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Research Article

Assessment of RFID Investment in the Military Logistics Systems through the Life Cycle Cost (LCC) Model

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Abstract- Radio Frequency Identification (RFID) is an emerging technology that has been recently used in numerous business and public fields. Most military applications of RFID have focused on logistics systems. Since RFID investment requires high initial cost and its benefits are hard to see in the short term, it needs an appropriate investment decision model. The purpose of this research is to propose a Life Cycle Cost (LCC) model for RFID integration into the Military Logistics System (MLS). The study primarily focuses on the question of whether the cost of integrating and operating the MLS with RFID is worth investing. The results of this study provide a strategic roadmap allowing decision makers to determine if the logistics system considered is a good candidate for RFID technology integration based on the comparison of the LCCs of the current and the RFID integrated MLS. This study also enlightens possible cost parameters and their impacts on the total cost of RFID technology implementation in MLS.

Keywords- Radio Frequency Identification, RFID, Military Logistics System, Life Cycle Cost, LCC, Supply Chain.

1. Introduction

Improvements in information processing, data transfer speeds, and communication technologies have enabled business practices to change and evolve throughout time (Çolakoğlu, 2014). Global competition drives companies to reduce their costs, concentrate on their core abilities, and respond to customer needs promptly. On the other hand, shrinking available resources, economic instability, emerging economies of new countries, increasing population, and increasing public scrutiny induces government organizations to spend taxpayers' money effectively and wisely. Therefore, companies, non-profit organizations, and governments are looking for better ways to increase the efficiency of their operations.

Logistics has been one of the most important business functions in today's world. Order processing, transportation, and inventory management are the main activities in a logistics system. Order processing could be a time-consuming activity if an organization does not have appropriate and up-to-date technology. For instance, bar code scanning technology helps retailers to identify products that have low inventories and thus allows them to update inventory levels and replenish these products. However, Radio Frequency Identification (RFID) technology has been implemented in future stores to improve the accuracy, speed, and full automation of these processes. Transportation is critical to meet customer demand and supply essential parts on time (Ghiani, Laporte, & Roberto, 2004). Inventory management plays a key role in cost reduction. The objective of inventory management is to determine optimum stock levels in order to minimize total operating cost while keeping processes working.

RFID technology implementation in logistics systems aims to increase effectiveness and efficiency in transportation, inventory management, and order processing activities. Although RFID technology implementation has some benefits, it requires substantial initial purchase and implementation costs. Therefore, organizations have to primarily analyze their processes, find areas to apply RFID technology, and assess and justify their decisions by using various investment decision models.

The purpose of this study is to propose a Life Cycle Cost (LCC) model for RFID implementation in MLS. The results of this study provide a strategic roadmap allowing decision makers to determine if the logistics system considered is a good candidate for RFID technology implementation based on the comparison of the models of the current and the RFID-integrated MLS.

The questions to be answered are;

- What are the general benefits obtained from RFID technology integration? Is there any limitation of the technology that makes the decision makers hesitate implementing it?
- What are the cost parameters pertinent to RFID technology? How can these cost elements be categorized?
- What are the cost parameters specific to MLS in RFID technology implementation?
- How much is the life cycle cost of both the current logistics system and the RFID-integrated logistics system? Is there any difference between the LCC models and how can these differences be concluded?
- Is it worth investing in RFID integration? Is there any gain resulting from the RFID integration in terms of the life cycle cost?
- What is the payback period? How long does it take to compensate the initial construction cost?

2. Background

2.1. Automatic Asset Identification Technologies

In today's world, optimizing logistics operations has a high priority for the success of organizations. Operations and supply management requires getting work done quickly, efficiently, without error, and at a low cost (Jacobs, Chase, & Aquilano, 2009). Automatic Asset Identification Technologies (AAIT) plays a crucial role in this effort by increasing visibility and traceability, reducing response time, improving processes and operations, and most importantly, reducing the investment in inventory. Most commonly used automatic identification technologies can be listed as basic labels, barcodes, Unique Identification (UID), and RFID technology.

The first Gulf War was the major turning point in the utilization of AAIT. The U.S. Army took a big lesson from the first Gulf War related to the importance of tracking and identifying supplies. During the war, the U.S. Army lacked the ability to track and identify supplies. The United States Air Force (USAF) General (ret.) Walter Kross, Director of Ops & Logistics of the U.S. Transportation Command during the first Gulf War, stated that: "During the Gulf War, we simply did not have good information on anything. We did not have good tracking; we had no real asset visibility. Materiel would enter the logistics pipeline based on murky requirements, and then it could not really be tracked in the system.... We lacked the necessary priority flows to understand where and when things were moving. It was all done on the fly, on a daily basis... It truly was brute force. Generally speaking, if front-line commanders weren't sure of what they had or when it would get there, they ordered more...The result was the oft-referenced iron mountains of shipping containers. We had too much, and, worse yet, we did not know what was where." (Ozdemir and Bayrak, 2010).

Lessons learned from the first Gulf War led the U.S. Army to change its concept of identifying and tracking material and initiate new projects to gradually integrate AAIT into its logistics system. These endeavors seem to be the pioneer of a more visible and easily traceable MLS.

2.1.1. RFID Technology

RFID is the name of the technology that uses radio frequencies to determine the unique identification information of an object via the RFID tag affixed to it.

RFID technology is one of the tools that performs the automatic collection of data similar to bar code technology. However, RFID technology differs from bar code technology in that it is more automatic and capable of performing higher-speed operations (Brown, 2007). RFID enables the system to identify the items from a distance, and unlike earlier barcode technology, it does so without requiring a line of sight.

2.1.2. History of RFID Technology

The first RFID system was used in World War II. The Germans, Japanese, Americans, and British were all using radar for early warning of an impending airplane while it was a couple miles away. However, they were not able to identify whether they were enemy and friendly airplanes. The Germans established the first passive RFID system to identify friendly airplanes. The

German pilots were rolling their planes as they returned to the base and it was changing the radio signal reflected back, so the radar crew on the ground was aware that a friendly airplane was approaching. Then, the British developed the first active RFID system. They put a transmitter on every plane. When the transmitter received a signal from the ground, it began broadcasting a signal back to be identified by the radar crew (RFID-Journal, 2009).

RFID technology has so far been used in a variety of applications. RFID application implemented by Gap Inc. in 2001 was the first use of RFID technology in a retail supply chain. Afterward, big players such as Marks & Spencer, Gillette, Tesco, Metro AG, and Wal-Mart implemented RFID applications in their retail supply chains.

