (Q, R) policies with and without reliability was conducted. As can be seen in Table 9, if NASA were to assume 100% reliability when that was not the case, they would only plan for about $275 million whereas the actual cost would be much higher because no RFID tags can assume 100% reliability. Table 9 shows that as the reliability of RFID decreases, the unaccounted costs for NASA increases. NASA plans for the amount of money that will be spent on launches per year. Without taking into account the reliability, NASA would plan to spend less money that they would spend in reality. Unaccounted costs represent the amount of costs that NASA would spend over their budgeted amount. Table 9 only displays values from 0.6 to 1 for the reliability factor because research shows that reliability would most likely not be less than 0.6.

Table 9: Unaccounted Costs

Alpha	Actual Cost	Planned Cost	Unaccounted Costs
0.6	$354,774,515.09	$274,787,267.64	$79,987,247.45
0.65	$340,852,065.39	$274,787,267.64	$66,064,797.75
0.7	$328,449,597.42	$274,787,267.64	$53,662,329.78
0.75	$317,309,266.64	$274,787,267.64	$42,521,999.01
0.8	$307,230,571.56	$274,787,267.64	$32,443,303.93
0.85	$298,054,954.01	$274,787,267.64	$23,267,686.37
0.9	$289,655,138.82	$274,787,267.64	$14,867,871.19
0.95	$281,927,623.67	$274,787,267.64	$7,140,356.04
1	$274,787,267.64	$274,787,267.64	$0.00

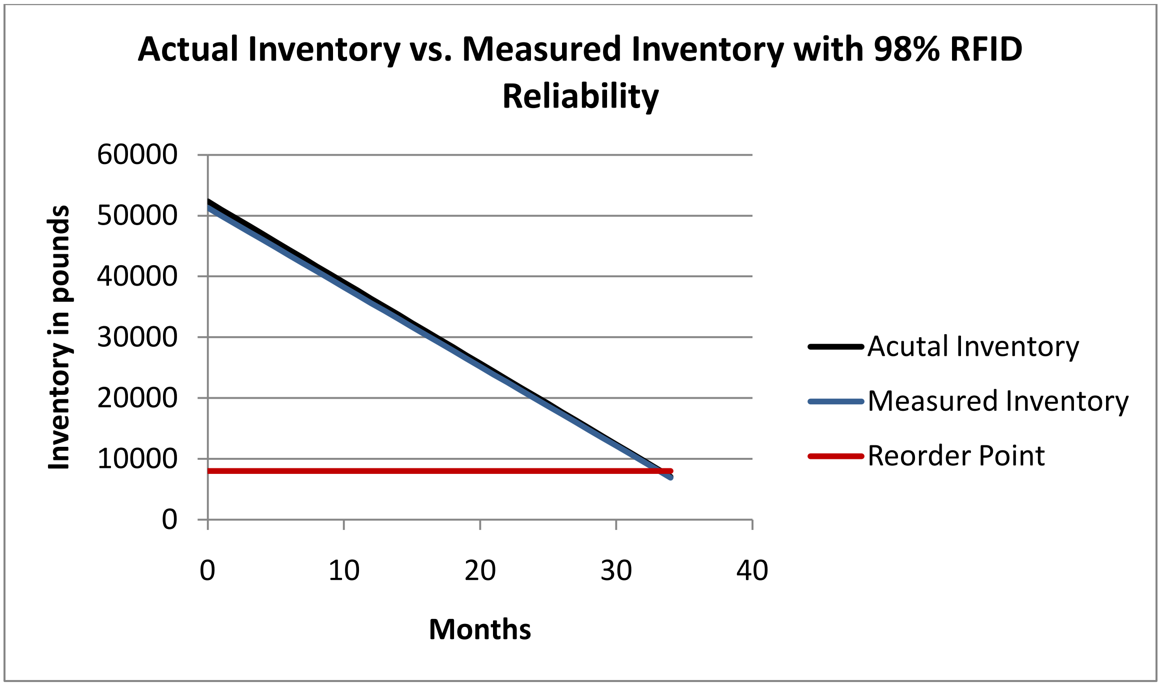
Finally, the actual inventory as opposed to the measured inventory was compared to determine how the reorder points were affected by inaccurate information. Figure 7 shows the effect 100% reliability information has on the reorder point.

