NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

POTENTIAL UTILIZATION OF PASSIVE RFID TO IMPROVE ASSET ACCOUNTABILITY IN THE MARINE CORPS

by

Jeffrey J. Medeiros and Joseph A. Zukowski

June 2021

Thesis Advisor: Glenn R. Cook
Second Reader: Thomas J. Housel

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REPORT DOCUMENTATION PAGE				*Form Approved OMB No. 0704-0188*
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC, 20503.				
1. AGENCY USE ONLY ***(Leave blank)***	**2. REPORT DATE** June 2021	**3. REPORT TYPE AND DATES COVERED** Master's thesis		
4. TITLE AND SUBTITLE POTENTIAL UTILIZATION OF PASSIVE RFID TO IMPROVE ASSET ACCOUNTABILITY IN THE MARINE CORPS				**5. FUNDING NUMBERS**
6. AUTHOR(S) Jeffrey J. Medeiros and Joseph A. Zukowski				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000				**8. PERFORMING ORGANIZATION REPORT NUMBER**
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A				**10. SPONSORING / MONITORING AGENCY REPORT NUMBER**
11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.				
12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.				**12b. DISTRIBUTION CODE** A

13. ABSTRACT (maximum 200 words)

The Marine Corps Consolidated Memorandum Receipt (CMR) is the method that is used to keep accountability of assets that are owned by the Marine Corps. Over a fiscal year (October–September), Responsible Officers focus their efforts on manual asset accountability at a minimum of once every quarter. This method of by-hand accountability is labor- and time-intensive. This additional time and labor saps valuable time that could be spent on training and refining critical warfighting skills. This thesis models the current CMR process model (As-Is) and a Radio Frequency Identification (RFID) enhanced process model (To-Be) utilizing Savvion business process modeling software. The output of this modeling is used to feed a Monte Carlo simulation, which is then analyzed in terms of time and cost. The researchers demonstrate that there are potential benefits to be gained if the Marine Corps adopted an RFID-enhanced process model. The RFID-enhanced process model has the potential to be fifteen times more efficient than the As-Is process model in terms of time. These efficiencies lead to a labor-hour cost savings of approximately $31,000 per instance of implementation when considering a communications company CMR of 770 items. The researchers recommend that physical trials be conducted to confirm the effectiveness of the use of RFID technology in the CMR accountability process.

14. SUBJECT TERMS Consolidated Memorandum Receipt, CMR, warehousing, RFID, radio frequency identification, passive radio frequency identification, passive RFID, United States Marine Corps, USMC, Savvion Software, As-Is, To-Be			**15. NUMBER OF PAGES** 73
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	**18. SECURITY CLASSIFICATION OF THIS PAGE** Unclassified	**19. SECURITY CLASSIFICATION OF ABSTRACT** Unclassified	**20. LIMITATION OF ABSTRACT** UU

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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POTENTIAL UTILIZATION OF PASSIVE RFID TO IMPROVE ASSET ACCOUNTABILITY IN THE MARINE CORPS

Jeffrey J. Medeiros
Major, United States Marine Corps
BSB, University of Colorado at Boulder, 2008

Joseph A. Zukowski
Major, United States Marine Corps
BA, Marist College, 2007

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN INFORMATION TECHNOLOGY MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL
June 2021

Approved by: Glenn R. Cook
Advisor

Thomas J. Housel
Second Reader

Alex Bordetsky
Chair, Department of Information Sciences

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The Marine Corps Consolidated Memorandum Receipt (CMR) is the method that is used to keep accountability of assets that are owned by the Marine Corps. Over a fiscal year (October–September), Responsible Officers focus their efforts on manual asset accountability at a minimum of once every quarter. This method of by-hand accountability is labor- and time-intensive. This additional time and labor saps valuable time that could be spent on training and refining critical warfighting skills. This thesis models the current CMR process model (As-Is) and a Radio Frequency Identification (RFID) enhanced process model (To-Be) utilizing Savvion business process modeling software. The output of this modeling is used to feed a Monte Carlo simulation, which is then analyzed in terms of time and cost. The researchers demonstrate that there are potential benefits to be gained if the Marine Corps adopted an RFID-enhanced process model. The RFID-enhanced process model has the potential to be fifteen times more efficient than the As-Is process model in terms of time. These efficiencies lead to a labor-hour cost savings of approximately $31,000 per instance of implementation when considering a communications company CMR of 770 items. The researchers recommend that physical trials be conducted to confirm the effectiveness of the use of RFID technology in the CMR accountability process.

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	automated information systems
AIT	automatic identification technology
AO	accountable officer
BIC	Blount island command
CMR	consolidated memorandum receipt
GSCC-MC	global combat support system Marine Corps
HMMWV	high mobility multipurpose wheeled vehicle
MSC	military sealift command
RFID	radio frequency identification
RI	responsible individual
RO	responsible officer
SL-3	stock list 3
SN	serial number
USMC	United States Marine Corps
USNS	United States Naval Service

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ACKNOWLEDGMENTS

First and foremost, we would like to thank Glenn R. Cook for all the help and assistance he has provided with our thesis. Without his guidance, we would be like poorly placed RFID tags unable to be scanned.

We would also like to thank Lynnsey Medeiros and Lauren Seuch for all the time they gave us to complete our requirements while we were here at Naval Postgraduate School.

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I. INTRODUCTION

The Marine Corps asset accountability process requires many person-hours to produce its outputs. Due to the human factors associated with manual accounting, it can have some inaccuracies in tracking and accountability of end items and stock list 3 (SL-3) accessories. Manual misreading of serial numbers, miscounted items, and a general lack of understanding of the item can create confusion for those involved in the accountability process. Long-range passive Radio Frequency Identification (RFID) technology could be implemented force-wide to improve the asset tracking and accountability process, reducing the person-hours spent accounting for, and locating, assets. Additionally, this technology would provide real-time visibility for asset accountability that would provide accurate and timely material readiness information to higher commands.

The focus of this research will be on determining the feasibility of utilizing RFID technology to create an efficient and accurate method of maintaining accountability of the Consolidated Memorandum Receipt (CMR) assets. This is an essential area of study because Marine Corps units spend a significant amount of time accounting for and locating CMR assets. This is time spent for asset accountability that could be spent on training and refining valuable warfighting skills. The potential efficiency and accuracy created by using RFID technology could lead to labor cost savings by reducing accountability inaccuracies and increasing accountability efficiency.

A. PROBLEM STATEMENT

The Marine Corps Consolidated Memorandum Receipt is the method that is used to keep accountability of assets that are owned by the Marine Corps. Over a fiscal year (October-September), responsible officers focus efforts on manual asset accountability at a minimum frequency of once every quarter. The current method of manual accountability is inefficient in terms of the manual labor intensive effort and the challenges of ensuring asset inventory accuracy. An automated asset accountability process, that uses RFID technology, should prove superior to this dated legacy manual labor intensive process. Until now, there are no studies available to determine the basic efficiency and accuracy of the existing process. Knowledge gained from such a study could be useful in increasing the efficiency and accuracy of the process. The introduction and use of passive RFID technology for the accountability of CMR records could provide significant gains in efficiency and accuracy across fleet communications companies.

B. PURPOSE STATEMENT

The purpose of this thesis will be to examine the feasibility of applying passive RFID technology to aid in the accountability of CMR records that would reduce the labor intensive, error prone costs of the manual legacy process. This study will determine whether passive RFID implementation will provide adequate benefit to offset the implementation costs of such a system in the CMR records accountability process. It will analyze the cost of system installation, potential cost reduction of the CMR accountability process, level of accuracy, and elapsed time differences in the CMR reconciliation process. The researchers will determine if the passive RFID technology benefits in the asset accountability process outweigh implementation and basic system costs.

C. SCOPE

The modeling of the difference between the current legacy process and its potential improvement with passive RFID technology will be based on the use of the Savvion modeling tool for the current manual accountability CMR (As-Is) process as well as for modeling of the potential passive RFID enhanced CMR (To-Be) process. These processes will be outlined in detail in chapters two and three of this thesis. This comparison will be made with only the passive RFID technology as the primary system enhancement. The researchers have chosen this passive RFID modeling scope based on its lower cost and easier implementation considerations when compared to semi-passive and active RFID infrastructures. Both the As-Is and To-Be models will use a communication company CMR example to conduct a comparative analysis. A communications company CMR was chosen because the CMR contains many items that will help demonstrate if there is a statistically significant difference between the As-Is and To-Be processes in terms of cost and elapsed time.

D. THESIS ORGANIZATION

This thesis is divided into five chapters. Chapter I outlines the need for this research and the potential impact it may have. Chapter II provides a literature review of the current state of RFID technology, demonstrates its capabilities and limitations within the context of warehousing, outlines the current Marine Corps accountability procedures, and reviews a relevant Marine Corps case study on RFID implementation. Chapter III provides a detailed description of the methodology used in this thesis. It specifically covers the Savvion modeling software and the model's parameters to simulate asset accountability under the current legacy process and the potential of changing the process for asset accountability that utilizes passive RFID technology. Chapter IV provides a detailed analysis of the results and an analysis of the cost structure of the As-Is and To-Be models. Finally, Chapter V provides a conclusion and includes a summary of the thesis and recommendations for further research.

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II. LITERATURE REVIEW

To remain effective at its diverse mission, the Marine Corps could move from physical accountability to technologically driven inventory control to create potential efficiencies and potentially recoup person-hours to focus on its warfighting capabilities. The current equipment retrieval method sends an individual to look for the piece of equipment in a warehouse with little reference other than the equipment's last recorded location. The increase in RFID technology's proliferation and capabilities may enhance the Corps' ability to track and identify equipment locations in the back end and rapidly provide support to the front-end user (Yan et al., 2008). The potential to know an item's location before sending an individual to retrieve it because it had a recent ping could save person-hours, reduce the logistic burden of units, and enable rapid deployment of the specific assets.

A. RADIO FREQUENCY IDENTIFICATION OVERVIEW

1. Radio Frequency Identification

Radio Frequency Identification (RFID) is a wireless technology that automates the identification of objects remotely (Bolic et al., 2010; Dobkin, 2007). This wireless technology operates across a wide band of frequencies in the electromagnetic spectrum. There are two major components to an RFID system, the RFID tags, and the RFID interrogators. RFID tags, also known as RFID transponders, are attached to an object and act as the object's unique identifier. RFID interrogators, or readers, are devices that remotely communicate with the RFID tags to perform object identification. There are two types of RFID in use today. Active RFID uses battery-powered active tags to communicate with RFID interrogators (Bolic et al., 2010; Dobkin, 2007). Passive RFID uses interrogators, which provide the power to communicate with passive RFID tags through backscattered signals (Bolic et al., 2010; Dobkin, 2007).

2. Spectrum

RFID systems can operate at many different frequencies depending on the system type and application. The most common frequency bands associated with RFID are 125/134 kHz, 13.56 MHz, 860–960 MHz, and 2.4–2.45 GHz (Bolic et al., 2010; Dobkin, 2007). Figure 1 provides a visual representation of where each of these frequencies is located across the electromagnetic spectrum.

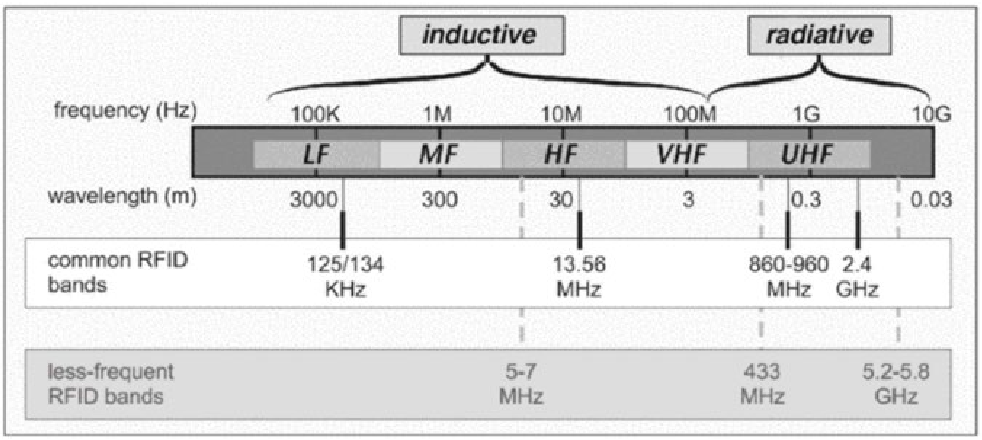

Figure 1. RFID Electromagnetic Spectrum use. Source: Dobkin (2007).