RFID has widely been used in military applications as well. The biggest military RFID application was implemented by the Department of Defense (DoD). In October 2003, the DoD established the policy for the use of RFID and initiated a strategy to take maximum advantage of the inherent life-cycle asset management efficiencies that can be realized with the integration of RFID throughout the DoD. Moreover, the DoD announced that its 43,000 suppliers would be required to implement RFID at the pallet and case level by 2005 (Gaukler, Seifert, & Warren, 2007).

2.1.3. Components of an RFID System

RFID technology works based on the receiving of preprogrammed information stored in the RFID tag through a reader. Fig. 1. displays how an RFID system works. RFID requires a tag (transponder), a reader (interrogator), and an antenna (coupling device). Typically, the reader is connected to a host computer that runs the RFID middleware in it. This simple architecture can be seen as the basic structure of the full spectrum of RFID-enabled solutions, whether simple or complex (Bhuptani & Moradpour, RFID Field Guide, 2005).

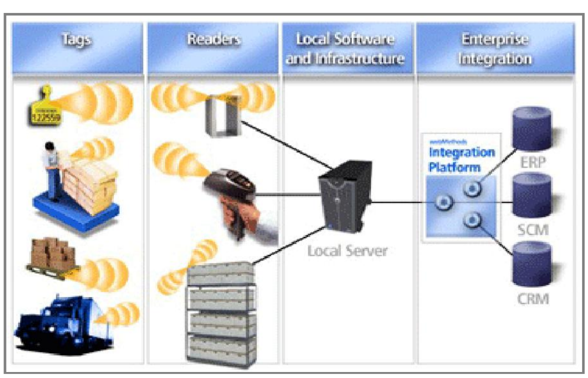

Fig. 1. RFID Infrastructure (From olympic-data-capture.com)

A RFID tag is also called a transponder. It is a small microchip-antenna composition that can be attached on an item to identify it. The chip is made up of a radio receiver, a radio modulator that is used to send a response signal back to the reader, control logic, a memory system, and a power system.

RFID tags are programmed with unique identification information such as the identification (ID) number, manufacturing date, expiration date, etc. When a tag is in the electromagnetic zone broadcasted by a reader it sends the identification information as radio signals back to the reader. Fig. 2. 0displays a sample set of RFID tags.

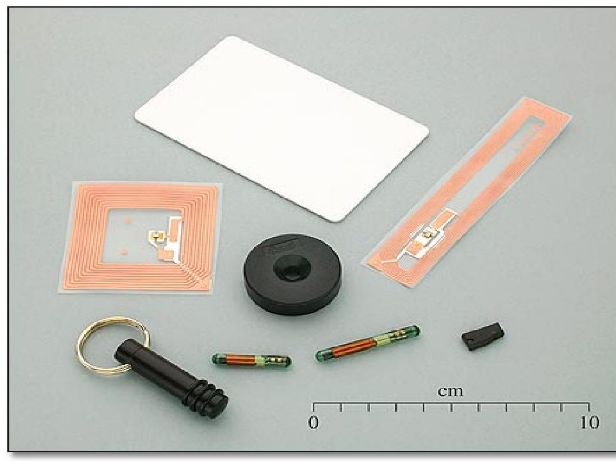

Fig. 2. RFID Tag Types (From openlearn.open.ac.uk)

RFID tags can be classified into three groups based on the way they perform radio frequency transmission and their support for specialized tasks, which are passive, active and semi-passive or semi-active (Lahiri, 2005).

Active tags can send signals using their own transmitter. On the other hand, passive tags can produce a weaker signal, because they get their power from the reader. Passive tags can only function in presence of a reader. Semi-passive RFID tags can be considered passive tags, because they use the same way of radio frequency transmission as passive tags. The difference is that they have an internal power source, which is used for additional functions. With the help of this power source, semi-passive tags can both monitor the environmental conditions such as temperature, humidity, etc. and extend the tags' signal range.

The purpose of the antenna is to convert energy between flowing electricity and broadcast radio waves. Both readers and tags have antennas. As the conduit for data communication between the tag and the reader, the design and placement of the antenna is crucial in determining the coverage zone, range, and communication reliability (Tedjasaputra, 2006).

RFID readers are also called interrogators. The basic role of the RFID readers in the system is to communicate with the RFID tags. The RFID reader with its attached antenna generates a radio signal and broadcasts it. When a tag is in the effective zone, it releases the identification data stored in it. The reader decodes the data and sends it to the host computer for storing or processing, or retains it for future usage. Some readers can have the ability to write data into the microprocessor of the tag.

Readers can be small, handheld devices or large readers placed at the warehouse doors. Fig. 3. 0displays some examples of RFID readers.

Fig. 3. Examples of RFID Readers

Middleware is used to integrate the existing software with the RFID technology. Middleware is the software loaded on the RFID host computer that bridges the communication between all the information gathered by the RFID readers and existing back-end system or application software such as a warehouse management system, enterprise resource planning software, or manufacturing execution system.

Middleware can be seen as the central nervous system of RFID technology and provides the core functionalities such s sharing the obtained data both inside and outside of the enterprise, managing massive data produced by the RFID system, and providing the filtering and aggregation logic (Lahiri, 2005).

2.1.4. Benefits and Limitations of RFID Technology

The initial benefits gained from RFID integration in a warehouse or distribution center is mainly derived from automating manual processes and effectively using greater amounts of data. RFID technology provides various benefits and solves many different problems. For example, using RFID tags to automate the receiving operation not only reduces labor cost for that function, but also enhances accuracy and helps decrease the amount of time that an item spends in a distribution center. RFID provides corresponding benefits that accrue at various RFID tagging levels, ranging from pallet tagging to item tagging as displayed in Fig.4.

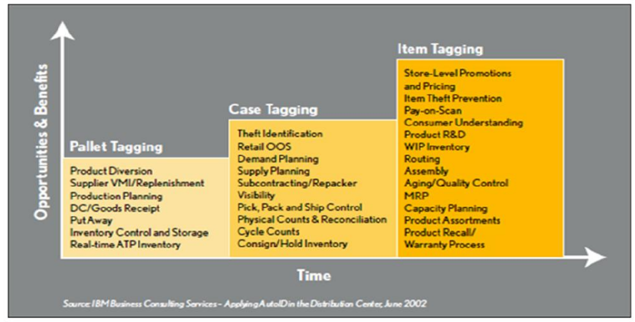

Fig. 4. Benefits at Different Levels of Tagging (From idspackaging.com)

Although, the benefits gained from RFID technology will vary depending on the level of the tagging, there will be general benefits that will be accrued. These benefits are interdependent and can be described as a chain of benefits as displayed in Fig. 5.