Figure 7: 100% Reliability



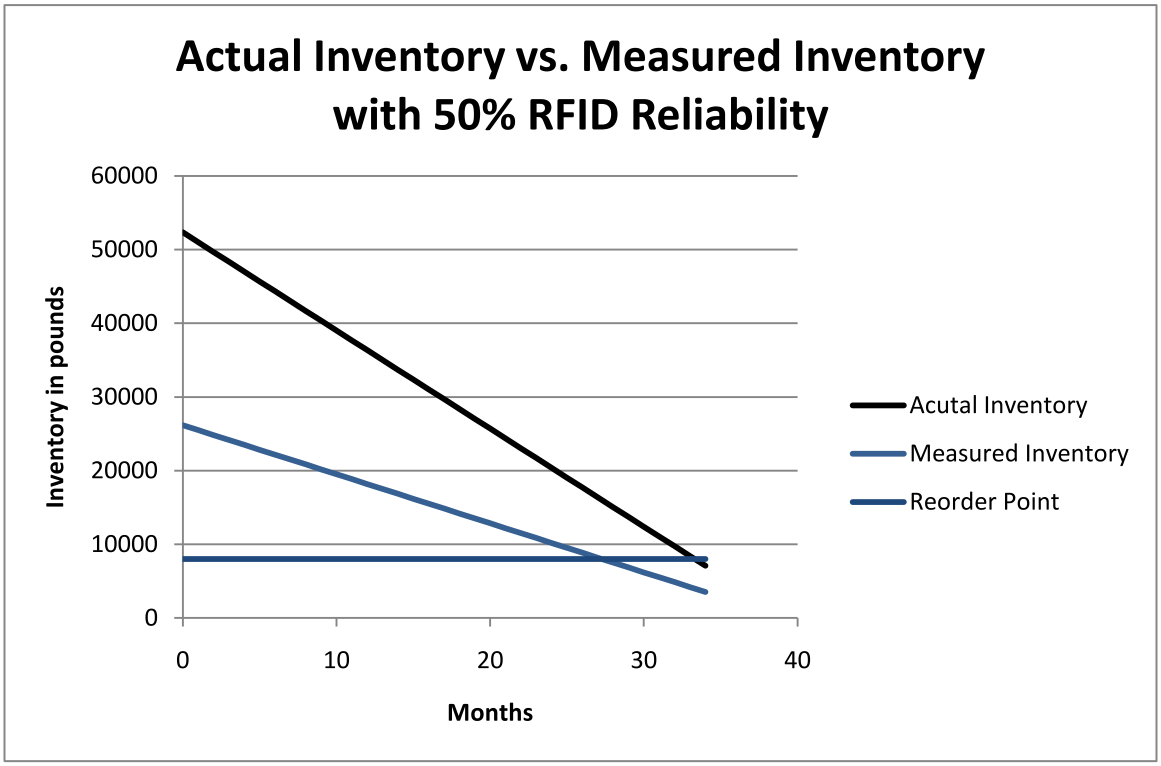
As can be seen from Figure 8, the actual and measured inventory levels are equal, so the reorder points are the same.

Figure 8: 98% Reliability



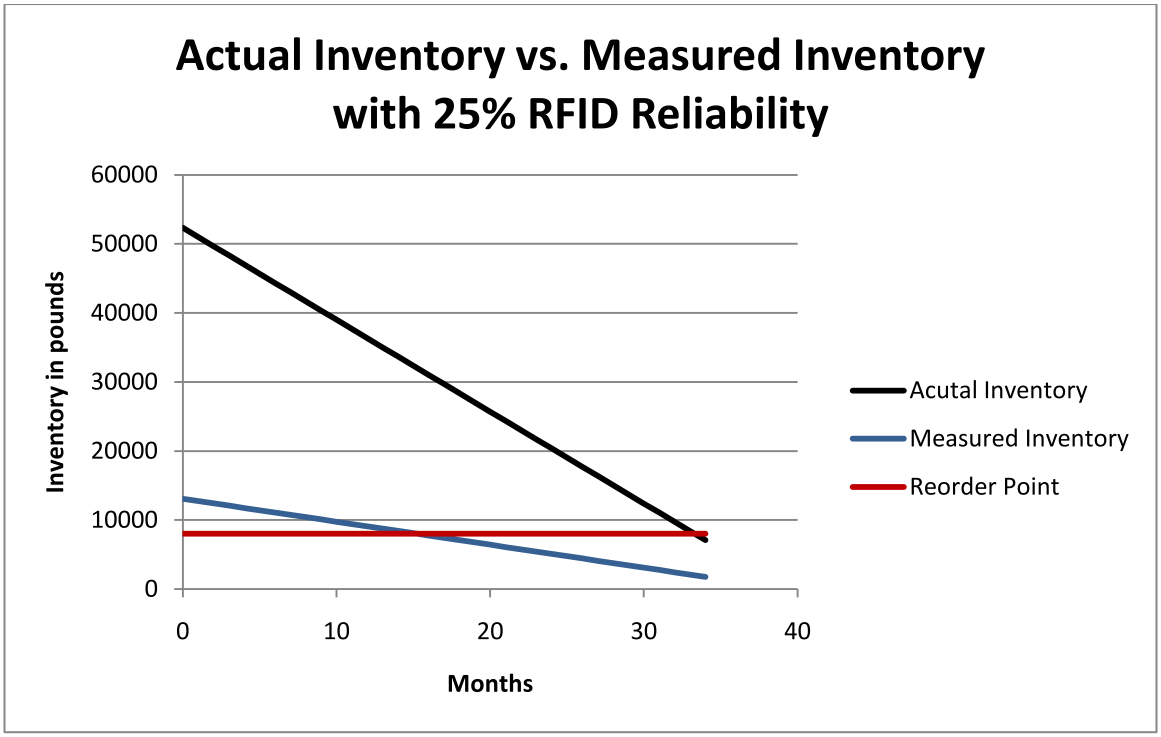
The decrease in reliability does not show that much effect on the policy, but results in reordering a month before it is necessary. Although the total holding cost would not increase by that much, it is still an increase in total annual cost.