RFID systems operating in the low-frequency band (125/134 kHz) have a much higher wave lengthen than those operating in the high frequency and ultra-high frequency bands. Therefore, low-frequency RFID is typically used in systems that require short-range and limited data transmission (Bolic et al., 2010; Dobkin, 2007). Livestock tracking and access control systems make use of low-frequency RFID (Dobkin, 2007). Similarly, high-frequency tags have a short-read range; however, they have a much high data transmission rate because bandwidth increases (Bolic et al., 2010; Dobkin, 2007). These tags are typically used in passports, near-field communication devices, and encrypted access control (Dobkin, 2007). Ultra-high frequency RFID benefits from its long-range, high data rates and low cost (Bolic et al., 2010; Dobkin, 2007). These tags are widely used in roadway tolling, railroad management, shipping management, and warehousing (Dobkin, 2007).

3. Tags

Tag Operation

There are three types of RFID tags in use today: Passive, Semi-passive, and Active RFID tags. RFID tags communicate to the interrogator either through backscattered signals or transmitted signals depending on the type of tag (Bolic et al., 2010; Dobkin, 2007). Passive RFID tags have no local power source and use backscatter to communicate with the interrogator (Dobkin, 2007). They derive their power from the radio waves they receive from an interrogator to power their internal circuitry and radio (Dobkin, 2007). Once powered, these tags send their information to the interrogator. Semi-passive RFID tags have local battery support to power their onboard circuitry (Dobkin, 2007). Still, they use received radio frequencies to power their embedded radio, communicating to the interrogator using a backscattered signal (Dobkin, 2007). Active RFID tags have a local power source that powers their circuitry and radio to communicate with the interrogators (Dobkin, 2007). In this way, active RFID tags function as a traditional communications system. See Figure 2 for a visual representation of how each type of tag communicates.

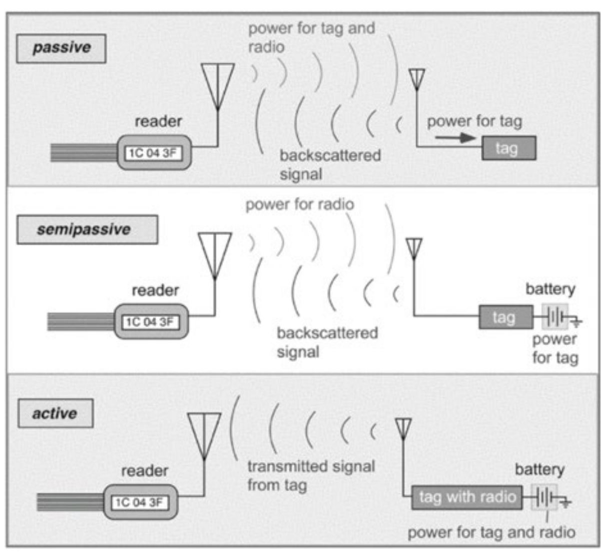

Figure 2. RFID Tag Configuration. Source: Dobkin (2007).

Tag characteristics

Passive RFID tags are the simplest and lowest cost tags available with no battery, complicated circuitry, or radio equipment built into the tag, as seen in Figure 3 (Dobkin, 2007). These tags are easy to manufacture, have a minimal form factor, and require no maintenance throughout their life cycle (Dobkin, 2007). Passive tags have limitations because of these characteristics. Passive tags have a limited range of approximately 3 m because of the need for the interrogator to provide power through radio frequency (Dobkin, 2007). These RFID tags can be as small as 10 cm in length and 1 mm thick (Dobkin, 2007). Additionally, these tags typically lack the computational power to handle encryption and other computationally taxing information protocols (Dobkin, 2007). These tags are well suited for warehouse operations where inventory remains static and environmental factors are relatively well controlled.

Semi-passive RFID tags are the mid-cost and maintenance variant (Dobkin, 2007). These tags are much larger, around 9.5 cm wide and 1.5 cm thick, than passive RFID tags due to the inclusion of a battery to power the tag's circuitry, as depicted in Figure 4 (Dobkin, 2007). The addition of a battery also adds a maintenance and additional cost component to each tag. With the battery also comes additional computational capability that allows for a read range up to 100 meters and a much higher successful ID acquisition under challenging circumstances (Dobkin, 2007). These tags are well suited for automobile tolls, where accuracy under challenging conditions is required.

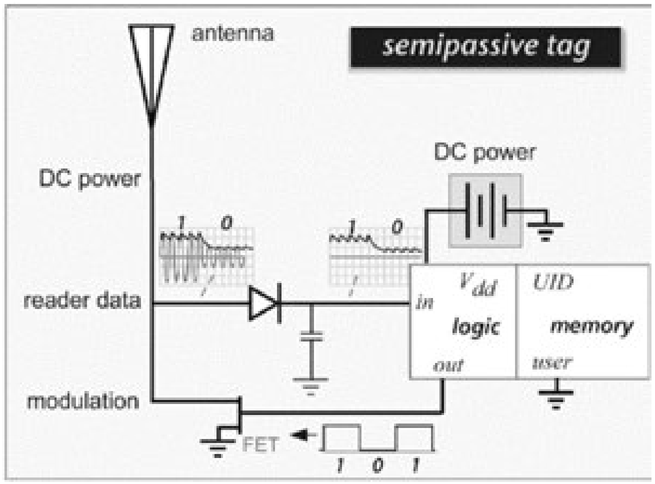

Figure 3. Semi-Passive RFID Tag. Source: Dobkin (2007).

Active RFID tags are radios and incur a significant increase in size, cost, and maintenance compared to passive and semi-passive RFID tags, see Figure 5 (Dobkin, 2007). Typical size for an active RFID tag is 10 cm long, 6 cm wide, and 2 cm thick (Dobkin, 2007). The increased size facilitates the inclusion of a radio, battery pack, additional circuitry that increases the cost of the tags to approximately 50 dollars per tag (Dobkin, 2007). As a radio, they are subject to all the regulatory standards in the location they may operate (Bolic et al., 2010). These tags have a very long read range of about 900 meters, which has positive and negative characteristics (Dobkin, 2007). Often multiple tags are used on a single piece of equipment to triangulate its location (Dobkin, 2007). These tags are well suited for commercial shipping, where large containers may be stacked together over a large outdoor space.

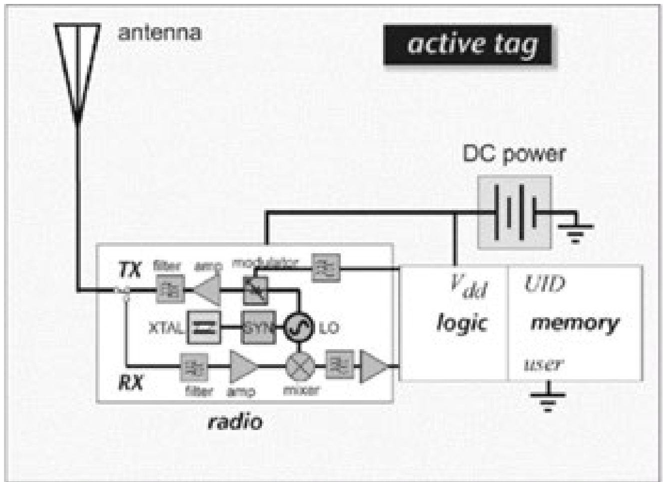

Figure 4. Active RFID Tag. Source: Dobkin (2007).

Tag Challenges

Tag orientation plays a significant role in the reader's ability to identify a tag (Bolic et al., 2010) positively. The read range of a tag decreases significantly when the tag antenna is oriented away from the reader, which prevents the tag from collecting enough energy to transmit (Bolic et al., 2010). This creates a problem where poorly oriented tags or items that have been returned to their storage location with a tag facing in a less than ideal direction may go unread. One thing that can be done to overcome this challenge is to use tags with a high level of orientation insensitivity due to their antenna design (Bolic et al., 2010).

Similarly, the environment that the tags and readers are deployed in determines positive read rates. Signals-based technology is susceptible to multipath interference issues, signal fade, and absorption (Bolic et al., 2010). Positive read rates can decrease due to blind spots in environments with many competing signals through multipath interference (Bolic et al., 2010). Signal absorption can occur when tags are on objects that contain fluids or are highly metallic (Bolic et al., 2010). These factors typically result in a reduction of read range and not an overall loss of readability (Bolic et al., 2010).

Tag collisions can also create issues in positive read rates. Tag collisions are when two or more tags attempt to select the same communication slot to communicate with the reader (Bolic et al., 2010). Tag collisions can significantly increase the time it takes for an

RFID reader to query a population of tags and receive positive responses (Bolic et al., 2010). A simple method of overcoming these collisions is to know the number of tags in the queried population (Bolic et al., 2010). This will allow the technician to assess the accuracy of the reader query and conduct rereads as required.

4. Interrogator

An RFID interrogator, also known as a reader, can take many forms. The critical element of an RFID interrogator are its radio and the antenna or antennas to communicate with the RFID tags (Dobkin, 2007). These interrogators send radio waves to communicate with the RFID tags. The type of radio waves and means of their deployment depend on the type of tag used. Passive RFID readers send radio frequency signals to power passive tags and interpret the backscatter signals that the tag generates when powered on (Dobkin, 2007). The radio that an interrogator uses will determine which types of tags that the reader is compatible with. These interrogators serve as links between the RFID tags and the middleware that facilitate business process integration in an organization (Dobkin, 2007).

5. Network Interface

Integration into existing warehousing solutions is critical to reaping the benefits of the use of RFID. RFID middleware is the software and hardware solution that integrates the RFID system with the current warehousing software solution an organization has (Bolic et al., 2010). RFID middleware allows for reader management, RFID data management, and application integration. It can solve other interface problems between the RFID system and the organization's business process and information technology solution. Middleware is a critical piece of the puzzle when integrating RFID to enhance any business process.

B. RFID FOR WAREHOUSING

Our research pertains to RFID use for material accountability in inventory management and control, which is widely discussed in the available literature. Heese (2007), Tao et al. (2017), and Hardgrave et al. (2013) discussed in detail the benefits of RFID when conducting a retail inventory to reduce inventory inaccuracy, misplacement, and shrinkage. Each demonstrates that there are inherent inaccuracies in retail inventory management both locally in warehousing and storage and through the supply chain (Heese 2007, Tao et al. 2017, Hardgrave et al. 2013). Misplacement refers to the temporary lack of accountability of an item, and shrinkage defines an item's permanent loss due to damage, theft, or loss (Tao, Fan, Lai, & Li, 2017).

Hardgrave et al. (2013) found a 30% decrease in inventory inaccuracy when RFID was implemented to assist with inventory management after conducting a study consisting of 62 retailers (31 test stores and 31 control stores), five product categories, and 1268 unique stock-keeping units. Tao et al. (2017) showed that inventory management policies could remain static or be simplified with the implementation of RFID technology for inventory management. Heese (2007) demonstrated that RFID adoption improves supply chain coordination by reducing record inaccuracy in decentralized supply chains.

C. USMC STANDARD WAREHOUSING (AS-IS)

The purpose of a CMR is to ensure that assets that are owned by the USMC and assigned to a specific account are locatable and useable based on mission requirements and that items are not missing, lost, or stolen. The structure for a typical Marine Corps supply account at the Battalion level consists of one Accountable Officer (AO), the overarching owner of all equipment assigned to the specific command. The overarching unit account is then parsed out to the individual sections and companies Responsible Officers (RO). These ROs at the company and section level are responsible for maintaining physical accountability of all items listed on their CMR and any Stock List–3 (SL-3) items associated with the equipment. SL-3 items are components of military systems that are listed on the CMR (United States Marine Corps [USMC], 2020). The RO is also provided the authority to appoint, in writing and with permission of the AO, Responsible Individuals (RI). These RIs responsibilities are similar to that of the RO. However, the accountability for the CMR's correctness still rests with the RO.

The Marine Corps breaks down assets into various Table of Authorized Material Control Numbers (TAMCN), then adds serial numbers or uses the asset's organic serial numbers to identify specific items. These items are often individually serialized. In some but not all scenarios, pieces of equipment will also have associated stock list items. Stock

Lists are used to provide detailed and updatable information for all Marine Corps supply and maintenance operations for all managed items (United States Marine Corps [USMC, 2020). Specifically, Stock List 3 identifies all components associated with specific managed items (USMC, 2020). The SL-3 is identified on an associated SL-3 extract and is documented in the asset's record jacket.

In some cases, there are pieces of equipment that are serialized and can be stand-alone items; however, they are associated with another piece of equipment based on their anticipated operation (USMC, 2020). This relationship is called a Parent-Child relationship. In this case, the Parent asset is the serialized asset that is accounted for using the CMR, and the Child assets are identified on the SL-3 extract and record jacket.