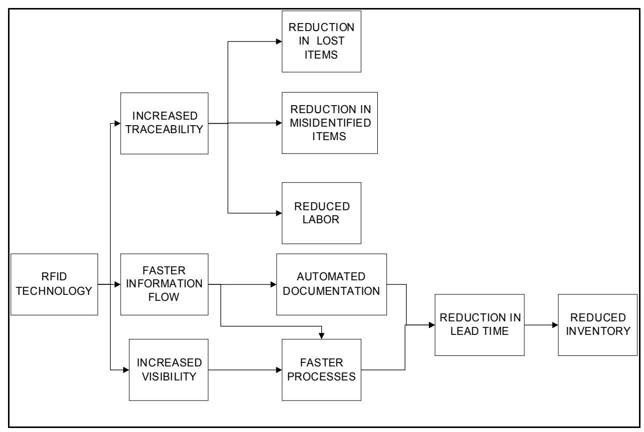

Fig. 5. Benefit Chain of RFID Technology

First, RFID technology supports the information in the supply chain by increasing the visibility. Visibility describes the ability of anyone to have access to inventory, orders, raw materials, and receiving and delivery points at any time. The real-time nature of RFID provides the latest information in order to make the best decision (Jones & Chung, 2007). In addition to better visibility, RFID will help the information to flow quickly throughout the supply chain. Another benefit of RFID technology will be increased traceability. Traceability can be explained as the capability of identifying and counting the items, following their movements, and helping the related personnel to determine the location of the items in a warehouse/depot. Traceability is related to the RFID's fundamental attribute of not requiring a direct line of sight when reading the tags and its ability to communicate all the tags in the effective zone of its radio signal in milliseconds.

Faster information flow will result in a reduction of the required time and efforts to document the activities. Furthermore, better visibility and faster information flow will lead to faster processes throughout the supply chain, thus helping managers in their decision-making and assisting the system's users in accessing the information faster and easier. As to the increased traceability, it will reduce the labor in both the receiving and delivery points responsible for identifying, counting, locating, documenting, and managing the movements of the items.

"The major cost component for typical distribution centers is labor, accounting for around 50-80% of their total distribution costs. According to some surveys, RFID technology can reduce the receiving check-in time by 60-93% and it could also yield labor savings of up to 36% in order picking and a 90% reduction in verification costs for shipping processes. These figures demonstrate the significance of labor in supply chains and that even small reductions can deliver considerable financial savings." (Katina & Luke, 2005).

Automated documentation and faster processes will reduce the lead time between the major actors in the supply chain, result in a reduction in the safety stock level or reorder point depending on the inventory concept used, and reduce the level of inventory accordingly.

In many manufacturing facilities and distribution centers, barcode systems have been used for many years. Since barcode systems are commonly accepted, are mature and efficient enough and represent a substantial investment, it can be difficult to justify a change to RFID. In any organization, moving from a familiar and trusted technology to a new one poses a challenge, especially when it requires process change. Therefore, resistance to change is one of the big challenges for deciding to invest in RFID technology.

Cost of the technology is another limitation for the decision makers to justify. For example, the average cost of writing a barcode on an object is nearly five to ten times cheaper than putting an RFID tag on it. Moreover, a barcode scanner is two to three times cheaper than an RFID reader is. High initial construction cost, hardware and software costs, and the cost of the integration with the existing system compel managers to decide whether it is worth investing this significant amount of money in an immature technology. Moreover, the benefits accrued from the integration are difficult to realize and calculate in the short term.

The physical properties of the products that are subject to tagging and other environmental factors such as moisture can affect the reliability of readers. Liquids absorb radio frequency signals while metals reflect them. As a result, the material used to make the tagged item can significantly affect the performance of the reader. Furthermore, external factors like radio frequency (RF) noise from nearby electric motors can have an impact on performance.

Data overload and data noise are other challenges to deal with. Data overload results from continuously scanning the RFID tags in the range and sending them to the host computer. Thus, the network capacity, the features of the host computer and the quality of the middleware will be determinant factors in preventing data overload. Data noise is a consequence of the torrent of the RFID data, especially in the overlapping areas. Moreover, the read rates are not 100%, due to unreadable, damaged, or missing tags. In addition, mistakes can happen because the reading is based on proximity. To prevent inaccurate data from being transmitted to enterprise applications, a successful RFID solution must be able to deal with erroneous or missing information (Solidsoft, 2006).

Finally, privacy concerns may be a limitation for RFID technology. Some privacy advocates have stated their concerns about the potential of RFID technology to seriously infringe on personal privacy. Beth Givens, director of the Privacy Rights Clearinghouse, an advocacy organization in San Diego, said the following:

"If ever there was a technology calling for public-policy assessment, it is RFID,…RFID is essentially invisible and can result in both profiling and locational tracking of consumers without their knowledge or consent, …So far, the development and implementation of RFID has been done in a public-policy void. What is needed is a formal technology assessment process to be done by some sort of a nonpartisan body comprised of all stakeholders, including consumers. The unique information contained in each RFID tag could also be captured by various readers and used to track a person's movements through tollbooths, public transportation and airports." (Vijayan, 2003).

2.2. RFID technology implementation issues

RIFD is a relatively simple technology providing intensified capabilities compared to other technologies such as barcode technology. Modern supply chains have many problems related to the lack of precise and integrated data. RFID provides important potential solutions to these problems. Seymour, Lambert-Porter, & Willuweit (2008) categorize implementation issues for RFID technology applications into five categories, as displayed in Fig. 6. The first category is the RFID technology itself, which might invoke some problems in terms of cost and resources, usefulness, complexity, accuracy, and infrastructure issues. The second category is the inter-organizational issues in regards to concerns about security, customer needs, and intensity of information change. The third category is the personnel-related issues such as management support, resistance to change, and experience. The fourth category is the intra-organizational issues including organizational culture, training and support, and organizational-wide readiness. Lastly, environmental factors such as standardization of RFID tags and a coding system as well as an unwillingness to collaborate among vertical or horizontal supply chain partners might result in negative impacts on RFID technology implications. Decision makers should consider these issues and prospective solutions as well as an implementation strategy beforehand for the success of an RFID application.

