The Application of Automatic Identification Technology
Onboard Naval and Commercial Ships

by

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ABSTRACT

Automatic Identification Technology (AIT) has numerous potential applications in the maritime field. By putting AIT tracking devices, such as Radio Frequency Identification (RFID) tags, on materials and equipment, items can be accurately located, tracked, and recovered, while reducing the manpower and other costs associated with these tasks. This results in more efficient movement and utilization of materials and equipment, and thus helps to reduce the cost of ship construction and operation.

This research investigates the use of RFID tags onboard both naval and commercial ships, focusing on the tracking of materials being loaded and unloaded from the vessels. To examine the benefits of the use of RFID for shipboard applications, several proof-of-concept demonstrations were conducted, and a computer model was created to permit analysis of these operations. These demonstrations along with the model provided the framework necessary to provide quantitative data on the current practices, as well as after modifications to simulate what effect the addition of RFID technology will have to the process.

Finally, a financial analysis was performed on a shipboard storeroom scenario, to determine the economic feasibility of implementing an RFID system. This thesis presents the results of the analysis, plus other potential application of RFID aboard ships. The data supports the conclusion that RFID technology does offer significant benefits when implemented with shipboard applications.

Thesis Advisor: Henry S. Marcus, Professor of Marine Systems,
NAVSEA Professor of Ship Acquisition
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Chapter 1: Introduction

Automatic identification technology (AIT) has improved the operations of many land-based businesses. In the manufacturing, logistics, and retail industries, AIT has revolutionized how items are located, tracked, and inventoried. AIT, which includes barcodes, magnetic stripes, integrated circuit cards, optical memory cards, and radio frequency identification (RFID), changes the way data is collected, and provides valuable information on utilization, location, movement, and distribution.

The recording and tracking of assets are vital to any shipping company, whether it be a commuter ferry operator, a cruise line, or the United States Navy. AIT has the potential to significantly improve a variety of tasks aboard ships, including vessel loading and overall safety.

RFID technology connects all phases of the supply chain, from resourcing and manufacturing to inventory and distribution. Whether there is a need to identify and manage raw materials, manufactured goods, or products in transit, RFID creates real time information, which helps speed production, improve quality, and streamline delivery.

The ability to track, locate, and inventory items quickly and automatically, allows ship owners to increase the efficiency of their replenishment processes, reducing the effort involved in material control, increasing the accuracy of this process, and reducing costs.

This thesis analyzes the application of Radio Frequency Identification (RFID) technology aboard naval and commercial ships, and its ability to expedite the collection of information materials being loaded onto vessels. RFID speeds the collection of data and eliminates the need for human operations in the process, contributing to the optimization of manning both ashore and afloat. The research identifies the potential for increased productivity in the area of documenting material flows through the application of RFID.
As technology progresses, and the continued demand for more accurate data collection and monitoring grows, RFID will play an increasing important role onboard naval and commercial ships. This thesis addresses some of these issues, and suggestions are made as to how RFID can be applied efficiently in ship operations.

A background of the automatic identification industry is given in Chapter 2. Chapter 3 presents a description of the specific AIT investigated in this research, RFID technology. Chapter 4 describes the loading process of a vessel. The Proof of Concept demonstrations conducted, based on the model scenario, are detailed in Chapter 5.

Chapter 6 describes some current processes onboard commercial and naval vessels, while Chapter 7 proposes how RFID technology could be introduced to these processes. A description of the model framework is provided in Chapter 8, and Chapter 9 contains a financial analysis of shipboard RFID solutions.

Some additional potential applications for RFID systems onboard passenger commuter ferries, cruise ships, and naval vessels are presented in Chapter 10. Synergies between shipboard and shore-side RFID systems are suggested in Chapter 11. The research is then summarized, and conclusions made in Chapter 12.
Chapter 2: Background

To gain an understanding of Radio Frequency Identification (RFID) Technology -- what it is, how it can be used -- it is valuable to examine the history and motivation behind its development.

Barcodes

The use of conventional barcodes has revolutionized many everyday processes; from expediting tasks such as checkout at public libraries and retail stores, to the tracking of express letters and packages.

Barcodes were first developed in the late 1940’s, by a group of university researchers, as a means to automatically read product information during the checkout process. Early systems first utilized punch cards, then ultraviolet light, and finally a bull’s eye code. On October 20, 1949, the first barcode patent application was filed, entitled "Classifying Apparatus and Method." The inventors, two graduate students at the Drexel Institute of Technology in Philadelphia, PA, described their invention as relating "to the art of article classification...through the medium of identifying patterns".