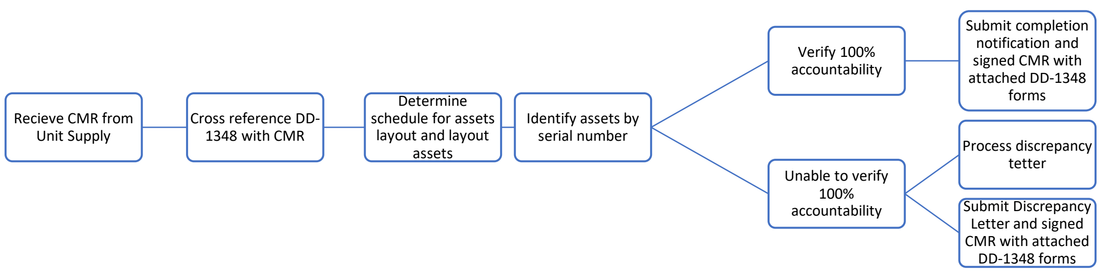

Figure 5. Current CMR Reconciliation Process

The CMR process for a RO begins upon receiving a copy of the current CMR distributed by the unit supply section (USMC, 2020). The RO has 15 days to complete a full CMR reconciliation from the date of receipt (USMC, 2020). A CMR reconciliation is conducted quarterly at a minimum (USMC, 2020). A unit can increase accountability requirements depending on mission parameters, cost of the item, or likelihood of theft or loss. Inventory-controlled items, such as rifles and radios, are accounted for through the same process; however, serialized inventories are conducted monthly based on their sensitivity. An RO typically begins by comparing the items listed on their CMR with the

Department of Defense Form 1348 (DD-1348) used to add or remove items from the CMR since the last reconciliation (USMC, 2020). A DD-1348 form is an issue or release form that acts as a paper receipt to account for gained or lost equipment from a CMR (USMC, 2020). These paper receipts are uploaded and entered into the Global Combat Support System Marine Corps (GCSS-MC) (USMC, 2020). This comparison allows the RO to determine if the CMR is accurate and updated with current equipment levels. If any gains or losses are not reflected on the CMR, the RO annotates this. These receipts are used to justify a discrepancy letter to the AO via the supply section to add or drop items from the CMR (USMC, 2020). Following the DD-1348 reconciliation, the RO delegates the layout of all equipment associated with the account.

The purpose of laying out items is to facilitate the RO validating each serial number and cross-referencing that serial number with the serial number on CMR to confirm that the item is on hand. This process varies based on the individual preference of the RO. Some best-practice solutions are to lay out the items in the order that the TAMCNs and serial numbers appear on the CMR. This process costs time upfront but helps to alleviate errors and prevents searching for serial numbers during the accountability process. Units may devise their own standard procedures and inventory control measures to control this process further. The team assigned to conduct the layout can have a broad range of ranks that vary but will require at the minimum an officer and a squad of twelve Marines to conduct the process. Upon validating and cross-referencing items, the RO will generate either a completion letter or a discrepancy letter. Depending on the size, state, and geographic dispersion of the account, an RO can take as little as three days or require an extension to complete the required inventory and associated paperwork accurately.

D. USMC RFID POLICY

> The Marine Corps RFID vision is: The Marine Air Ground Task Force (MAGTF) Deployment Support System II (MDSS II) is the Commander's unit level deployment database capable of planning and supporting rapid military deployment anywhere in the world. MDSS II enables BIC to build and maintain a database that contains the prepositioned Maritime Prepositioning Equipment / Supplies (MPE/S) data, reflecting how the MAGTF is configured for deployment. It is vitally important that the data contained in MDSS II is complete, correct, and timely. The processes to

> enter the data into MDSS II are manual and subject to human error. (United States Marine Corps [USMC], 2009)

The Marine Corps looks to utilize many facets of Automatic Identification Technology (AIT) throughout its future. The Marine Corps recognizes the value of these technologies for use in its logistical chain. Specifically, they look to incorporate the technology into their Automated Information Systems (AIS) by using the AIT for identification, location, and condition (United States Marine Corps [USMC], 2013). The current Marine Corps policy, Marine Corps Order 4000.51C, centers around the use of active RFID technology (USMC, 2013).

The Marine Corps recognizes that the use of AIT is intended to decrease human interaction for transferring data to the AIS that the Marine Corps utilizes (USMC, 2013). It notes that this would be a "force multiplier with the potential capability to link adjacent and higher logistical organizations" (USMC, 2013). This policy directs that the use of AIT in the supply chain for the Marine Corps is required unless a proven and thorough cost-benefit analysis has been done to show that AIT is not practical (USMC, 2013). The policy directs active RFID use for all principal end items, 463L pallets, and containers during deployment and redeployment operations (USMC, 2013). This process was put in place to provide the commander with in-transit visibility during large personnel and supply movements. The Marine Corps pushes to use the technology available as documented in the policy letter. However, the implementation has been limited to deploying and redeploying units. It could be expanded technologically to other forms of RFID and garrison forces to take advantage of the technology's capabilities.

E. BLOUNT ISLAND CASE STUDY

In 2009, the Marine Corps completed a report to assess Passive UHF RFID's implementation to track Marine Corps prepositioned equipment at Blount Island Command (BIC). BIC is the storage depot for the Maritime Prepositioned Force (MPF) located in Jacksonville, Florida. The report compared the use of the current physical CMR accountability process with the use of passive RFID sensors to conduct asset accountability. Throughout the report, the RFID system's statistics were impressive and showed promise. Based on these results, the USMC adopted the system for use at BIC.

The Blount Island case outlines the current process used to conduct an inventory or reconciliation. The report outlined RFID requirements and how it would change and impact the inventory process. It then transitions to a proof of concept and a revised business process for implementation. The report continues with the loading of small items that are containerized and the use of a deployed system with RFID capability. Finally, it wraps up with follow-on steps and passive RFID performance testing results.

The USMC and Alien Technology cofounded the project to test utilizing passive RFID to conduct a CMR reconciliation at BIC, as depicted in Table 1. The breakdown of costs and investments was split evenly. The team consisted of both organizations' members to ensure that the process met the Marine Corps' requirements and maximized the technology's capabilities.

Table 1. BIC RFID Investment and Organizational Structure. Source: USMC (2009)

Resources	***BICmd***	***Alien Technology, Inc.***
Funding	$600K (Matching Funds)	$600K
Project Team (Full and Part Time Staff)	BICmd Project Management and oversight On-site contractor support (Stanley, Inc.)	Program Manager, Technical Project Manager, RFID technical support services as required
Facilities	Systems Integration and Training Facility	RFID Support Center for the purpose of conducting technical training
Equipment	Non-RFID equipment necessary for the completion of this Charter	All passive RFID equipment necessary for the completion of this Charter
Software Tools	Business process related software	RFID firmware and middleware (device management)

The system put in place at Blount Island was extensive and all-inclusive, serving as the testbed for future expansion. The robustness of the system was required due to the unique mission and force structure associated with BIC. It is a relatively small command responsible for managing a very robust equipment set across a 33 plus acre facility with multiple vessel berths for simultaneous loading and a large maintenance area (Marine Corps Blount Island Command > About > Cutting Edge of Logistics, n.d.). Such a large area requires a system that can track items in real-time to conduct asset management properly. Throughout the experiment, the results were tracked, and due to the use of RFID, there was a noticeable reduction in personnel and person-hours required.

The study conducted on the CMR and the reduction in person-hours were done in a piecemeal method due to the overall operation's large footprint. The findings were that with a sample of 158 items, the person-hours could be reduced by 1.28 hours (USMC, 2009). These savings could amount to a total time saved of 58 person-hours for a complete CMR review. That is nearly eight business days of accounting that could be eliminated. This is a considerably sized account; however, it includes many large items stored in a very deliberate fashion to facilitate a speedy CMR process. This deliberate storage is not always the case with smaller accounts. The system put in place looked as follows and used a COTS solution. See Figure 6.

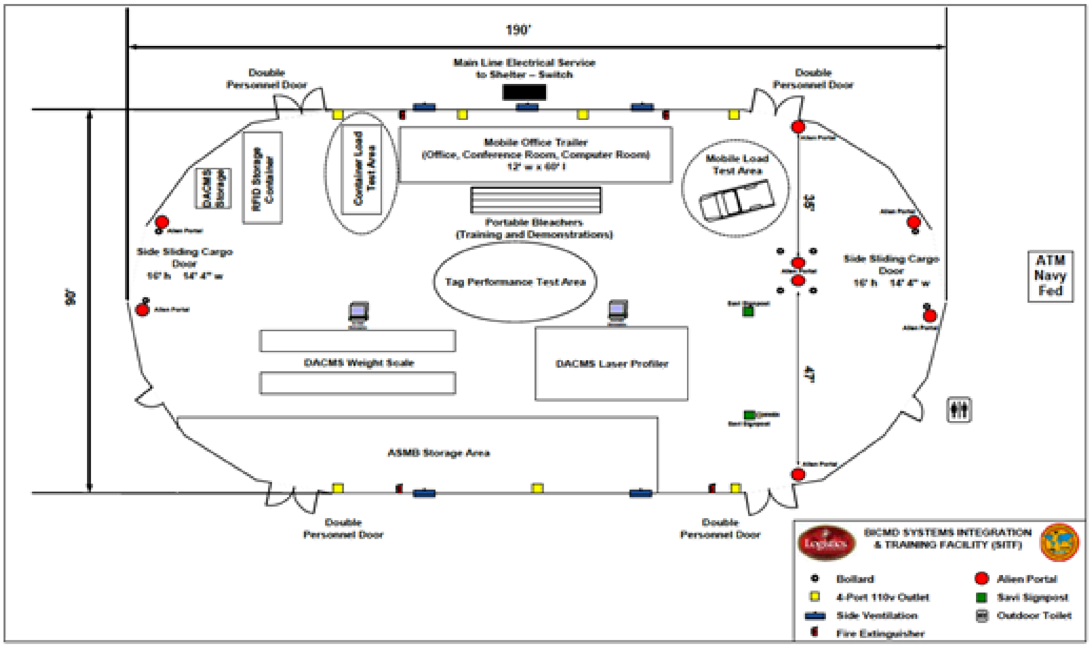

Figure 6. BIC Passive RFID Integration with COTS. Source: USMC (2009).

Only a passive system was tested in the CMR portion of the experiment, even though the Marine Corps had a program of record for an active RFID system at the time. However, during further experiments related to the technology, the two system types were tested against each other.

The follow-on tests conducted had a passive system versus an active system in a backload of equipment and offload of United States Naval Service (USNS) ships, operated by the Military Sealift Command (MSC). Backload, in this instance, refers to the loading of equipment from a port onto a vessel. An offload refers to the download of assets from the vessel to the port. During this execution, the results were documented, which concluded that the active tags were far less accurate than the passive tags. See Table 2 and Table 3 for tag accuracy results.

Table 2. Active RFID Read Percentages. Source: USMC (2013).

Active RFID Tag Identification Performance for MPS "Backloads"

Ship	Backload Date	Total Tagged Items	Total Tags Read	Overall %
USNS Sisler	8-17 Sep 2008	1,306	1,122	86%
USNS Williams	27 Oct – 4 Nov 2008	961	764	80%
USNS Kocak	2-10 Mar 2009	1,066	933	88%
USNS Lopez	30 Mar – 7 Apr 2009	1,053	875	83%
USNS Stockham	22-30 Jun 2009	1,031	697	68%
USNS Pless	28 Oct – 2 Nov 2009	1,095	870	79%

Active RFID Tag Identification Performance for MPS "Offloads"

Ship	Offload Date	Total Tagged Items	Total Read	Overall %
MV Hauge	28 APR - 5 MAY 09	771	577	75%
MV Bonnyman	5 - 12 MAY 09	952	729	77%
MV Anderson	12 - 20 MAY 09	955	656	69%
USNS Pless	11 - 17 JUN 09	1,395	704	50%

Table 3. Passive RFID Read Percentages. Source: USMC (2013).

Ship Backload Passive RFID Tag Read Performance

Total Containers Tagged	254		
Total Containers Missed		13	5.1%
Total Containers Read		241	94.9%

Total Principal End Items Tagged	452		
Total Principal End Items Missed		33	7.3%
Total Principal End Items Read		419	92.7%

Overall Tagged Items	706		
Total Tagged Items Missed		46	6.5%
Total Tagged Items Read		660	93.5%

While not perfect, the passive RFID accuracy was much better than that of the active RFID. The majority of the passive sensors' errors can be attributed to tag placement; many tag placement issues can be attributed to human error (USMC, 2009). Based on the results, the passive system showed a significant improvement over the active RFID system. The highest accuracy rating from the active RFID system was 88%, which was 4 points lower than the lowest accuracy rating of 92.7% for passive RFID. With corrections, it is assumed that the read rate for passive tags could be increased by 5% to reach almost 98% accuracy (USMC, 2009).