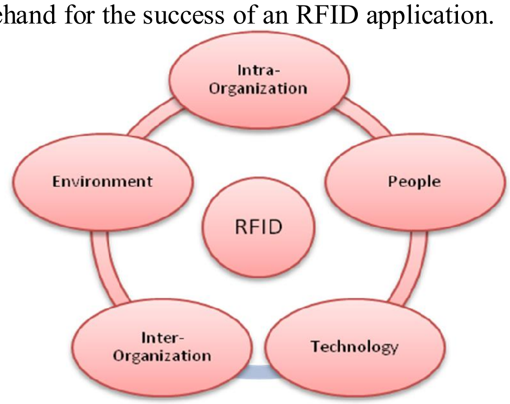

Fig. 6. RFID Implementation Issue Categories

The maturity level of an organization could be another consideration for the success of RFID implementation in addition to those issues aforementioned. In most cases, the maturity level of the organization plays an important role in the success of RFID technology implementation into Supply Chain Management (SCM). A SCM Logistics Maturity Model has been developed to determine the maturity level of an organization's SCM. This model consists of five sequential life stages. The model starts with the pilot studies stage where an organization is incapable of providing a stable environment for RFID technology-based infrastructure development. Then, the logistics projects stage comes after the pilot studies stage has been accomplished successfully and the organization is ready and capable to implement its strategies, goals, and objectives. The third stage is the organizational operations stage where a documented, new logistics system management is being developed and personnel go for training for the new RFID-based logistics system process. Following this stage, the organization reaches the logistics visibility stage where metrics have been developed to test logistics visibility within the supply chain. The organizational level stage is the last stage where the focus is on continuous process improvement (Myerson, 2006).

In their study, Jaska and Reyes (2007) propose guidelines to organizations for RFID technology implementation. They propose eight steps that need to be adapted, depending on organization type, including understanding what RFID can and cannot do, analysis of the current system, building a return on investment (ROI) business case, requirement analysis, prototype testing, implementation, and monitoring and continuous improvement. These steps can help managers minimize RFID implementation risks.

2.3. Cost-Related Issues

Even as RFID technology gets more mature every day, it is still considered as an expensive solution. Since RFID technology implementation has various system variables that in turn alter from one industry to another, it is very difficult to define the cost breakdown structure for RFID implementation (Randal, 2007). However, there are some studies that attempt to define and develop a model for RFID implementation. Szmerekovsky and Zhang (2008) tries to weigh the determined costs and benefits of RIFD implementation against the fixed costs of RFID implementation in a mathematical model by studying the effects on manufacturers and retailers of attaching RFID tags at the item level in a vendor-managed inventory system. Many authors designate general cost factors that every organization bears when they deploy RFID technology to their processes. Bhuptani and Moradpour (2005) categorize the cost of RFID deployment into three areas: hardware, software, and services.

2.3.1 Hardware Cost

Hardware costs consist of tags, readers, host computers, network equipment, and antennas. Types of tags generally determine the tag prices. Besides that, the shapes and sizes of tags, dependent upon the RFID applications, have impact on tag prices. In addition to these two factors, other factors such as capability of being rewritable, range capability, and on-board memory availability can affect tag prices (Bhuptani & Moradpour, 2005). The cost of a passive tag seems relatively less than active tags. Even though passive tag prices seem very low, the aggregated cost of tags becomes crucial depending on where RFID technology is applied. Especially, item-level tagging requires quite excessive amounts of tags that are usually made up of passive tags. The cost of a passive tag depends on its frequency, design of the antenna, the amount of memory, and packaging around its transponder. The cost of passive tags ranges from five cents when purchased in high volume to several dollars. On the other hand, the cost of an active tag depends on the size of the battery included, the amount of memory on the microchip, and the packaging around the transponder. The cost of active tags ranges from $10 to $100 or more (RFID System Components and Costs, n.d.). When the number of tags needed is considered then the question of which partner should pay for the RFID tag attachment to items or pallets in the supply chain emerges as an important issue. The DoD and Wal-Mart mandates require their vendors to affix RFID tags on their products. Therefore, vendors should consider the cost of the label printers, encoders, etc. as cost factors. However, the DoD still incurs tag costs and related label printer costs.

The immobilized RFID reader price ranges from $200 to $5,000. The variability results from the reader's range, multi-frequency flow, and antenna capability. On the other hand, the handheld RFID reader combines antenna and reader in the same appliance. The price for the handheld RFID reader ranges from $300 to $2,000. Yet, the effectiveness of the RFID reading capability might not be the same as the immobilized RFID readers.

In terms of antennas, there are two applications. One is connected to the RFID chip and the other is connected to the reader. The cost of the antenna connected to the chip might be considered within the RFID tag cost. Conversely, the cost of the antenna connected to the reader varies depending on size, range, and directional output. The cost ranges from five hundred dollars to thousands of dollars. Additional features such as the special design of antennas can add to the primary cost. In addition, Electronic Product Code (EPC) compliant or non-EPC compliant features can change the ultimate price of the antenna.

RIFD applications need local and integrator servers to run. The cost of a server starts at $2,000.

2.3.2 Software Costs

Middleware is an important cost driver. The price of middleware varies in the range of $25,000 to $800,000. The type of RFID technology implementation and application area identifies the cost of middleware. In addition, the RFID middleware appliance might cost from $8,000 to $20,000 per device.

2.3.3 Service Costs

Service costs consist of both installation costs and support and maintenance costs. Installation of readers and antennas, connection to the host computer, and setting up the infrastructure elements should be done with intense care since they can greatly impact the performance of the system. The environment where the RFID reader and antenna is to be set up varies from one application to another. Getting high performance from an RFID application rests on how well it is installed and tuned. The RFID engineer should tune the antenna and reader to get higher performance from radio frequencies. Maintenance and support costs also vary depending on an organization's definition of depreciation strategy, and how well current processes meet requirements. Software service costs might cost up to 15 % of the license costs.

2.4. Investment Decision Method, Cost of Ownership and Lifecycle Cost

An investment project starts with an idea for increasing shareholder's wealth by producing a new product or improving existing production or service processes in the business world. On the other hand, in the public sector, an investment project requires an assessment of economic efficiency to use resources.

The purpose of RFID investments in MLS could most likely target the reduction of operating costs such as inventory and labor. Whatever the goal of an investment is, it still needs to be compared to the current processes or alternative investments for justification. The decision of any investment can be assessed by various methods. These methods have their own characteristics. Whichever method is chosen, it is crucial to know the limitations and advantages of that method. Some investment decisions might vary depending on the method that is used for the assessment. Cost- benefit analysis (CBA), cost effectiveness analysis (CEA), net present value (NPV), payback period (PP), and internal rate of return (IRR) are some methods that have been used to assess and evaluate the investment opportunities.

The forecast or prediction of the total cost of investment alternatives is very valuable in making qualitative decisions. The cost of ownership (COO) is a concept to foresee the future financial obligations and liabilities that will have to be incurred to own the system. COO includes not only purchase costs but also the overall cost of the system over its lifetime. COO can be calculated via three different ways: life cycle cost (LCC), through life cost (TLC), and whole life cost (WLC). All these three ways are the same in general but each one serves different objectives and applications. LCC is a technical process that compares the cost of the relative features of two or more alternatives. TLC is a financial or budgetary process that estimates the cost of a single alternative over its intended lifetime by financial accounting period.