The next milestone in barcode history was the adoption of the Universal Product Code (UPC) in April 1973. This action transformed bar codes from a technological curiosity into a business bombshell, and was one of the most important events in the history of modern logistics.

Before the UPC, various numbering systems were starting to be used around the world, in stores, libraries, and factories, each with its own proprietary code. After the adoption of the UPC, any bar code on any product could be read and understood in every store in the country, with suitable equipment.

UPC codes were developed and standardized before barcode readers were developed. The developers of the system were confident that the technology would eventually come
about to make reading the codes easy. The two technological developments during the 1960s, which finally made scanners simple and affordable, were cheap lasers and integrated circuits.

It was estimated that the bar-code revolution would cost each of the nation's tens of thousands of grocery stores more than $200,000 to purchase new equipment. Chains would have to install new data processing centers, and re-train their employees in the use of this new equipment. Manufacturers would potentially spend $200 million a year on the new UPC labels. Yet studies and tests showed that the system would pay for itself after only a few years. Standardization made it worth the expense for manufacturers to put the symbol on their products.

There is no price information encoded in a bar code, it simply identifies the item labeled. When a product's bar code is scanned at the check out point, the cash register sends the UPC number to the store's central Point of Sale (POS) computer to look up the UPC number. The central computer then sends back the actual price of the item, instantaneously. This allows the store to change the price whenever it wants, for example to reflect a discount or sale price.

While the introduction of the barcode has revolutionized product management, and the way that groceries and other retail items are purchased, they also have many limitations. These limitations include: only being able to read one barcode item at a time; the need for the barcode to be completely exposed in a direct line of sight with the scanner; the barcode tag cannot be registered if covered with dirt, moisture or other substances; requirements for the interaction of human labor to either place the asset appropriately for automatic scanning or to perform the actual scanning.

**Automatic Identification**

The first RFID systems were developed during World War II, when allied aircraft were equipped with secret low-frequency devices know as IFF (identify friend or foe)**. These devices were used by allied pilots to aid them in identifying approaching aircraft.
When pilots received the transmission from passing aircraft, they knew the plane was a "friend." If no transmission was received, the pilots knew “foes” were present and to be on the alert. A more recent and well-known application of a similar technology is electronic article surveillance devices.

Shoplifting is a major concern of many retail stores. To safeguard against this problem, item security measures are taken, known in the industry as loss prevention. A system is used which has special tags attached onto everything, so that an alarm goes off whenever a shoplifter tries to walk out with an item. Such tag-and-alarm systems are better known as electronic article surveillance (EAS) systems.

**EAS Systems**

A typical EAS system works as follows: An EAS tag or label is attached to an item in a retail store, which is then placed on the sales floor. When a consumer wishes to purchase the item, the salesclerk rings up the item and then the tag is deactivated, or taken from an active state where it will alarm an EAS system, to an inactive state where it will not flag the alarm. If the tag is a hard, reusable tag, a “detacher” is used to remove it. If it’s a disposable, paper tag, it can be deactivated by swiping it over a pad or with a handheld scanner, that "tells" the tag it's been authorized to leave the store. If the item has not been deactivated or detached by the clerk, when it is carried through the gates, an alarm will sound.

There are several types of EAS systems that dominate the retail industry. In the United States the most commonly used systems are Radio Frequency (RF) Systems. An RF EAS system works like this: A label or tag (a miniature, disposable electronic circuit with an antenna) is attached to a product. If the product leaves the store without being deactivated, the tag responds to a specific frequency emitted by a transmitter antenna, located in one of the pedestals of the exit gate.

This response is then picked up by an adjacent receiver antenna in the other pedestal. When this occurs, the label response signal is recorded and an alarm will be triggered.
A frequency sweep technique is used by most RF systems, in order to deal with different label frequencies. Operating frequencies of RF systems generally range from 2 to 10 million cycles per second (MHz). This allows the distance between the two pedestals to be up to 80 inches wide.

On some systems the transmitter and receiver are combined in one antenna frame. These are called mono systems and they can apply pulse or continuous sweep techniques or a combination of both. The mono system is used with hard labels, which are slightly more expensive than paper labels used with RF sweep techniques.