One key point cited by the report in 2009 is that the active systems require person-hours to replace batteries in the system where the passive system does not (USMC, 2009). This eliminates additional person-hours for discovery and replacement of dead batteries, as well as the reoccurring cost of replacement batteries (USMC, 2009). Replacement batteries for a 3-year cycle are estimated to cost $729,050 (USMC, 2009). The other significant cost that is discussed is that of the tag itself; the average cost of an active RFID tag in 2016 was $15.00 versus the average cost of a passive tag in 2016 being $1.00 on the high end and $0.15 in the low end (Advanced Mobile Group, 2016).

As discussed earlier, the time saving was substantial when implementing RFID into the overall process. The time saved was 1.28 person-hours. This reduced the time to conduct a CMR from 1 hour 29 minutes to a mere 12 minutes for a 158 item account (USMC, 2009). The study was also conducted across three locations to measure differing spaces and the impact on the system. The authors looked further into larger accounts up to an account that was 5300 items, and the passive RFID produced a 43.88 person-hour savings (USMC, 2009). That equates to a little over a week of work for one service member. BIC's systematic structure means there are very few alternative locations for items that are not in their correct storage spots when a member is conducting a reconciliation. The investigator would only need to look in the following locations maintenance, storage area, and preload/offload area. If an item is not where it is typically stored, a counter can contact maintenance to locate it or look at the preload and offload area (USMC, 2009).

In addition to testing the system, BIC conducted testing of more than 30 types of RFID tags on over 500 items of equipment to compile a list of all commercially available RFID tags that would meet basic requirements and tested their performance (USMC, 2009). Different tags are better for particular objects and locations. Based on these results, it is important to utilize as few tag models as possible and, ideally, only one tag model (see Table 4).

Table 4. Tag model Comparison Source: USMC (2013).

Manufacturer	Model		Average Quote Price	IC (Integrated Circuit)	Frequency	IC Memory (bits)	Extended Memory (bits)	IP Rating	Size (in)	Length	Width	Height	Sq	Cubic	Application Surface Material
Alien	ALN-9640		$0.20	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP20	1 x 3	1	3	0.008	3	0.024	Inlay tag for labels, etc.
Confidex	Corona		$1.26	NXP UCODE G2XM	860-960 MHz	240 bits	512 bits	IP67	3.93 x 0.80 x 0.01 in	3.93	0.8	0.01	3.144	0.0314	Heat resistant label for various applications
Confidex	Halo		$1.72	NXP UCODE G2XM	902-928 MHz	240 bits	512 bits	IP68	2.36 x 0.47 x 0.55 in	2.36	0.47	0.55	1.1092	0.6101	On-Metal Tag Light-weight Magnetic holder
Confidex	Ironside		$3.38	NXP UCODE G2XM	902-928 MHz	240 bits	512 bits	IP68	2.03 x 1.87 x 0.39 in	2.03	1.87	0.39	3.7961	1.4805	On-Metal Tag
Confidex	Pino		$0.68	NXP UCODE G2XM	860-960 MHz	240 bits	512 bits	IP67	2.95 x 0.55 x 0.024 in	2.95	0.55	0.024	1.6225	0.0389	Optimized for wooden applications
Confidex	Survivor		$2.68	NXP UCODE G2XM	902-928 MHz	240 bits	512 bits	IP68	8.8 x 0.94 x 0.31 in	8.8	0.94	0.31	8.272	2.5643	All purpose tag
RCD Technology	Sentry M (UHF 3610-100)		$3.23	Alien Higgs-3	902 - 928 MHz	96 bits	512 bits	IP67	1.43 x 0.43 x 0.21 in	1.43	0.43	0.21	0.6149	0.1291	Any metallic surface
RCD Technology	Sentry M Small (UHF 3610-101)		$3.05	Alien Higgs-3	902 - 928 MHz	96 bits	512 bits	IP67	1.43 x 0.43 x 0.11 in	1.43	0.43	0.11	0.6149	0.0676	Any metallic surface
Alien	FrontWeb		$3.00	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP66	3.9375 x 0.4375 x 0.4375	3.9375	0.4375	0.438	1.72266	0.7537	Non-metallic survace
Omni-ID	White Brick		$1.80	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP68	4.1875x2.3125x.375	4.18	2.3125	0.375	9.66625	3.6248	Any metallic surface
Omni-ID	Long Range		$5.00	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP68	5.875 x 3.375 x .4375	5.875	3.375	0.438	19.8281	8.6748	Any metallic surface
Omni-ID	Prox		$1.15	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP68	1.3125 x 0.375 x 0.1875	1.3125	0.375	0.188	0.49219	0.0923	Any metallic surface
Omni-ID	MaxHD (Polycarbonate)		$4.50	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP68	5.51 x 2.6 x 0.55	5.51	2.6	0.55	14.326	7.8793	
FrontWeb	C (Part #6ARC-001)		$2.25	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP66	5.3125 x 0.8125 x .5	5.3125	0.8125	0.813	4.31641	3.5071	Any metallic surface
FrontWeb G1	G (Part #ARCG-00)		$2.25	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP66	5.25 x 1.75 x .5	5.25	1.75	0.5	9.1875	4.5938	Any metallic surface
FrontWeb	G2		$2.25	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP66	4.125 x 1.6875 x .5	4.125	1.6875	0.5	6.96094	3.4805	Any metallic surface
FrontWeb	M (Part #ARCM-003)		$2.25	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP66	4.125 x 1.6875 x .5	4.125	1.6875	0.5	6.96094	3.4805	Any metallic surface
FrontWeb G3	New (Part #GARC-001)		$2.25	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP66	4.9375 x 1.0625 x 1	4.9375	1.0625	1	5.24609	5.2461	Any metallic surface
FrontWeb G1e	Part #RFMD01S w/ RFMExtender		$3.00	Alien Higgs-3	840–960 MHz	96-480 bits	512 bits	IP67	5.3125 x .8125 x 1	5.3125	0.8125	1	4.31641	4.3164	Any metallic surface

The testing conducted involved attaching the tags on the back of a High Mobility Multipurpose Wheeled Vehicle HMMWV and testing the tags' effectiveness. The data in Table 4 depicts the outcome of the test.

F. CHAPTER SUMMARY

The literature review has demonstrated that this is a wide range of RFID solutions to enhance warehousing. It is widely used in the commercial sector to positively impact inventory control, reduce inventory loss, and enhance inventory accountability. The Blount Island Command case study of RFID demonstrated that these benefits could be carried over from the commercial sector to large-scale DOD shipping and warehousing operations. Specifically, there are significant person-hour and labor cost savings if RFID is used to enhance the traditionally end item accountability process. Additionally, RFID was demonstrated to be as accurate in the worst case or more accurate in the best case when compared to traditional accountability methods. In the next chapter, the researchers will outline the methodology for developing two models to compare the As-Is CMR process to the To-Be RFID enhanced CMR process. These models will be used to simulate these processes to generate sufficient data to compare results and make a determination on the value of changing the CMR process in the Marine Corps.

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III. METHOD

A. PROBLEM EVALUATION

During the evaluation of this topic, an in-depth examination was completed the how automatic identification technology is used to track people and assets throughout the warehouse and similar facilities. This led to crucial findings about passive and active RFID regarding location identification capability versus physical accountability. The BIC case study confirmed that passive RFID could lead to an 87% reduction in labor hours to conduct a CMR inventory over physical accountability (USMC, 2009). Additionally, it demonstrated tag read accuracy levels between 92% and 95% when scanning military equipment (USMC, 2009). Examination of commercial warehousing demonstrated similar results, most notably, a 30% reduction in inventory inaccuracies when RFID was applied to inventory control over physical accountability (Hardgrave et al., 2013).

The research was concentrated on RFID technology and its potential use to improve asset accountability and visibility for a Marine Corps Company level CMR. This was of interest to the authors, in part, because of past personal experiences counting and reading countless serial numbers, cross-referencing that with a paper copy CMR, and then repeating if any errors occurred. This process is monotonous and stressful and requires most other operations, such as dedicated occupation training and field operations, to stop until completed so items can be accurately accounted for and documented.

The modeling for this experiment was conducted utilizing Savvion modeling and simulation software because of constraints due to COVID-19. Raw data for the As-Is model was generated utilizing the authors' personal experiences as subject matter experts based on a combined 24 years of CMR reconciliation procedures in the operational forces and supporting establishment commands in the United States Marine Corps. The researchers relied on the BIC case study outcomes to generate inputs for the To-Be process model. COVID-19 prevented the researchers from testing a passive RFID-enhanced process model to validate the BIC case studies results and gather additional raw data.

B. WHY SELECT A COMMUNICATION COMPANY ACCOUNT?

The researchers chose a Communication Company CMR account for two main reasons. First, these accounts are essentially identical across communication line companies. By comparing the value added to a Communications Company and then extrapolating the findings, the authors were able to provide an estimated time and cost savings for all Communications Companies across the Marine Corps. Second, these accounts are large and diverse. The account analyzed consists of 770 serialized items valued near $50 Million. This large sample size helped demonstrate if there were significant enough cost savings to merit moving to an automated passive RFID accounting system.

C. WHAT ITEMS WILL TAGS WORK WITH?

In order to determine which items would be tagged in a real-world experiment, the authors researched how other industries have utilized passive RFID. The research findings determined that most items can be tagged with an RFID tag based on the numerous tags available in the passive RFID market today. For instance, Xerafy can produce tags in multiple sizes ranging from 5 cm by 2 cm to as small as .5 cm by .25 cm (Xerafy, n.d.). This range of sizes makes all items taggable (Xerafy, n.d.). Due to travel constraints imposed by the United States Department of Defense, the researchers could not conduct adequate research on tag placement, tag maintenance, and tag accountability for this thesis. Additional research will be needed into the tag placement, how to utilize tags best while maintaining accountability for the tags themselves.

D. COST OF LABOR

In order to create an accurate assessment of cost, the average salary of a typical CMR accountability team was calculated. The pay grades for the Marines that generally participate in CMR accountability range from Private First Class (E2) to First Lieutenant (O2). The basic pay of each of these pay grades does not vary based on location for the military. This simplifies the cost estimates associated with accountability and normalizes it across the force. To appropriately determine the cost of each employee for this process, the authors referenced the Fiscal Year 2021 Department of Defense (DOD) Military

Personnel Composite Standard Pay and Reimbursement Rates published by the Office of the Secretary of Defense (Office of the Secretary of Defense [OSD], 2020). A list of billable rates and composite standard rates for each paygrade in the military by service branch has been used to estimate workforce costs. The rates were broken down to hourly pay to determine the cost, providing a more accurate assessment of costs to conduct the activities purely associated with conducting the CMR reconciliation process. The assumption was made that service members are employed from 0730–1630 daily for five days a week. This period also includes a one-hour lunch period. The total work hours per week are calculated at 40 person-hours per service member.

The typical team used to simulate the As-Is CMR process to determine total person-hours and labor costs consisted of fifteen Marines. The team of fifteen Marines was comprised of the following pay grades: (1) First Lieutenant (O2) the RO, (1) Staff Sergeant (E6), (1) Sergeants (E5), and (12) Private First Class (E2). This team was constructed based on the average rank of the individuals typically involved in the CMR accountability process. The As-Is CMR team's hourly pay is shown in Table 5 (OSD, 2020).

Table 5. As-Is Team Employment Cost Chart

Title	Rank	Annual Rate	Daily Rate	Hourly Rate	Quantity	Total Cost
RO	First Lieutenant	$ 123,809.00	$ 559.62	$ 70.57	1	$ 70.57
CMR Layout Supervisor	Staff Sergeant	$ 103,269.00	$ 466.78	$ 58.86	1	$ 58.86
SN Supervisor	Sergeant	$ 80,120.00	$ 362.14	$ 45.67	1	$ 45.67
Layout workforce/SN reader	Private First Class	$ 43,064.00	$ 194.65	$ 24.55	12	$ 294.60
				Total Hourly Rate		$ 469.70

Fewer individuals were projected to conduct the To-Be CMR process. The researchers estimated that the passive RFID enhanced process would only require one Marine. The team of one Marine would be comprised of the following pay grades: (1) First Lieutenant (O2) the RO. The projected To-Be CMR team's total hourly pay is shown in Table 6 (OSD, 2020).