WLC is a prediction of the total required resources to purchase an alternative over its intended lifetime. It can be said that WLC includes TLC as well as costs of the infrastructure and training (Jones, 2006).

In this study, the authors will use LCC to calculate COO for the RFID applications. The main objective of conducting cost analysis is to estimate how much each alternative will cost during its projected lifetime. The LCC model determines the total cost of acquisition and ownership of the system over its intended lifetime to the government. LCC has been named the defense system total ownership cost (TOC) throughout the DoD acquisition environment.

The structure of LCC components varies depending on the system types. LCC for major weapon systems includes the cost of research and development (R&D), investment, operating & support (O&S), and disposal. R&D costs embrace the costs of prototypes, engineering development, equipment, test hardware, contractor system test and evaluation, government support to the test program, and related environmental safety, training, and data. Secondly, the cost of investment (acquisition) that occurs during the low-rate initial production, production, and deployment phases comprises the cost of procuring the major equipment and its support elements, which includes training, data, initial spares, war reserve spares, and military construction costs. Thirdly, operating and support costs embrace the costs that are incurred to operate, maintain, and support alternate system capability. Costs for personnel, consumable and repairable material, and all levels of maintenance, facilities, and supporting investment are parts of the operating and support cost. Finally, disposal cost is the cost of getting rid of excess or surplus property or material from inventory. It includes costs of demilitarization, detoxification, redistribution, transfer, donation, sales, salvage or destruction, as well as the costs of hazardous waste disposition and environmental cleanup.

The distribution of these cost categories throughout the LCC differs from one system to another. As seen in 0the historical cost distribution of cost types, O&S, and disposal cost comprises 70% of all ship acquisition costs, whereas for space systems it is only 15% (Office of Aerospace Studies, 2004).

Table 1. Historical Cost Distribution Data

System Type	R&D (%)	Investment (%)	O&S Disposal (%)
Space	18	66	16
Fixed Wing Aircraft	20	39	41
Rotary Wing Aircraft	15	52	33
Missiles	27	33	39
Electronics	22	43	35
Ships	1	31	68
Surface Vehicles	9	37	54

3. Military Logistics System

Management of military logistics is considered one of the oldest business processes in history. The sustainment and support of military personnel and equipment have been a principal concern of commanders since ancient times. Yet, applications of technological improvements in logistics systems have been considered far behind those in weapon systems. In recent years, there have been many attempts to improve the performance of military logistics systems because of improvements in information, identification, and tracking technologies.

The overall mission of MLS is to provide responsive and cost-effective support to military personnel and other units. Military personnel cannot win battles without having a highly agile and responsive logistics system that will effectively support their needs. It is essential that MLS use efficient business processes supported by up-to-date technologies.

The MLS consists of various components to manage materiel support, maintenance, and transportation issues. In order to simplify the study, the authors' main focus was on the supply chain that executes the materiel support mission in the MLS.

Supply Chain Management (SCM) in MLS is not very different from a commercial SCM as displayed in 0The supply chain starts with the suppliers that provide contracted materiel to the Main Supply Command (MSC), where quality inspection and storage activities take place. Then, materiel flows from the MSC to the Sub Supply Command (SSC) and from there to the customers who are the end users in military units.

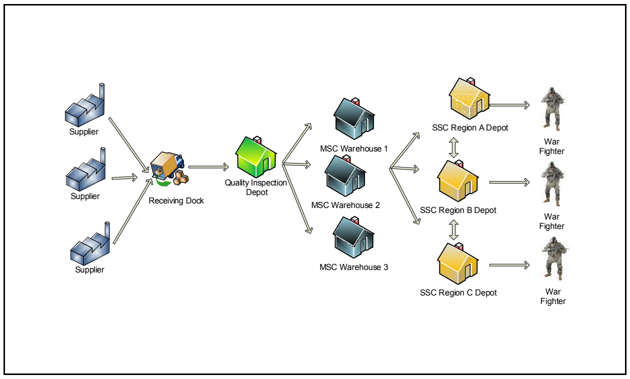

Fig. 7. Supply Chain Flow

SCM is composed of supply commands including a MSC and SSCs that are located in different regions in order to support the facilities and bases. The MSC includes warehouses that are located in the same region. Depending on its supportive capabilities, each SSC has five to twenty depots. Each supply command consists of inventory management, procurement, and transportation offices. These offices are broken into units that execute different and specified job descriptions. The number of personnel holding the positions and their job descriptions could vary subject to the supply command's workload.

The way the supply chain flows depends on both materiel categories and the policy. The SCM commences when aggregated needs of SSCs are contracted out to suppliers. The MSC usually procures and stocks most of the materiel, then ships them to SSCs. The main mission of SSCs is to support customers under their responsible regions. In addition to acquiring materiel from the MSC, each SSC has its own procurement department to purchase not only authorized materiel to meet regional requests but also items with the purchase order given from headquarters (HQ) to meet other regions' needs.

The materiel and information flow are composed of three consecutive phases in SCM as displayed in 0

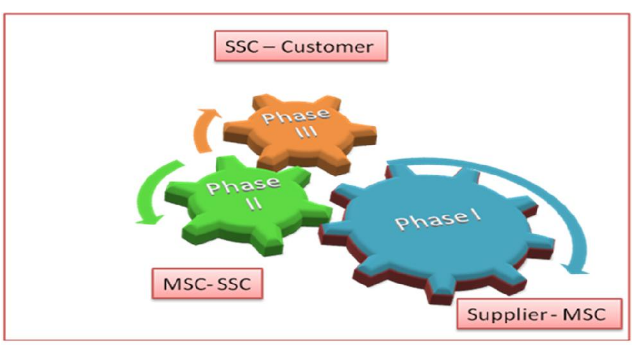

Fig. 8. Supply Chain Phases

4. Analysis

4.1. Methodology

Based on the literature review, the authors decided to use a LCC model as an investment decision method. The authors also conducted phone interviews with the personnel working in the Inventory Control Center (ICC). The primary focus of the interviews with the personnel was to gain an appreciation for the processes of the MLS. The authors' main knowledge about the MLS was based on one of the author's working experience. As a result of these interviews, the authors were able to identify the processes of the MLS, categorize them, and determine the parameters related to the LCC of the MLS. For the sake of easein the calculations, some assumptions were made. The data related to the initial infrastructure construction cost of RFID was collected from internet searches. Moreover, the authors strove to provide current average costs related to the cost element of RFID technology. After collecting the data, the authors used Easy Fit software (MathWave Technologies, 2005) to determine which distribution model best fits to the data. Some of cost element calculations required simulation to project future possibilities. Thus, the authors wrote code in Visual Basic and incorporated them into macros. Finally, the authors developed the LCC model in MS Excel 2007.