Figure 9: 50% Reliability



Use of RFID when the reliability is not accounted for results in the reorder of a quantity six months before it is necessary as seen in Figure 9. Excess inventory would lead to high holding costs. The total annual cost thus increases with the excess inventory yielding a non-optimal policy.

Figure 10: 25% Reliability



Use of RFID when the reliability is not accounted for results in the reorder of a quantity 15 months before it is necessary as seen in Figure 10. The excess inventory would increase holding costs significantly. The total annual cost thus increases with the excess inventory yielding a high cost policy that is not optimal.

As can be seen from the data, the total cost increases when reliability is not accounted for because quantities are reordered before they are needed. This demonstrates that by accounting for the reliability with the new model, a more accurate and more cost-effective policy exists.

CHAPTER 6 CONCLUSIONS

6.1 Conclusions

AITs have shown their value to the supply chain by increasing visibility. RFID, one such AIT, boasts real-time location and status of items, which its counterpart cannot compare to. By adding RFID, more accurate inventory policy can be created, but RFID does not come without its disadvantages. Its lack of 100 percent reliability leads to inaccurate measures of inventory levels. By creating an inventory model that accounts for that inaccuracy, costs can be reduced and the actual cost that NASA would be spending would be realized. As shown in the results, NASA may budget a certain amount for the inventory, but due to inaccurate systems, the measured inventory may lead to over ordering of inventory. NASA would save money in that they would spend less money sending food to the astronauts due to the more accurate system.

This thesis developed a new model based on previous (Q, R) policies that would account for the unreliability of RFID, which meant the objectives set forth. The second objective was met as a comparison was conducted to demonstrate that the new model allowed for a more accurate method of inventory management. This model can be used by future organizations to determine optimal order quantities and optimal reorder points. By using this model, total costs can be reduced and more accurate inventory levels can be achieved.

6.2 Contribution to the Body of Knowledge

Organizations are often faced with the challenge of implementing an inventory management system that accurately and efficiently manages their inventory. Without proper knowledge of inventory control techniques and deployment of automated technologies, these management systems would not give organizations the benefit of reducing their costs and accurately monitoring their inventory. There is a demonstrated need for high-cost organizations such as NASA where inaccurate inventory management can lead to dire consequences to develop an inventory policy that accounts for the reliability of RFID.

A gap existed in the literature when accounting for the reliability of RFID in inventory control policies. Although many proponents of RFID gloss over the reliability of RFID, the fact is that RFID is not 100% reliable; this is not to say that using RFID causes large scale inaccuracies, but like all systems, there is room for error. The proposed model presented in this thesis addressed the gap by presenting a model that considered the reliability of RFID and optimized order quantity and reorder point based on likely inventory values. The model addressed the uncertainty of RFID read rates faced by organizations that implement RFID within their inventory management systems. This thesis compared the proposed model to current practices to demonstrate a reduction in cost with more accurate inventory levels. The model developed can be used by several types of organizations in various industries.

6.3 Limitations

The most critical limitation is that the model needs further validation. Although the model was validated using current NASA data, further validation may be necessary using other data, such as hospital inventory. The model does not account for changes in the time of the reliability, which would occur in response to battery life. The expected shortage cost was estimated and may need further research to have a more accurate model. Also, as with any model that utilizes distributions, the model assumes the expected value of reliability; this means that reads may be above that reliability factor or below that reliability factor.

6.4 Future Work

There is a possibility of extension of the model by distinguishing between the use of active and passive technology. Active and passive technologies have different reliability rates. Future models could assess the distribution of the reliability factor. Also, the introduction of active technology adds another element of battery life, suggesting that as time passes by the number of failures of these tags increase. This type of situation would be better modeled with a Weibull distribution as this type of distribution takes into account the effect of time on reliability. Although accuracy of the model would most likely increase when using the Weibull, developing a new model would prove more challenging. Finally, research could be conducted to determine a model that addressed the situation where more inventory is found that actually exists (i.e. when RFID reads more tags than there actually are).

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