Table 6. RFID Team Employment Cost Chart

Title	Rank	Annual Rate	Daily Rate	Hourly Rate	Quantity	Total Cost
RO	First Lieutenant	$ 123,809.00	$ 559.62	$ 70.57	1	$ 70.57
				Total Hourly Rate		$ 70.57

E. INFRASTRUCTURE COST BASELINE

A baseline passive RFID system cost was determined to conduct a first-year implementation cost comparison between the As-Is and To-Be process models. This baseline included the estimated cost of passive RFID equipment to outfit a single company space. The price of interrogators, both handheld and static, the cost of passive RFID tags, cabling, and other basic infrastructure needs were included in the system cost estimates.

The following assumptions were made regarding the system that would be put in place for a communications company. Each company would have (1) fixed reader at each access point in their storage areas. Based on the experiences of the authors, this would require (4) fixed antennas. Each company would require (2) handheld readers to use simultaneously or serve as a primary and redundant system. The software and training cost would be a Marine Corps-wide expense and was not considered in the cost comparison.

F. MODELING THE ACCOUNTABILITY PROCESS

Two simulations were conducted using the Savvion modeling software. The first simulation was a model of the As-Is physical CMR accountability process. The second simulation was a model of the To-Be RFID enhanced CMR accountability process. Each of these models was simulated numerous times. These simulations were then averaged to determine the average costs, completion time, and bottleneck time of the process and subprocesses associated with each model. These results were then used as the input feeds for a ten thousand iteration Monte Carlo simulation. The results were discussed in a cost-per-year format, and the researchers highlighted areas where bottlenecks occurred and slowed the process in general.

The first simulation was based on a manual accountability process for all items, including the following process and subprocesses. The 770 item CMR was broken down into five 154 item sections to layout. This number was based on the typical space and time constraints faced in Marine Corps communication units based on the experience of the authors and the ease of comparability to the BIC case study. The entire As-Is process included some subprocesses that cannot be simulated due to the constraints inherent in the Savvion software. Those specific subprocesses included the reception of the CMR, cross-referencing DD-1348 forms, and designing and issuing the layout plan. Figure 7 depicts the As-Is CMR process model. The researchers do not believe that the exclusion of these subprocesses will significantly impact the outcome of this research. In the researchers' expert opinion, RFID enhancement can not be effectively applied to these subprocesses. Note that those subprocesses circled in red were not included in the simulation.

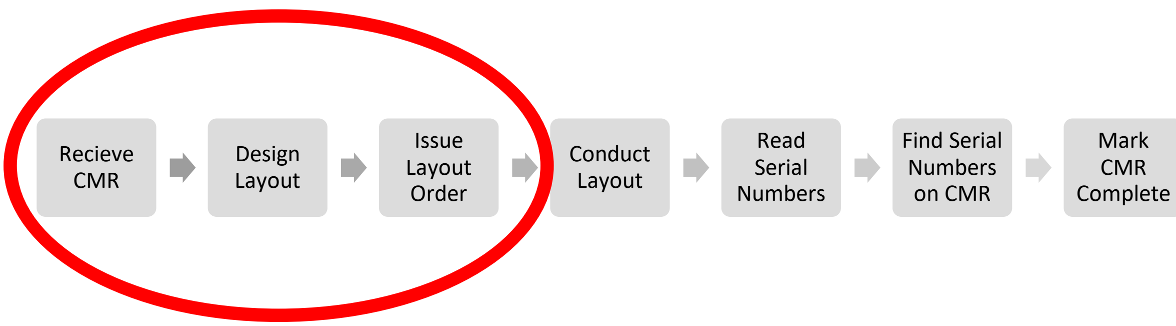

Figure 7. As-Is CMR Process

The 154 items will be laid out to allow for a serial number to quickly identify the item's serial number in accordance with CMR layout best practices. Upon completing the layout, a team of Marines will read serial numbers to the RO, who will either acknowledge the serial number or ask for it to be reread. Upon successfully understanding the serial number read, the RO will cross-reference with the serial numbers on the CMR paperwork. If a match is not found, the RO will look again. When found, the serial number will be marked as on hand on the CMR paperwork. The process will then be repeated with five 154 item blocks to simulate the process as it would most likely be completed because of working hour constraints and other duties that occur daily at the company level. Figure 8 depicts the Savvion model used to simulate the As-Is CMR process.

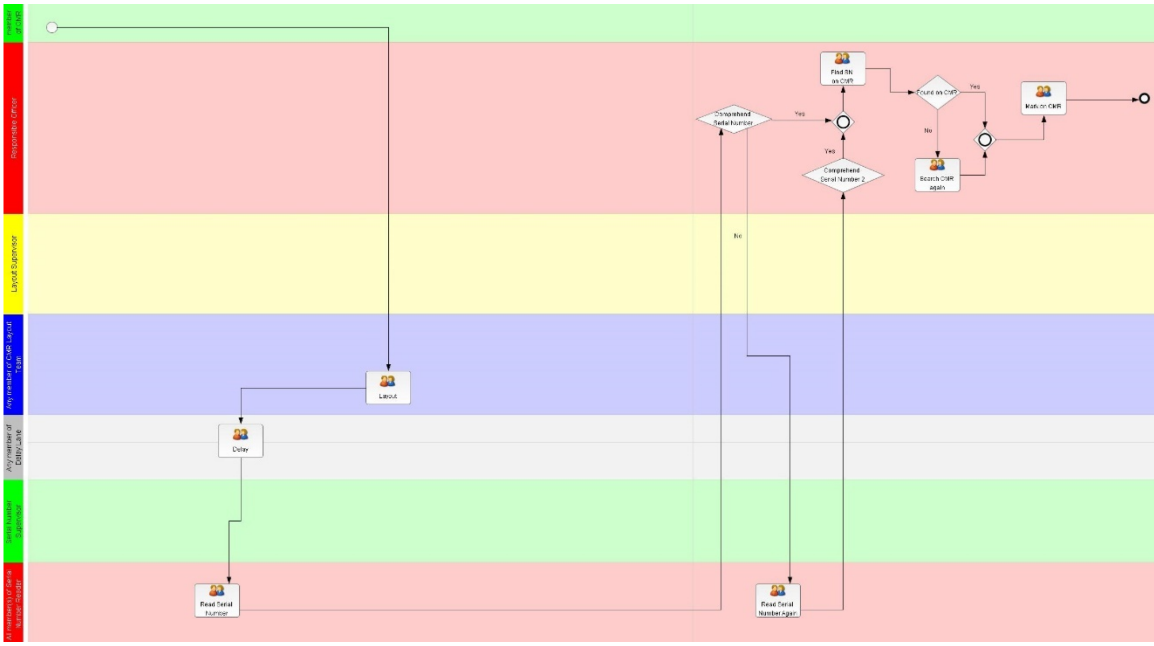

Figure 8. Savvion Model As-Is Process

The second model will be simulated to depict the To-Be process utilized if passive RFID were used to enhance accountability. This process will consist of fewer steps because the items will no longer need to be laid out, and individual serial numbers do not need to be read aloud. The passive RFID tags will transmit the data for each serial number back to the reader while the item remains on the shelf. This process will also remove the requirement to cross-reference the serial numbers read with those on the CMR. The RFID system will produce a read-out of individual serial numbers that will either be automatically compared with those on the CMR through software intervention or manually compared once the process is complete. Figure 9 depicts the To-Be system process model.

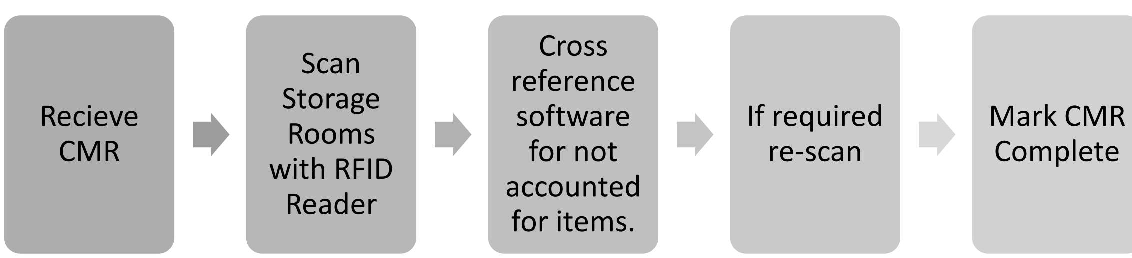

Figure 9. To-Be CMR Process

The process will have the RO use the RFID hand scanner and walk through the storage area, scanning items as they pass them. Upon completing one scan, the data will be downloaded from the scanner and compared to the CMR submitted from the supply section. Once the initial comparison is completed, a second walk-through will be conducted if required. This scan will be done to pick up any missed during the initial scan. Upon completion of the second scan, the output will be downloaded and compiled with the original scan and compared with the issued CMR. At this point, if there are any unaccounted for pieces of equipment, the RO will go and look for the specific items that were not readable via RFID. Figure 10 depicts the Savvion model for the To-Be CMR process.

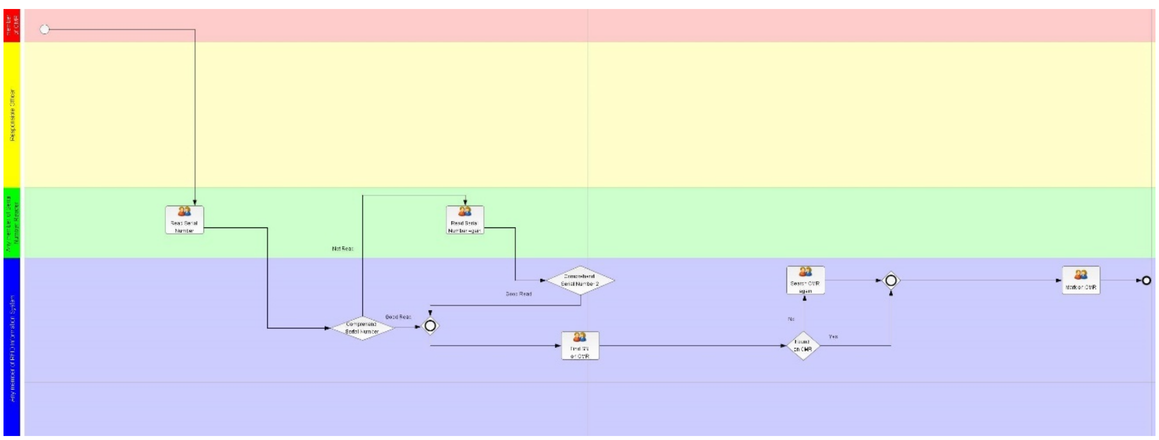

Figure 10. Savvion Model To-Be Process

G. CHAPTER SUMMARY

In this chapter, the researchers discussed the rationale behind their selected parameters for this study. Additionally, the researchers outlined both the As-Is process and the To-Be process employed to a CMR. The As-Is process consists of physical accountability by a team of Marines each quarter. The As-Is process contains, on average, seven subprocesses and requires fifteen Marines to complete. The envisioned To-Be process is enhanced with passive RFID. Because of the addition of RFID, this process only requires five subprocesses and one Marine to complete. In the next chapter, the researchers will discuss their analysis of the As-Is and To-Be processes.

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IV. ANALYSIS

In this chapter, the researchers will analyze 20 simulations of both the As-Is and To-Be process models ran using the Savvion modeling software. Using these 20 simulations, the researchers will then analyze a ten thousand iteration Monte Carlo simulation for both the As-Is and To-Be process models. First, the researchers will outline some critical assumptions that were made before the analysis of the results. Second, the researchers will conduct a simple analysis of the time disparity between the As-Is and To-Be processes. Third, the researchers will monetize that time using the cost figures for everyone involved in the process. Lastly, the researchers will then conduct a comparative analysis between the As-Is and To-Be models in terms of cost for each process model's first year of implementation.

A. ASSUMPTIONS

Three critical assumptions were made before conducting this analysis. The first critical assumption is that the RFID tags were placed and tested beforehand. This step is not included in the To-Be process model. The second assumption is that the cost of a middleware software suite to connect the RFID system to the already existing suite of Marine Corps systems and services is beyond the scope of this thesis. The third assumption is that the Marine Corps will place the requisite amount of trust in RFID technology to see an adequate return.

The As-Is process and To-Be processes are not equal in the number of the subprocess. Figures 7 and 9 show the disparity between the two processes. The As-Is process contains six total subprocesses, and the To-Be process only contains five. It is key to note that the final four subprocesses of both models are similar enough to conduct a direct comparative analysis. The necessity to physically lay equipment out to be accounted for is replaced with the scanning of the storage room with the introduction of RFID. The critical assumption here is that the RFID tags have been placed on the equipment and tested before the conduct of the simulation. This time is unaccounted for in the simulation for two specific reasons. First, the researchers believe that tag placement and testing can occur during the final physical inventory as they transition to an RFID-enhanced process model. Second, there was not enough data available to accurately assess the time it would take to tag military equipment.