4.2. Categorization of the cost elements

The proposed LCC model includes infrastructure construction cost, logistics operation cost, and miscellaneous cost categories. Each cost category consists of cost elements that represent different cost components of a logistics system.

4.2.1. Infrastructure Construction Cost

The authors subcategorized the infrastructure construction cost as program management office (PMO) cost, integration cost, equipment cost, and test cost.

PMO cost defines the labor and stationary costs required to plan, program, and execute the acquisition of RFID technology. Integration cost is the cost that is incurred to incorporate RFID technology into the existing system, such as the middleware cost. Equipment cost embraces the purchasing of the equipment required for construction of the RFID-integrated logistics system. It consists of door and hand-held readers, antennas, label printers, an integrator server, and local server costs. The last cost element, namely the test cost, is the cost required to figure out how well- a constructed RFID-integrated logistics system performs and whether it needs further improvements.

Among all of these cost elements, infrastructure construction cost is incurred mostly at the beginning phase of the construction of the RFID-integrated logistics system.

4.2.2. Logistics Operating Cost

Logistics operating cost is the cost that is incurred to order, receive, store, process, and distribute the supplies using the RFID-integrated logistics system. This cost is comprised of the RFID tag purchase cost, maintenance cost, inventory cost, and labor cost.

The RFID tag purchase cost is the cost that defines the cost of buying RFID tags that are used on cases of supplies. This model requires disposable tags. In other words, once the RFID tag is applied on cases, it cannot be used again. Therefore, the annual demand of the RFID tags equals to the total number of cases of supplies purchased. Maintenance cost involves the sustainment cost of all the components of the RFID system. It includes both corrective and preventive maintenance costs. Inventory cost defines the conversion of physical inventory levels into dollar values. This conversion includes the ordering cost, purchase cost, and handling cost. Ordering cost includes all costs endured during preparing and sending the orders to suppliers and receiving them. Purchase cost is the total cost spent on acquiring supplies. Purchasing cost is ignored in the calculations because it has to be incurred for both scenarios. Holding cost is the total amount paid for conserving supplies such as the facilities used, electricity, and security. Labor cost is the amount of money paid to the personnel that are assigned to work in the logistics system. Labor cost embraces the salaries paid to custodians, accountants, managers, the inspection team, stock controllers, workers, and check and count teams.

4.2.3. Miscellaneous Costs

Miscellaneous costs are incurred due to the loss or misidentification of supplies. Loss cost is incurred as a result of any lost or stolen items throughout the supply chain. Misidentification cost emerges when an item is not classified correctly and treated as another item. Misidentified items will remain on the shelves or move between supply commands. Thus, disutility cost of these items will consist of the holding cost and purchasing cost.

4.2.4. Scenarios

In order to get an appreciation for the effects of RFID technology on the LCC of the MLS, the authors will perform a LCC analysis for each scenario to compare total life cycle costs of both scenarios.

4.2.5. "As-is" Scenario

This scenario is based on the current, manually driven logistics system as described above.

4.2.6. "To-be" Scenario

This scenario uses the "as-is" scenario and integrates it with RFID technology. According to this scenario, RFID technology integration will be completed within four years. It is required to implement RFID into the MSC in the first year. The reason for this requirement is that the MSC is the key component of the supply chain. Moreover, the MSC is the trigger point for almost all of the supply chain activities. All the SSCs will be equipped with RFID in due course according to the decision of management. RFID readers will be mounted at the gates of warehouses and depots.

The supply chain phases will be modified due to improvements or process flow changes to make the phases more efficient and leaner.

4.2.7. Assumptions

The model developed required the authors to make some assumptions based on their experience, literature review, and interviews. Due to difficulty obtaining the exact data, and the fact that the supply process has many complex components, the authors simplified the supply chain processes and input parameters.

The authors divided the assumptions into three categories including environmental assumptions, supply-chain specific assumptions, and process-related assumptions.

The first environmental assumption is that the supply chain in the model is available at any time and no shortage of resources exists such as equipment, personnel, software, etc. The second environmental assumption is that the system is up during its lifetime without any significant component failure. The third environmental assumption is that it is a mandatory requirement to construct the new RFID-integrated supply chain within four years and the MSCs must be the first places to adopt it in the first year.

The first assumption specific to supply chains is that it is expected to mandate the suppliers to be compliant with RFID technology in at most ten years. Thus, all RFID tags are anticipated to be purchased by the MSCs during this time. After the ten-year period, the cost of RFID tags should be incurred by the suppliers. Moreover, the tag prices are estimated to reduce gradually due to the improvements in RFID technology and the increase in the number of tags to be purchased. The second assumption specific to supply chains is that the SSCs do not purchase any items by themselves and have to acquire the items by means of the MSCs. The third assumption specific to supply chains is that all the supply items have the same priority designators. This means that no item has precedence over other items, and each item has to run through the same processes. The fourth assumption is that the transportation cost and time of the items are neglected throughout the MLS. Furthermore, no delays exist due to the lack of transportation.

The first process-related assumption is that the inventory cost does not include the purchasing cost of the items. The second process-related assumption is that supply items delivered to supply commands will be in cases. The third process-related assumption is that demand size represents the quantity of cases and not the number of items. The fourth assumption is that the standard deviations of the daily demand for all cost categories are the same. The last process- related assumption is that the needed database infrastructure has already been established and has enough capacity to meet the overload of data.

4.2.8. Input Parameters

The authors divided the input parameters into ten categories.The Salary and Manpower input parameters are named according to job titles and grouped by both the type of supply command and the processes they work in. The variable parameters include salaries and the number of personnel working under this title.

The general parameters are comprised of the discount rate; inflation rate; the number of MSC, SSC, and warehouses per MSC; depots per SSC; door readers per warehouse/depot; hand readers per warehouse/depot; door-reader antennas per reader; local servers per SSC; integration server; and label printers per MSC/SSC. Construction time is assumed to be constant at four years. Finally, system lifetime value will be retrieved from the user by means of an input box. Reduction goal parameters define the reduction goals in terms of personnel titles as well as misidentification and loss rates.

Construction cost parameters are related to all the costs incurred prior to and during the construction of the system. PMO labor cost reflects the total amount of salary of all acquisition personnel. Test cost per warehouse depot, integration cost to the current system per command and the purchase of a door reader, hand reader, antenna, labor printer, and an integrator server are variable parameters in this category.