Another commonly used system is the Electromagnetic (EM) system. The EM system is dominant in Europe, and is used by many retail chain stores, supermarkets and libraries around the world.

In this technology, a magnetic, iron-containing strip with an adhesive layer is attached to the merchandise. This strip is not removed at checkout -- it's simply deactivated by a scanner that uses a specific highly intense magnetic field. (One of the advantages of the EM strip is that it can be re-activated and used at a low cost.)

A magnetized piece of semi-hard magnetic material (essentially, a weak magnet) is put up next to the active material to deactivate it. When the semi-hard material is magnetized, it becomes saturated and puts the tag in an inactive state.

With the EM system, the transmitter antenna generates intensive low frequency magnetic fields. When the tag or magnetic strip passes through the gates, it will transmit a unique frequency pattern. The adjacent receiver antenna then picks up this pattern. The small signal is processed and then triggers an alarm.

EM systems operate at lower frequencies, typically between 70 Hz and 1 kHz, so EM antennas are larger than those used by most other EAS systems. The low frequency
permits the strips to be attached directly to metal surfaces, and so EM systems are often used at hardware, book, and record stores. They are also often used at libraries, as the strips can be reactivated, by demagnetizing the semi-hard magnetic material.

As a result of the relatively weak response of the strip, the low frequency, an intensive magnetic field is required, so the maximum distance between antenna pedestals is only 40 inches.

EAS, Barcodes, and RFID

EAS systems are essentially simplified RFID systems, which provide an on/off signal to trigger an alarm. EAS systems do not provide the information necessary to identify any product data, such as the stock number or price of the item. As stated previously, barcode systems are being used for this purpose in retail stores.

While a barcode system may be sufficient for processing of individual items, it is still rather a time consuming and error prone method for tracking and data collection of any multiple item or bulk process. RFID offers many advantages over traditional barcodes for data collection when tracking inventory, or keeping track of key physical assets.

Some advantages of RFID include:

- Non-contact readability
- No direct line of sight necessary
- Readability of the tag despite dirt, moisture, or other substances that might accumulate on the tag
- Passive data capture, requires no interaction by the worker
- Parallel rather than serial reading

A RFID system is able to tell the retailer: what product was sold, who the manufacturer was, what price was charged, how many products are left on the floor and how much is left in stock, which colors sell best, and when it is time to reorder.

RFID in Commercial Applications

RFID has been used effectively for several years for a variety of applications. Among the most popular are electronic article surveillance, transportation management, access
control, and item management. Examples of RFID technology being used in everyday consumer products include consumer “point of sale” (POS) interfaces such as the Mobil Speed Pass™ retail gas pump application (figure 1,) and General Motors’ and Ford’s use of RFID chips on automobile keys for theft immobilization, known as immobilizers (figure 2).

Mobil Speed Pass customers fill up their tanks with gasoline, press a key-chain-sized device against a reader at the pump, and their accounts are automatically charged for the purchase.

Battery-less RFID transponders, small enough to fit in the head of a key are used for authenticating purposes in automotive, as anti-theft immobilization. These devices use a fixed, unique, read-only code programmed at the factory. When the key turns in the ignition lock casting, electromagnetic signals are sent from the base station in the steering column to power the transponder. Once the transponder is verified as the owner’s key, the ignition starts.

RFID is currently being used in many shore-based applications. The technology is capable of “hands-off”, error-free identification and tracking of numerous and rather diverse objects, from packages to hospital patients, automobiles to groceries. It seems natural then that RFID technology be applied to shipboard applications.
RFID and Shipboard Applications

Chapter 10 will examine this topic in greater detail, however it is important to present some ideas on how the introduction of RFID technology to the marine environment will improve many processes.

Consider the following scenario: A longshoreman sitting in his forklift drives a pallet of RFID-tagged boxes through a side-port of a cruise ship. The boxes have been thrown on the pallet without regard to orientation. As the pallet passes through the opening in the ship, an electronic manifest is immediately captured, containing a listing of all of the items on the pallet. The simultaneous identification process occurs passively - without requiring any human labor.

The present system in use at most cruise ship terminals, uses a manual paper-based system to record the assets being loaded (figure 4), which can be time-consuming, costly, and error-prone, as inaccuracies may occur should entries be incorrectly written or are illegible.