Research into the price of middleware systems to integrate RFID into existing infrastructure does not produce tangible results and therefore places it outside the scope of this thesis. The cost of middleware significantly varies in both the commercial and military sectors in general. Further research into the cost is required to understand the price and impact of adding middleware to fully integrate RFID into the suite of services and systems that the Marine Corps currently owns.

The To-Be process model assumes a significant amount of trust in the available passive RFID technology. Reducing the number of subprocesses places a high-level inherent trust in the passive RFID scanning system, especially when moving from physically and visually accounting for equipment to scanning shelves and cages. The researchers believe there is good reason for the USMC to trust this technology. First, if trust is not placed in the system, any potential benefits from this technology could be nullified. Second, as demonstrated in the literature review of this thesis, many commercial organizations have utilized RFID technology to significant effect. It has been shown to reduce accountability errors, loss, and even theft when employed.

B. TIME SELECTION CRITERIA

1. As-Is

The researchers have personally conducted no less than 50 CMR inventories in their careers thus far. Additionally, as company commanders, they supervised the conduct of no less than an additional 50 CMR inventories. Utilizing this knowledge, the researchers derived what they felt was an average time to complete each subprocess of the CMR inventory. Table 7 depicts the time and distribution associated with each subprocess.

Table 7. As-Is Subprocess Work Time and Distribution

Name	Work Time	Distribution
Find SN on CMR	01:00.0	Exponential Distribution
Layout	01:00.0	Normal Distribution (STDev=(none))
Mark on CMR	01:00.0	Exponential Distribution
Read Serial Number	01:00.0	Constant
Read Serial Number Again	01:00.0	Normal Distribution (STDev=(none))
Search CMR again	01:00.0	Exponential Distribution
Average Subprocess Time	01:00.0	

Based on the researcher's vast experience conducting a CMR, one minute per item was chosen as the starting point for each subprocess. The distributions vary based on the subprocess to denote how much variance there is in each process. The Layout process is normally distributed around one minute. This is based on the idea that some items are easier to find and lay out while others may be more difficult to find. It also factors in the time variability to move items from shelving or storage into a lineup. Find SN on CMR, Search CMR again, and Mark on CMR are exponentially distributed because as items are found and marked, the process becomes quicker. Read SN is constant. The researcher assessed that this would take the same amount of time to pick up the item, locate the SN, read the SN, and replace the item. Reread SN is normally distributed because when read once, if a reread is required, one reread may be very quick; however, another reread may be very slow and require third-party intervention to determine if the SN is correct.

2. To-Be

The researchers used the Blount Island Command case study as a seminal example of the time-saving potential for adopting RFID technology. In that case, the time to conduct a CMR inventory was reduced from 1 hour and 29 minutes to 12 minutes to account for 158 items (USMC, 2009). This is approximately an 87% reduction in time to complete an inventory of 158 items. Table 8 depicts the individual and average subprocess time for the To-Be model.

Table 8. To-Be Subprocess Work Time and Distribution

Name	Work Time	Distribution
Find SN on CMR	00:06.0	Exponential Distribution
Mark on CMR	00:06.0	Exponential Distribution
Read Serial Number	00:10.0	Constant
Read Serial Number Again	00:10.0	Normal Distribution (STDev=(none))
Search CMR again	00:06.0	Exponential Distribution
Average Subprocess Time	00:07.6	

As depicted in Table 7, the As-Is process model has an average process time of 60 seconds. Using the outcome of the BIC study, the researchers reduced the average time associated with each subprocess for the RFID enhanced model by 52.4 seconds to 7.6 seconds. The time for each subprocess and the average subprocess time are depicted in Table 8.

These times may seem slower than expected for the use of passive RFID to scan, read, and verify items. It is anticipated that human intervention will be necessary at each process junction to ensure that the process is functioning correctly or to validate the subprocess output. For instance, during the Mark on CMR subprocess, the RO may need to cross-reference the RFID output to a physical copy of their CMR. While the scanner may work at machine speed to validate tags, humans will take a short amount of time to cross-reference the output to provide validation. This human interaction time is inherently built into each subprocess time. If this were not done, the To-Be process would be completed unreasonably fast and would not have matched the 87% reduction in time demonstrated in the BIC case study.

C. ANALYSIS PROCESS

The researcher chose to conduct 20 simulations in the Savvion Modeling software of both the As-Is and To-Be process models. Twenty simulations were chosen because they felt it was representative of the typical number of CMR inventories conducted by a company in an annual period. This simulation number assumes a company that contains four platoons with active CMRs. Each would conduct four CMR inventories annually for a total of sixteen CMR inventories. An additional four inventories were included to account for USMC-directed inspections, deployments, or field exercises where CMR inventories may be required. These twenty simulations were then tabulated to determine the mean, median, mode, standard deviation, maximum value, and minimum value of the total duration of the simulation and each of the individual subprocess involved in the model. This information was then used to conduct a Monte Carlo simulation to extrapolate over ten thousand iterations. Ten thousand iterations were chosen to ensure a wide diversity in the range of values for each subprocess. The researchers felt that this number of iterations would ensure that the average time of each subprocess was closer to its true mean.

The normal inverse function was used to generate values to feed the Monte Carlo simulation for each process model. A random probability was assigned, and the mean and standard deviation of the total duration and each of the individual subprocess was used to generate the feed values. These feed values were then used to generate the ten thousand iterations of the Monte Carlo simulation. Figure 11 depicts sample feed values in seconds for the As-Is and To-Be process models. Seconds were chosen for the feed values to give the highest level of accuracy when conducting the Monte Carlo simulation.

To-Be Feed Values	
Total Duration	1585.666219
Find SN on CMR	911.3335522
Mark on CMR	1001.368464
Read SN	1540
Read SN Again	811.7351404
Search CMR again	36.59089081

As-Is Feed Values	
Total Duration	15300.229
Layout	9240.000
Read SN	9240.275
Find SN on CMR	7499.440
Read SN Again	-845.304
Search CMR Again	323.307
Mark on CMR	11159.736

Figure 11. Sample Feed Values (in seconds)

Once inputted, the feed values generated ten thousand data points for each of the subprocesses. The researchers then took these data points and statistically analyzed them in terms of Mean, Median, Mode, Standard Deviation, Maximum value, and Minimum Value. When reviewing the total duration mean of 27.5245 hours to complete a CMR with 770 pieces of equipment, the researchers noted that this was very close to what they had seen in a real-world CMR inventory. This would suggest that the model and subsequent Monte Carlo simulation produced an accurate picture of the As-Is CMR inventory process.

D. TIME ANALYSIS

1. As-Is

The average time for the simulation to complete the As-Is process to account for 154 items is approximately five and a half hours. Table 9 shows the total duration of the As-Is process and the individual times to complete the associated subprocesses.

Table 9. As-Is CMR Inventory Activity Times (in Minutes)

Simulation	Total Duration	Layout	Read SN	Find SN on CMR	Read SN Again	Search CMR Again	Mark on CMR
1	443	154	154	138	146	4	138
2	289	154	154	130	8	7	130
3	287	154	154	129	8	4	129
4	350	154	154	173	8	5	151
5	335	154	154	153	8	7	153
6	363	154	154	168	8	5	168
7	372	154	154	170	8	9	170
8	386	154	154	177	8	11	177
9	305	154	154	138	8	8	138
10	349	154	154	161	8	6	161
11	307	154	154	138	8	9	138
12	362	154	154	167	8	5	167
13	237	154	154	105	8	4	105
14	353	154	154	161	8	10	161
15	292	154	154	133	8	5	213
16	318	154	154	144	8	8	144
17	314	154	154	142	8	8	142
18	305	154	154	136	8	11	136
19	298	154	154	135	8	7	135
20	339	154	154	153	8	12	153
MEAN	*330.2*	*154*	*154*	*147.55*	*14.9*	*7.25*	*150.45*
MEDIAN	*326.5*	*154*	*154*	*143*	*8*	*7*	*147.5*
MODE	*305*	*154*	*154*	*138*	*8*	*5*	*138*
STD DEV	*43.59082472*	*0*	*0*	*18.05401617*	*30.07640271*	*2.446936861*	*22.12120024*
MAX	443	154	154	177	146	12	213
MIN	237	154	154	105	8	4	105

Three tasks in this process run in parallel. Find SN on CMR, Read Serial Number, and Mark on CMR are parallel tasks. The total duration column of Table 9 shows the total duration for each simulation. In conducting the twenty simulations, the maximum duration of the As-Is accountability process for 154 pieces of equipment was 443 minutes or 7.38 hours. The minimum duration was 237 minutes or 3.95 hours. The mean of the twenty simulations results in an average As-Is process time of 330.2 minutes or 5.50 hours to conduct accountability for 154 pieces of equipment. Extrapolated, this suggests that the total time to conduct an entire CMR inventory of 770 items would take, on average, 27.5 labor hours or approximately three and a half days of labor.

The researchers used the data from the twenty simulations to run a ten thousand iteration Monte Carlo simulation. Table 10 depicts the output of the Monte Carlo simulation.

Table 10. As-Is Monte Carlo Simulation Output (in Minutes)

10,000 Iteration MONTE CARLO Simulation							
MONTE CARLO	**Total Duration**	**Layout**	**Read SN**	**Find SN on CMR**	**Read SN Again**	**Search CMR Again**	**Mark on CMR**
MEAN (Sec)	19817.776	9240.000	9240.006	8837.605	857.311	432.728	9043.209
MEAN (Min)	330.296	154.000	154.000	147.293	14.289	7.212	150.720
STD DEV (Sec)	2646.718	0.000	1.001	1082.731	1815.053	148.108	1332.023
STD DEV (Min)	44.112	0.000	0.017	18.046	30.251	2.468	22.200
MEDIAN (Sec)	19796.214	9240.000	9240.003	8851.300	869.235	431.038	9052.209
MEDIAN (Min)	329.937	154.000	154.000	147.522	14.487	7.184	150.870
MAXIMUM (Min)	502.594	154.000	154.059	224.269	128.530	16.934	232.034
MINIMUM (Min)	174.851	154.000	153.936	78.166	-94.485	-2.066	69.975
AVG Total Process Time (Hrs)	5.504937877						
AVG Total Work Time (Min)	627.514						
MONTE CARLO	**Total Duration**	**Layout**	**Read SN**	**Find SN on CMR**	**Read SN Again**	**Search CMR Again**	**Mark on CMR**
	21472.398	9240.000	9239.176	8045.702	3616.446	502.771	9975.484

This simulation resulted in an average As-Is Process time of 5.5049 hours to conduct accountability of 154 pieces of equipment. Using this as the average As-Is process time results in 27.5245 hours to complete a CMR with 770 pieces of equipment associated with it. A maximum total duration of 502.594 minutes or 8.377 hours and a minimum total duration of 174.851 minutes or 2.914 hours arose over the ten thousand simulations. This would suggest that the As-Is process could take 41.885 hours or a whole work week to account for a 770 item CMR in the worst-case scenario. A 770 item CMR could take as little as 14.57 hours or almost two days to complete in the best-case scenario.

2. To-Be

The average time over twenty simulations to complete the To-Be process to account for 154 items is approximately twenty-two minutes. These twenty-two minutes are broken down into the following activities: Read SN, Find SN on CMR, Mark on CMR, Read SN again, Search CMR again. Table 10 shows individual time to complete the listed tasks.