Supply command construction plan parameters show when and how many supply commands should be integrated with the RFID technology. The construction has to be finished in four years and the MSCs must be the first places to be integrated with RFID in the first year. These are variable parameters. All these parameters inserted by the user are controlled by the macro developed in Visual Basic (VB). Expected tag price parameter contains the probable purchase price of a tag. The prices are expected to reduce gradually due to technological improvements and the size of the batch purchased.

Lead-time parameters refer to the time required to transport the supplies between to points. Specifically, the lead time for the first phase reflects time spent to acquire items from a supplier to the MSCs. The second phase lead time is the time consumed to transfer an item from the MSCs to the SSCs. The third phase lead time is the final process time that takes place between the SSCs and customers.

Inventory parameters are grouped by the unit costs to simplify the calculations. Each unit cost between intervals is fixed to the upper limit of the interval. Misidentification and loss probabilities, namely expected annual demands for the SSCs, are variable parameters. Expected annual demand for the MSC and standard deviations of the daily demands of the SSCs as well as the MSCs are obtained through calculations embedded in the model. Historical misidentified and lost item data parameters are retrieved from historical data.

Operating cost parameters are made up of the ordering cost, holding cost rate, system maintenance cost per command, the review interval, inventory on hand, confidence level, and rate of standard deviation parameters. The rate of standard deviation is used in the calculation of the safety stock and represents the percentage of the daily demand.

4.2.9. Model

The authors developed equations for each cost elements. Then, the total cost of each category obtained by adding the costs of these related cost elements. Formulas used to get the cost elements are displayed in 0

Table 2. Formulas Used in the Model

Cost Category	Cost Element	Formula
Construction Cost	Labor (PMO)	Monthly labor cost of PMO x 12
	Integration Cost to Current System	Integration cost x Number of SSCs and MSCs constructed in the corresponding year
	Door Reader Cost	Door reader cost x Number of door readers required
	Hand Reader Cost	Hand reader cost x Number of hand readers required

	Antenna cost	Antenna cost x Number of antennas required
	Label Printer Cost	Label printer cost x Number of label printers required
	Integrator Server Cost	Integrator server cost x Number of integrator server required by the MSCs
	Local Server Cost	Local server cost x Number of local server required by the SSCs
	Test Cost	Test cost x Number of warehouses/depots integrated with RFID
Operating Cost	Tag Purchase Cost	Tag cost for the corresponding year x Annual demand
	Maintenance Cost	Annual Maintenance Cost x Number of MSCs and SSCs integrated with RFID
	Inventory Cost	As explained below
	Labor Cost	Monthly salary of each personnel x Number of personnel x 12
Miscellaneous Cost	Misidentification cost	As explained below
	Loss Cost	As explained below

Inventory costs for both scenarios are obtained by incorporating the multi-period inventory systems. The authors used a "fixed time period with safety stock model" for the "as-is" scenario because it is the preferred model for the current system. However, for the "to-be" scenario, the authors decided to use a "fixed order quantity model" due to the increased real-time visibility and traceability resulting from the integration with RFID technology. This is one of the significant benefits of RFID technology implementation in a supply chain.

The "fixed time period with safety stock model" is based on fixed time intervals to order supplies. In other words, orders are placed at the time of review. The model consists of two components. The first component is safety stock and the latter is required inventory for the fixed review period. The safety stock level is

$$SS = z\sigma_{T+L} \tag{1}$$

where

SS = safety stock level

z = the number of standard deviations for a specified service probability

T = the number of days between reviews

L = lead time

σ_{T+L} = standard deviation of demand over the review and lead time

After the safety stock level is calculated, the order quantity will be:

$$Q = d(T+L) + SS + I \tag{2}$$

where

Q = quantity to be ordered

d = average daily demand

I = inventory on hand

After all of these calculations, the level of inventory and total annual inventory cost for the "as-is" scenario will be:

$$Avg\,(Inventory\,) = SS + \frac{Q}{2} \tag{3}$$

$$\sum Inv.Cost = \frac{D}{Q}S + (SS + \frac{Q}{2})H \tag{4}$$

where

D = annual demand

S= ordering Cost

H = holding Cost

On the other hand, the "fixed order quantity model with safety stock" attempts to determine the reorder point as well as the order quantity. The following formulas are used in the calculations:

$$SS = z\sigma_L \tag{5}$$

$$R = dL \tag{6}$$

$$Q = \sqrt{\frac{2DS}{H}} \tag{7}$$

where

σ_L = standard deviation of demand over the lead time

R = reorder point

The authors obtained historical data regarding misidentified items in previous years and calculated the mean and the standard deviation, then estimated a misidentification probability distribution based on experience as displayed in 0

Table 3. Misidentification Probability Distribution

Misidentified Item Avg.Unit Cost	*Probability*
\$ 10,000.00	0.010
\$ 8,000.00	0.015
\$ 6,000.00	0.020
\$ 4,000.00	0.025
\$ 2,000.00	0.030
\$ 1,000.00	0.120
\$ 500.00	0.220
\$ 250.00	0.260
\$ 100.00	0.300

The authors created a simulation model to calculate the misidentification cost throughout the lifecycle of the system. The number of misidentified items is randomly created by the simulation for each year using the mean and standard deviation of the historical data. The average unit cost of the misidentified items for each year is generated by the simulation as well. For every misidentified item, the simulation generates a random number between zero and one. This number is looked up in the table and the corresponding unit cost is found. This process is iterated as many times as the generated misidentified item numbers for each year. The average unit cost for all these misidentified items is calculated by averaging these generated unit costs. Eventually, the total misidentification cost is equated to the sum of the total value of misidentified inventory and holding cost of these items.

The authors used exactly the same simulation architecture in their loss cost calculations. Similar to the misidentification cost calculation, the authors estimated a historical loss data, the associated mean and standard deviation and the loss probability distribution table, which is displayed in **Error! Reference source not found.**

Table 4. Loss Probability Distribution

Lost Item Avg. Unit Cost	*Probability*
$ 10,000.00	0.005
$ 8,000.00	0.008
$ 6,000.00	0.010
$ 4,000.00	0.020
$ 2,000.00	0.030
$ 1,000.00	0.090
$ 500.00	0.220
$ 250.00	0.280
$ 100.00	0.337

The number of lost items for a specific year is randomly created by the simulation using the mean and standard deviation of the historical data. The average unit cost of the lost items for each year is calculated by the simulation as well. For every lost item, the simulation generates a random number between zero and one. This generated number is looked up in the table and the corresponding unit cost is found. This process is iterated as many times as the generated lost item numbers for each year. The average unit cost for all of the lost items is calculated by averaging these generated unit costs. Finally, the total loss cost is calculated by multiplying the generated number of lost items with the average unit cost of these items.