The age old practice of keeping records by writing them down on a pieces of paper, or by manually checking off of forms are becoming obsolete, as electronic paperless systems are increasingly being used. It is thus essential for any operation to have an accurate way of individually numbering each of their assets, and to have this information collected automatically.
The recording and tracking of assets are vital to any shipping company, whether it be a commuter ferry operator, a cruise line, or the United States Navy. The following chapters address some of these issues, and suggestions are made as to how RFID can be applied efficiently in ship operations.

RFID equipment is a part of the Automatic Identification and Data Collection (AIDC) industry, which also includes barcode, electronic data interchange (EDI), and magnetic stripe technology. As technology progresses, and the continued demand for more accurate data collection and monitoring grows, RFID will play an increasingly important role onboard naval and commercial ships. Before examining some of these applications, it is important to provide a more detailed description of RFID technology.
Chapter 3: Description of RFID Technology

RFID is a technology of storing and retrieving data through electromagnetic transmission to an RF compatible integrated circuit. This communication takes place without human intervention, direct contact, or line of sight between components. The RFID tag or integrated circuit, is usually a single solid state memory chip, but could also be designed where several electronic components together are used to form an integrated circuit design.

The circuit includes one or several memory chips that are used for data storage, a substrate backing material or circuit board structure, and an antenna of some type or design. This circuit may also contain a power source (battery) depending on the tag (transponder) design.

System Components
A typical RFID system consists of the following basic components:

Transponder - A transponder is an RFID tag. As stated above, it is an enclosed integrated circuit that stores data.

Interrogator - The interrogator or “reader” is a device that is used to primarily read and write data to RFID tags.

Radio Frequency - RFID uses a defined radio frequency and protocol to transmit and receive data from RFID tags. These RFID radio signals are subjected to the same physical phenomenon laws that affect normal electromagnetic radio transmissions, such as penetration difficulties through metal and liquids.
Tag Identifies Asset

The RFID tag works well in hostile environments being attached to, or fitted into, items for identification, and provides reading distances ranging from 5 cm to 100 m, depending on the type of tag or equipment used.

The tag contains a unique number, which is provided at the manufacture or distribution level, and is never duplicated. This number acts as a trigger when captured by the reader and is used to identify the asset, record its details, and subsequently update the asset's record in the main database. Tags provide for billions of individual identification codes, which could include customer, categorization, routing, encrypting, and security codes.

Types of RFID Tags
There are two major classifications of RFID tags: passive and active.

Passive Tags
Passive digitally encoded tags contain no internal power source, such as a battery, and thus are easier and less expensive to manufacture, than their active tag big brothers. These tags are purely passive or “reflective”, and rely upon the electromagnetic energy radiated by an interrogator (reader) to power the RF integrated circuit, which makes up the tag itself. The tag reacts to a specific reader produced, inductively coupled, or radiated electromagnetic field, by delivering a data modulated radio frequency response. These types of tags are said to be “beam powered”.

Figure 5: Assorted Passive Tags
(Source TTI*RFID)
Passive tag systems, using magnetic or radio encoded transceivers (tags) and specific antenna units (readers), (theoretically) provide for communication and reading of hundreds of stacked tags, providing full collision avoidance while moving at a high speed. Typical passive tag systems offer:

- Read capacity: up to 250 tags/second (static)
- Operating range: up to 1 meter by 1 meter by 1 meter passive (3-D readability)
- Read error rate: <0.01%

**Active Tags**

Active tags contain both a radio frequency transceiver and battery to power the transceiver. Batteries may be replaceable, or sealed within the device (often referred to as a unitized active tag). The onboard radio in the active tag allows it to get substantially more range (up to 300 feet) than a passive tag, as the data modulated radio frequency response is amplified and broadcast to the reader.

Active tags are generally more expensive to manufacture than passive tags, and are limited by the battery life, typically between 3 and 5 years. As with any battery powered product, battery life is dependent on level of use, or how frequently the tag broadcasts its signal.

Like all electrical devices, RFID tags and their reader/interrogator components are becoming smaller, more durable, longer-lived, and capable of being used over increasingly longer distances. Just as computer chips are becoming more imbedded and less intrusive, so is RF identification and tracking technology.

**Readers**

Readers generally consist of an RF antenna, transceiver, and a micro-processor. The transceiver sends activation signals to and receives identification data from the tag. The antenna can be enclosed within the reader or located outside the reader as a separate piece. The reader can be a stationary or a hand-held component, housing a micro-
processor that checks and decodes the data it receives. Once received, the reader transmits the data to a centrally located system server for record-keeping and processing.