Table 11. To-Be CMR Inventory Activity Times (in Minutes)

Simulation	Total Duration	Find SN on CMR	Mark on CMR	Read SN	Read SN Again	Search CMR Again
1	24.700	16.000	16.000	25.667	22.833	0.667
2	24.533	15.467	15.467	25.667	22.833	0.600
3	24.533	14.700	14.700	25.667	22.833	0.600
4	24.733	16.633	16.633	25.667	22.833	0.467
5	24.800	16.333	16.333	25.667	22.833	0.867
6	15.200	13.700	13.700	25.667	2.833	0.667
7	14.533	15.367	15.367	25.667	2.833	1.033
8	24.367	15.600	15.600	25.667	22.833	0.833
9	24.800	16.333	16.333	25.667	22.833	0.867
10	24.800	13.033	13.033	25.667	22.833	0.667
11	24.467	14.033	14.033	25.667	22.833	0.633
12	15.067	16.133	16.133	25.667	2.833	0.700
13	24.467	16.200	16.200	25.667	22.833	1.000
14	24.433	16.100	16.100	25.667	22.833	0.467
15	24.467	14.033	14.033	25.667	22.833	0.633
16	15.067	16.133	16.133	25.667	2.833	0.700
17	14.800	14.533	14.533	25.667	2.833	0.600
18	24.467	16.600	16.600	25.667	22.833	0.967
19	24.533	16.533	16.533	25.667	22.833	0.633
20	24.467	18.033	18.033	25.667	22.833	1.100
MEAN	*22.162*	*15.575*	*15.575*	*25.667*	*17.833*	*0.735*
MEDIAN	*24.467*	*16.050*	*16.050*	*25.667*	*22.833*	*0.667*
MODE	*24.467*	*16.333*	*16.333*	*25.667*	*22.833*	*0.667*
STD DEV	*4.177*	*1.191*	*1.191*	*0.000*	*8.660*	*0.178*
MAX	24.800	18.033	18.033	25.667	22.833	1.100
MIN	14.533	13.033	13.033	25.667	2.833	0.467

Three tasks in this process run in parallel in this process as well. Find SN on CMR, Read Serial Number, and Mark on CMR are parallel tasks. The total duration column of Table 11 shows the total duration for each simulation. In conducting the twenty simulations, the maximum duration of the To-Be accountability process for 154 pieces of equipment was 1488 seconds or 24.8 minutes. The minimum duration was 872 seconds or

14.533 minutes. Calculating the mean of the twenty simulations results in an average To-Be process time of 1329.7 seconds or 22.162 minutes to conduct accountability for 154 pieces of equipment. Extrapolated, this suggests that the total time to conduct accountability of a complete CMR inventory of 770 items would take, on average, 110.81 minutes or approximately two hours of total labor.

Table 12. To-Be CMR Monte Carlo Simulation Output (in Minutes)

10,000 Iteration MONTE CARLO Simulation						
MONTE CARLO	**Total Duration**	**Find SN on CMR**	**Mark on CMR**	**Read SN**	**Read SN Again**	**Search CMR Again**
MEAN (Sec)	1328.303711	934.5617984	934.537267	1540	1063.815783	44.06575676
MEAN (Min)	22.13839519	15.57602997	15.5756211	25.66666667	17.73026305	0.734429279
STD DEV (Sec)	250.4822713	72.33566382	71.5013564	9.97199E-09	520.1871772	10.72104115
STD DEV (Min)	4.174704522	1.205594397	1.19168927	1.662E-10	8.669786286	0.178684019
MEDIAN (Sec)	1327.315233	932.623798	934.757745	1540	1064.666833	44.04492134
MEDIAN (Min)	22.12192055	15.54372997	15.5792958	25.66666667	17.74444722	0.734082022
MAXIMUM (Sec)	2448.446988	1195.921071	1205.86071	1540	3002.530704	82.98676509
MINIMUM (Sec)	192.7495676	653.4429124	677.421579	1540	-815.1120827	4.546078204
AVG Total Process Time (Hrs)	0.368973253					
AVG Total Work Time (Min)	75.2830101					
MONTE CARLO	**Total Duration**	**Find SN on CMR**	**Mark on CMR**	**Read SN**	**Read SN Again**	**Search CMR Again**
FEED	1121.532598	909.7132185	963.347823	1540	483.3843875	56.44603007

This simulation resulted in an average To-Be Process time of 0.369 hours to conduct accountability of 154 pieces of equipment. This results in 1.845 hours to complete a CMR with 770 pieces of equipment. We also see a maximum total duration of 40.8075 minutes or 0.680 hours and a minimum total duration of 3.2125 minutes or 0.0535 hours over the ten thousand simulations. This would suggest that the RFID-enhance process could take 3.5 hours to account for a 770 item CMR in the worst-case scenario. In the best-case scenario, a 770 item CMR could take as little as 15 minutes to complete.

3. Comparative Analysis

Comparing the results of the As-Is and To-Be systems in terms of time demonstrates an enormous difference. The To-Be process, at 1.845 hours, is approximately fifteen times quicker than the As-Is process, at 27.5245 hours. The researchers also noticed a more significant variance in the To-Be process model's minimum and maximum total duration values compared to the As-Is process model. The maximum value of the To-Be process is approximately 84% higher than the mean. While in the As-Is process, the maximum value is only 52% higher than the mean. Similarly, the minimum total duration of the To-Be process is 85.5% lower than the mean, while the As-Is process model is approximately 51.3% lower than the mean.

E. COST ANALYSIS

1. As-Is

The pay grades for the Marines that generally carry out the CMR tasks range from Private First Class (E2) to First Lieutenant (O2). This pay does not vary from location to location, which lends itself to determining labor costs across the force. The simulated team used consists of the following paygrades: (1) First Lieutenant (O2) the RO, (1) Staff Sergeant a Layout Supervisor, (1) Sergeant a Serial Number Supervisor, and (12) Private First Class (E2), who will both layout the equipment as well as read the serial numbers to the RO. Table 13 depicts the average grade and hourly wage for each member of the simulated CMR accountability team.

Table 13. As-Is CMR Accountability Team

Position	Average Grade	$/HR
Responsible Officer	First Lieutenant	$ 70.57
CMR Layout Team	Private First Class	$ 24.55
CMR Layout Supervisor	Staff Sergeant	$ 58.86
Serial Number Reader	Private First Class	$ 24.55
Serial Number Supervisor	Sergeant	$ 45.67

The total cost shown in Table 14 displays the cost for a team of this size and structure to conduct an As-Is CMR inventory based on the average times for each process taken from the Monte Carlo simulation.

Table 14. Average As-Is CMR Inventory Cost

Activity	Performer	Hours	Users	154 Item Cost	CMR Cost	Annual Cost
Supervise Layout	Layout Supervisor	2.567	1	$ 151.07	$ 755.37	$ 3,021.48
Layout	Any member of CMR Layout Team	2.567	12	$ 756.14	$ 3,780.70	$15,122.80
Supervise SN	Serial Number Supervisor	2.567	1	$ 117.22	$ 586.10	$ 2,344.39
Read SN	All member(s) of Serial Number Reader	2.567	12	$ 756.14	$ 3,780.70	$15,122.80
Find SN on CMR	Responsible Officer	2.455	1	$ 173.24	$ 866.21	$ 3,464.82
Read SN Again	All member(s) of Serial Number Reader	0.238	12	$ 70.16	$ 350.79	$ 1,403.18
Search CMR again	Responsible Officer	0.120	1	$ 8.48	$ 42.41	$ 169.65
Mark on CMR	Responsible Officer	2.512	1	$ 177.27	$ 886.36	$ 3,545.44
Total Cost				**$2,032.46**	**$10,162.28**	**$40,649.13**

While some of these tasks run in parallel for time-keeping purposes, they need to be accounted for separately for cost-keeping purposes. This results in an average of $2,032.46 to conduct accountability for 154 pieces of equipment. Extrapolated, this suggests that the total cost of conducting accountability of an entire CMR of 770 items would be $10,162.28. When conducted quarterly, the annual cost of the As-Is process would amount to $40,649.13.

Table 15. Maximum As-Is CMR Inventory Cost

Activity	Performer	Hours	Users	154 Item Cost	CMR Cost	Annual Cost
Supervise Layout	Layout Supervisor	2.567	1	$ 151.07	$ 755.37	$ 3,021.48
Layout	Any member of CMR Layout Team	2.567	12	$ 756.14	$ 3,780.70	$15,122.80
Supervise SN	Serial Number Supervisor	2.567	1	$ 117.22	$ 586.10	$ 2,344.39
Read SN	All member(s) of Serial Number Reader	2.567	12	$ 756.14	$ 3,780.70	$15,122.80
Find SN on CMR	Responsible Officer	3.738	1	$ 263.78	$ 1,318.89	$ 5,275.55
Read SN Again	All member(s) of Serial Number Reader	2.142	12	$ 631.08	$ 3,155.41	$12,621.65
Search CMR again	Responsible Officer	0.282	1	$ 19.92	$ 99.59	$ 398.34
Mark on CMR	Responsible Officer	3.867	1	$ 272.91	$ 1,364.55	$ 5,458.21
Total Cost				**$2,695.35**	**$13,476.75**	**$53,907.02**

Table 15 depicts the maximum cost associated with the worst-case CMR inventory based on the results of the Monte Carlo simulation. This results in a cost of $2,695.35 to conduct accountability for 154 pieces of equipment. Extrapolated, this suggests that the total cost to conduct accountability of an entire CMR of 770 items would be $13,476.75. The worst-case annual cost of the As-Is process would amount to $53,907.02.

Table 16. Minimum As-Is CMR Inventory Cost

Activity	Performer	Hours	Users	154 Item Cost	CMR Cost	Annual Cost
Supervise Layout	Layout Supervisor	2.567	1	$ 151.07	$ 755.37	$ 3,021.48
Layout	Any member of CMR Layout Team	2.567	12	$ 756.14	$ 3,780.70	$15,122.80
Supervise SN	Serial Number Supervisor	2.567	1	$ 117.22	$ 586.10	$ 2,344.39
Read SN	All member(s) of Serial Number Reader	2.567	12	$ 756.14	$ 3,780.70	$15,122.80
Find SN on CMR	Responsible Officer	1.303	1	$ 91.94	$ 459.68	$ 1,838.72
Read SN Again	All member(s) of Serial Number Reader	0.000	12	$ -	$ -	$ -
Search CMR again	Responsible Officer	0.000	1	$ -	$ -	$ -
Mark on CMR	Responsible Officer	1.166	1	$ 82.30	$ 411.51	$ 1,646.05
Total Cost				**$1,872.51**	**$ 9,362.55**	**$37,450.20**

Table 16 depicts the minimum cost associated with the best CMR inventory based on the results of the Monte Carlo simulation. The Monte Carlo simulation produced negative results as the minimum for the Read SN Again and the Search CMR Again subprocesses. In a real-life application, this does not make sense. These results are reduced to zero. This best-case scenario results in a cost of $1,872.51 to conduct accountability for 154 pieces of equipment. Extrapolated, this suggests that the total cost to conduct accountability of an entire CMR of 770 items would be $9.362.55. The best-case annual cost of the As-Is process would amount to $37,450.20.

2. To-Be

The reduction in subprocess requirements for the To-Be system also reduces personnel to conduct these subprocesses. The simulated team consisted of the following paygrades: (1) First Lieutenant (O2) the RO. The RO has a cost of $70.57 per hour.

Table 17. Average To-Be CMR Inventory Cost

Activity	Performer	Hours	Users	154 Item Cost	CMR Cost	Annual Cost
Find SN on CMR	Responsible Officer	0.2596005	1	$ 18.32	$ 91.60	$ 366.40
Mark on CMR	Responsible Officer	0.2596005	1	$ 18.32	$ 91.60	$ 366.40
Read SN	Responsible Officer	0.427777777	1	$ 30.19	$ 150.94	$ 603.77
Read SN Again	Responsible Officer	0.295504384	1	$ 20.85	$ 104.27	$ 417.07
Search CMR again	Responsible Officer	0.012240488	1	$ 0.86	$ 4.32	$ 17.28
Total Cost				**$ 88.55**	**$ 442.73**	**$ 1,770.92**

Using the mean times to complete each subprocess from the Monte Carlo simulation results in an average of $88.55 to conduct accountability for 154 pieces of equipment. This suggests that the total cost to conduct a complete CMR inventory of 770 items would be $442.73, with an associated annual cost of $1,770.92. See Table 17 for a cost breakdown by subprocess.

Table 18. Maximum To-Be CMR Inventory Cost

Activity	Performer	Hours	Users	154 Item Cost	CMR Cost	Annual Cost
Find SN on CMR	Responsible Officer	0.332200298	1	$ 23.44	$ 117.22	$ 468.87
Mark on CMR	Responsible Officer	0.334961308	1	$ 23.64	$ 118.19	$ 472.76
Read SN	Responsible Officer	0.427777778	1	$ 30.19	$ 150.94	$ 603.77
Read SN Again	Responsible Officer	0.834036307	1	$ 58.86	$ 294.29	$ 1,177.16
Search CMR again	Responsible Officer	0.023051879	1	$ 1.63	$ 8.13	$ 32.54
Total Cost				**$ 137.75**	**$ 688.77**	**$ 2,755.09**

Table 18 depicts the maximum cost associated with the worst-case To-Be CMR inventory based on the results of the Monte Carlo simulation. This worst-case results in a cost of $137.75 to conduct accountability for 154 pieces of equipment. Conducting accountability of an entire CMR of 770 items would cost $688.77. The worst-case annual cost of the To-Be process would amount to $2,755.09.