The authors calculated all the cost elements for each year within the lifecycle as constant dollars. First, constant dollar values are adjusted for inflation using the following formula:

$$(IAV)_t = (CV)_t (1+i)^t \qquad (8)$$

where
IAV = inflation-adjusted value
CV = constant dollar value
i = inflation rate
t = time

Then, these inflation-adjusted values are discounted to current dollars using the formula:

$$(PV)_t = (IAV)_t / (1+i+r)^t \qquad (9)$$

where
PV = present value
r = discount rate

In addition, the total cost of each cost element is calculated as adding all the annual present values together.

$$PV = \sum_{t=1}^{n} (PV)_t \qquad (10)$$

where
n = lifetime

Finally, the present values of all the cost elements are added up to obtain the total ownership cost of the system.

$$LCC = (PV)_{construction} + (PV)_{operating} + (PV)_{miscellaneous} \qquad (11)$$

The authors elucidated in this chapter how they developed the model, in the next chapter the results of the analysis will be evaluated.

5. Results

5.1. Life cycle costs

The model developed by the authors encompasses all cost elements incurred during the lifetime of the system. Lifetime can be determined by the user before running the model. The results are obtained for a 20-year lifetime. Misidentification and loss costs are obtained by means of a simulation embedded in the worksheet. Every time the user runs the model, the simulation replicates itself 100 times to ensure the confidence intervals around the estimates are sufficiently small. Moreover, a year consists of 250 days.

5.1.1. As-is Scenario

The LCC of keeping the current system in operation is $152.4M. This cost is the sum of $144.5M in logistics operating costs and $7.9M in miscellaneous costs. Under the "fixed time period with safety stock inventory control" model, inventory cost represents 39.29% of the LCC. Labor cost, which constitutes 55.53% of the LCC, is the largest cost element for the current system. Miscellaneous cost, which consists of misidentification and loss costs, accounts for $7.9M of the LCC, which represents 5.18% of the total cost. Table 5 depicts the summary of the cost elements.

Table 5. LCC of As-is Scenario

Cost Elements	As-Is Scenario	Distribution
Infrastructure Construction Cost	**$ -**	**0.0%**
Logistics Operating Cost	**$ 144,444,232**	**94.8%**
- Tag Purchase Cost	*$ -*	*0.0%*
- Maintenance Cost	*$ -*	*0.0%*

- Inventory Cost	*$ 59,854,632*	*39.3%*
- Labor Cost	*$ 84,589,600*	*55.5%*
Miscellaneous Cost	**$ 7,890,178**	**5.2%**
- Misidentification Cost	*$ 3,383,450*	*2.2%*
- Loss Cost	*$ 4,506,729*	*3.0%*

5.1.2. To-be Scenario

The LCC of constructing and operating the new RFID-integrated system is $140.9M. This cost is the sum of $20.4M in infrastructure construction costs, $118.9M in logistics operating costs, and $1.6M in miscellaneous costs. Under the "fixed quantity with safety stock inventory control" model, inventory cost represents 28.16% of the LCC. Labor cost constitutes 44% of the LCC for the proposed system. Furthermore, miscellaneous cost, which consists of misidentification and loss costs, accounts for $1.58M of the LCC. This cost represents 1.12 % of the total cost. Table 6. depicts the summary of the cost elements.

Table 6. LCC of To-be Scenario

Cost Elements	To-be Scenario	Distribution
Infrastructure Construction Cost	**$ 20,394,127**	**14.5%**
Logistics Operating Cost	**$ 118,861,046**	**84.4%**
- Tag Purchase Cost	*$ 6,259,478*	*4.4%*
- Maintenance Cost	*$ 10,969,725*	*7.8%*
- Inventory Cost	*$ 39,656,810*	*28.2%*
- Labor Cost	*$ 61,975,033*	*44.0%*
Miscellaneous Cost	**$ 1,578,036**	**1.1%**
- Misidentification Cost	*$ 676,690*	*0.5%*
- Loss Cost	*$ 901,346*	*0.6%*

Given these results, with the integration of RFID technology, the LCC of the system reduces from $152.4M to $140.9M. Within the proposed lifetime of 20 years, there is an approximate reduction of $12M, which accounts for an 8% reduction in the LCC of the current system.

5.1.3. Payback Period

One of the biggest concerns related to RFID technology is its initial construction cost. From this point of view, it is crucial to determine the payback period. The payback period is the period of time required for the return on investment to repay the sum of the original investment. For the model developed by the authors, the payback period refers to the length of time where the LCC of the proposed system is equal to that of the current system and begins being less than that of the current system. After the payback period the benefits gained from the proposed system is greater than the initial construction cost of the system. Briefly, the payback period is the point where LCCs of the two scenarios are equal.

To calculate the payback period the authors changed the lifetime parameter and held all the other variables constant. Since the initial construction is assumed to finish at the end of the fourth year, the authors run the model for the lifetime range of 5 years to thirty years. Fig. 9. displays the graph of the LCCs of both the proposed and current system. The results indicate that beginning from the eleventh year the LCC of the proposed system is less than that of the current system.

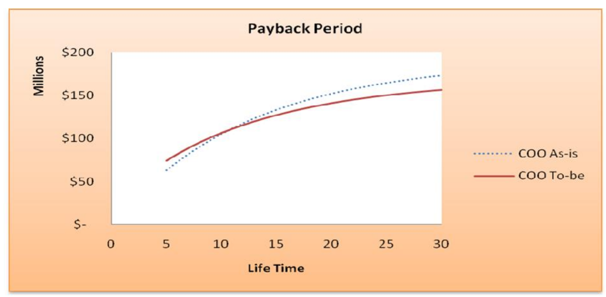

Fig. 9. Payback Period

As a result of this analysis, the payback period is eleven years. At first glance, a payback period of eleven years may seem to be too high for a decision maker to justify the investment in the RFID technology. However, this technology still has not matured and with further improvements in the RFID technology and in turn, with the reductions in the initial construction cost, the payback period may reduce gradually in the future.

6. Conclusion

This study examined the Lifecycle cost of a RFID-integrated military logistics system. The study primarily focused on the question of whether the cost of integrating and operating the MLS with RFID was worth the investment. To answer this question, the authors developed a LCC model. The main result of the study revealed that the cost of ownership of the RFID-integrated logistics system cost less than that of the current logistics system despite the huge initial integration cost. Moreover, this study identified the key cost parameters that have significant impact on the lifecycle cost.

Finally, the authors developed this model for a military logistics system, but it could also be used as a basis for any other supply chain. The decision makers can adopt this model to their own supply chain processes with small changes. Thus, they can determine the total cost of integrating their supply chain with RFID technology. Furthermore, they can decide on the worthiness of the investment by comparing the difference between LCCs of their current and RFID-integrated systems.

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