Table 19. Minimum To-Be CMR Inventory Cost

Activity	Performer	Hours	Users	154 Item Cost	CMR Cost	Annual Cost
Find SN on CMR	Responsible Officer	0.18151192	1	$ 12.81	$ 64.05	$ 256.19
Mark on CMR	Responsible Officer	0.188172661	1	$ 13.28	$ 66.40	$ 265.59
Read SN	Responsible Officer	0.427777778	1	$ 30.19	$ 150.94	$ 603.77
Read SN Again	Responsible Officer	0.0012628	1	$ 0.09	$ 0.45	$ 1.78
Search CMR again	Responsible Officer	0.0012628	1	$ 0.09	$ 0.45	$ 1.78
Total Cost				**$ 56.46**	**$ 282.28**	**$ 1,129.10**

Table 19 depicts the minimum cost associated with the best CMR inventory based on the results of the Monte Carlo simulation. The Monte Carlo simulation produced negative results as the minimum for the Read SN Again. This subprocess time was made equal to the Search CMR Again subprocess. This was done because the Search CMR Again subprocess cannot be executed without firing the Read SN Again subprocess. This best-case scenario results in a cost of $56.46 to conduct accountability for 154 pieces of equipment, a total CMR labor cost of $282.28, and an annual cost of $1,129.10.

3. Comparative Analysis

It is immediately noticeable that the To-Be CMR inventory process is substantially less costly than the As-Is CMR process. The maximum annual cost associated with the To-Be CMR inventory is approximately 13.5 times lower than the minimum annual cost of the As-Is CMR inventory process. This results from the To-Be process both being substantially faster and requiring significantly fewer laborers to conduct each subprocess. The 87% reduction in time-based on the BIC case study results in approximately a 96% reduction in cost when comparing total mean CMR inventory process costs of the As-Is and To-Be models. There is a wide variance in cost when comparing the mean, maximum and minimum costs of the To-Be process model. Of note, the best-case cost scenario for the To-Be process model results in an approximate 33% in cost savings over the mean scenario. When comparing the best-case and mean cost scenario for the As-Is process model, we only see an 8% cost savings emerge for the best-case outcome.

F. INFRASTRUCTURE COST FINDINGS

The cost of the infrastructure could be slightly different in each location that a Communications Company is located. Table 20 depicts what the researchers believe the average RFID infrastructure setup would contain.

Table 20. Sample Company RFID Infrastructure

Item	Quantity
RFID Reader / Interrogator	One (1)
Fixed Antenna	Four (4)
Handheld Antenna	Two (2)
Passive UHF RFID Tags	1000 per company only paper tags
Antenna Cable	150’ will vary based on site

Figure 12 depicts an example of RFID infrastructure implementation using the equipment depicted in Table 20.

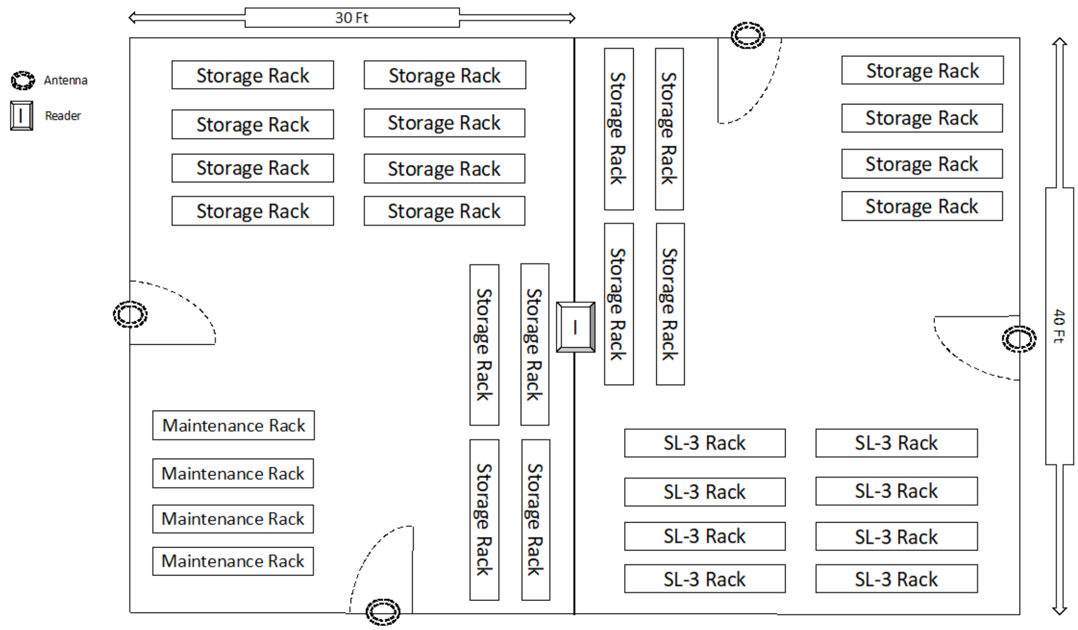

Figure 12. Sample Company RFID Implementation

In Figure 12, the fixed antennas are depicted by the circles over the door frames. This will not be the precise location, but for the purpose of surveying the facilities, it is used to define the need for fixed sensors that will read items as they cross through the threshold of the door frames. The interrogator is located at a central location between the two storage rooms, and all antennas will route to that point. The current price for an interrogator is approximately $1000 (PTS Mobile, 2021). Four antennas cost $202.11 each, coming to a total of $804.44 (PTS Mobile, 2021). Two handheld scanners to conduct accountability cost $4385.00 (PTS Mobile, 2021). The total cost, including in-house installation and cabling, is expected to be approximately $6310.12 (PTS Mobile, 2021). RFID tags rated for use on metallic objects cost approximately $1.00 each, totaling about $1000 for enough tags suitable to tag 770 items with spares (Advanced Mobile Group, 2016). Table 21 displays the total breakdown of one system for a Communications Company. The total cost of this sample infrastructure is approximately $7,310.12.

Table 21. Total Cost of Sample RFID Implementation

Total Cost Single Company RFID Accountability System		
Item	**Quantity**	**Cost**
RFID Reader / Interrogator	One (1)	$934.56
Fixed Antenna	Four (4)	$804.44
Handheld Antenna	Two (2)	$4385.00
Passive UHF RFID Tags	1000 per company	$1000.00
Antenna Cable	150'	$186.12
Total Cost		**$7310.12**

The To-Be system is estimated to be priced at $7,310.12 as a fixed one-time cost per company. The average first-year cost of the To-Be process labor would be projected at $1,770.92, plus the additional $7,310.12 initial infrastructure investment. This equates to a total first-year cost of $9,081.04. The total annual cost to complete CMR accountability and meet the Marine Corps requirement of one CMR per quarter using the As-Is system is $40,649.13.

G. CHAPTER SUMMARY

In this chapter, the researchers conducted a comprehensive analysis of the results of the Savvion simulation of the As-Is and To-Be process models. Using twenty simulations and a ten thousand iteration Monte Carlo simulation, the researchers compared both process models' results confidently. Apparent differences between both process models emerged from the data. An initial infrastructure estimate was done to determine the potential first-year cost of the To-Be process model. In the next chapter, the researchers will summarize their thesis, provide conclusions based on their analysis, and provide recommendations for further research.

V. CONCLUSION

A. SUMMARY

The Marine Corps As-Is CMR inventory process relies on the physical accountability of assets. This process includes the retrieval and layout of equipment and the manual reading of serial numbers to ensure that assets are accounted for. The physical nature of this process makes it time and labor intensive. The researchers have demonstrated that it takes fifteen Marines of various grades, on average, approximately 5.50 hours to inventory 154 pieces of equipment. This labor costs the Marine Corps an average of $2,032.46 per 154 items inventoried.

Significant advancements in passive RFID technology have been made in recent years. It has become the preferred asset accountability model for commercial organizations and has demonstrated significant benefits in retail inventory control by reducing inventory inaccuracy, misplacement, and shrinkage (Heese 2007, Tao et al. 2017, Hardgrave et al. 2013). These benefits have been demonstrated in military applications as well. The Blount Island Command conducted a pilot test utilizing passive RFID to account for military equipment. This test demonstrated an 87% reduction in time to account for 158 pieces of equipment (USMC, 2009). It also demonstrated an average passive RFID read accuracy of approximately 94% (USMC, 2009).

The researcher devised a simulation using Savvion modeling software to compare the physical As-Is CMR inventory process that the USMC currently employs with an RFID-enhanced To-Be CMR inventory process utilizing the BIC as a case study. After running twenty simulations of each model, the researchers used the outputs from these simulations to run a ten thousand iteration Monte Carlo simulation to analyze the As-Is and To-Be processes in terms of time and cost.

On average, the As-Is process takes 5.5049 hours to conduct accountability of 154 pieces of equipment. These person-hours are spread over fifteen Marines and cost an average of $2,032.46. This translates into 27.5245 hours to complete a CMR with 770 items at the cost of $10,162.28 per inventory. A single company conducts a minimum of four inventories a year, taking 110.098 hours and costing $40,649.13.

On average, the To-Be process takes 22.162 minutes to account for 154 pieces of equipment. This labor time is completed by a single Marine and costs an average of $88.55. This would indicate that it would take an average of 1.8468 hours to complete a 770 item CMR inventory and cost $422.73. This results in an annual cost of $1,770.92 and an annual time commitment of 7.3872 hours. The researchers have assessed a fixed one-time cost associated with the To-Be system of approximately $7,310.12 per instance. With this fixed cost factored in, the first-year annual cost of the To-Be process model would be $9,081.04.

Analysis of the data demonstrates a stark difference in both time and cost between the As-Is and To-Be process models.

B. CONCLUSIONS

This time savings of the To-Be process model is directly attributed to the fact that the RFID-enhanced process removes the need to conduct a physical layout of equipment. Additionally, because it removes the human element of reading and comprehending serial numbers and replaces it with machine speed comparatives, each of the other subprocesses fires much quicker. The researchers believe that time can be used as a surrogate to demonstrate increased efficiency in the To-Be CMR process. This is demonstrated when comparing the mean process times for a complete 770 item CMR. The As-Is model takes 27.5245 hours to complete. The To-Be model, in contrast, only takes 1.845 hours to complete. Based on this, the researchers believe that a comparative analysis of the As-Is and To-Be process models demonstrates that a RFID-enhanced To-Be system could be up to almost fifteen times more efficient than the current accounting process.

This efficiency results in an annual time savings of 102.718 hours or approximately 2.5 forty-hour work weeks per Company. If extrapolated to the twelve communications line companies across the three Marine Expeditionary Forces, this would save a collective of 1,232.616 hours or 30.8 forty-hour work weeks. Further extrapolation to other CMR accounts across the Marine Corps would exponentially increase the time savings per year.

Due to the reduction in both time and personnel required, there are enormous potential cost reductions in person-hours if a RFID-enhanced CMR accountability process is implemented to replace the current physical accountability process. These cost reductions reflect an already mature RFID enhance CMR process. The researchers assessed some basic RFID infrastructure costs to determine if the first-year cost of implementing commercial off-the-shelf RFID equipment to facilitate the To-Be has similar cost-saving potential.

This first-year cost of the To-Be process model in total is approximately $1,000 less than the $10,162.12 it costs to conduct one quarterly CMR reconciliation in labor hours. A cost savings of $31,568.09 per instance of implementation would be achieved when factoring in the sample infrastructure costs for the first year of the To-Be process implementation. Every subsequent year the cost of the To-Be process model would save $8,391.20 per quarter or $33,564.80 in person-hours a year over the As-Is process model. Extrapolating these savings to the twelve communication line companies results in an annual savings of $402,777.60 in labor hours.

Based on the Savvion simulations and Monte Carlo simulation, the researchers believe that significant efficiency can be gained over the current As-Is CMR inventory process. In terms of time, the researchers believe that automating the physical As-Is accountability process can save a significant amount of time that could be refocused on other requirements. In terms of cost, the researchers believe that automating the As-Is model will significantly increase the process return on investment for the Marine Corps. While the Marine Corps will not recoup these cost savings in a traditional manner, the saved labor hours can be shifted to higher-value tasks to increase the Marine Corps' return on investment.

C. RECOMMENDATIONS FOR FURTHER RESEARCH

Based on the estimated time savings and cost savings, the researchers recommend that a follow-on study be conducted to confirm the effectiveness of the To-Be process model under real-world conditions. A study of this nature is required to validate the increased efficiency of the RFID-enhanced process model. This follow-on research can also be used to capture metrics regarding the placement of RFID tags on equipment and the training required to implement and use RFID in the CMR inventory process. The researchers also recommend an assessment on the requirement for middleware to allow the RFID system to interface with the current Marine Corps systems and services.

The researchers also recommend that further studies be conducted to how the RFID enhanced To-Be process model can support total inventory control and in transit asset visibility. This research could inform the USMC on how to further reduce inventory shrinkage as items move through the supply chain.

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