**Tag Frequencies**

RFID systems operate in several radio bandwidths divided into low, intermediate and high frequency ranges.

A system operating in the low-frequency range, between 30 kilohertz (kHz) and 500 kHz, generates strong and broad signal spread. In this range, the device requires a shorter distance to communicate with a reader, typically at a distance of no more than 10 feet.

Most low-frequency systems are passive, so the tag is “off” until activated by the reader. Such devices can easily be activated and interrogated by hand-held readers. Since these systems allow for accurate transmission through most non-metallic materials, they are ideal for tracking, monitoring, or controlling process status, such as the work flow of products or containers in manufacturing, production or assembly lines.

The medium range is not as popular for RF tagging systems. This range is widely used by citizen band radios, automatic door openers, and remote control toys. Thus RF tagging applications operating in this range often experience interference. Despite this, many tagging applications, including inventory control or asset tracking systems, rely on medium range radio frequency, due to its versatility and strength.

High frequency systems operate in the ultrahigh frequency band from, 500 megahertz to 2.5 gigahertz. These systems are mostly applied in the automobile and trucking industries. These tags can often communicate with readers at distances greater than 250 feet, while moving at higher speeds.

**RFID System Manufacturers**

There are numerous manufacturers of RFID tags, readers, and supporting software. In his 1999 master’s thesis at MIT entitled “Applied Information Technology For Ship Design,
Production and Lifecycle Support: A Total Systems Approach”, Gary Dunlap examines a number of RFID vendors, and compares their products and potential applications.

As stated previously, RFID systems operate in low, intermediate and high frequency ranges. There are also many different type of RFID tags on the market, ranging from simple “disposable” single-use paper tags to sophisticated “intelligent” tags, each offering its own level of benefit. The operating frequency and the tag type is determined by the specific application.

At the lower end of the spectrum, there are quite a few companies in the RFID industry who manufacture a variety of "unintelligent" transponder products, or passive tags. These systems and tags are functionally similar to bar codes but offer the additional benefit of non-line of sight readability and hands-free data transmission and collection.

As of mid-2001, with the lack of any uniform standard, many potential uses of passive tags still considered them to be too expensive to compete in a market dominated by the bar code and magnetic-stripe technologies.

According to their web-site the Uniform Code Council (UCC) has as their mission “to take a global leadership role in establishing and promoting multi-industry standards for product identification and related electronic communications. The(ir) goal is to enhance efficient supply chain management, thus contributing added value to the customer.” ***

Several RFID companies are specializing in the development of real time locating systems (RTLS) technology. RTLS provides managers constant, real-time on-demand information about the supply chain. This includes information on what, where, how much, and the current status of inventory and resources.

I.D. Systems, Inc. (IDS)
IDS, headquartered in Hackensack NJ, produces wireless monitoring and tracking systems for a wide range of customers, including shipping and delivery companies, car
rental companies, railcar and transportation companies, and companies with forklift fleets. IDS has designed, developed, and manufactured a patented wireless programmable communications and monitoring system for vehicles, materials, equipment and personnel since the company’s founding in 1993.

While the industry trend has been toward less functional, cheaper tags, IDS has taken a different approach. To meet the demands of the emerging industry, IDS has chosen to focus on making the tag do more, instead of making the tag cost less. The system can offer more to a customer than the previous systems. As a result, the expense of the tag can be more easily justified. In addition, IDS feels that their "intelligent" approach to tag design has actually lowered the overall system cost.

The primary components of the IDS system are the intelligent tags or miniature computers (the Asset Communicators), which are affixed to the items being tracked or monitored. Each Asset Communicator possesses its own unique identification code. Once affixed to its assigned asset, the Asset Communicator provides for the two-way transfer of information using radio transmissions to and from strategically located monitoring devices (the Gateways). Typically, numerous Gateways are networked together throughout a facility, to provide real-time visibility of the location and status of assets measured from a central location.

IDS products are being used in a wide range of applications, from shipping and deliveries, to fleet management of rental cars, forklifts, railcars, and transportation vehicles, and also personnel monitoring.

**PinPoint Corporation**

PinPoint Corporation, located in Billerica, MA, is a leading developer for mobile resource management solutions. Their systems are developed for industries requiring a high degree of live information on resources and critical assets. These include industrial, manufacturing, and healthcare environments, which use PinPoint solutions to locate, monitor, and manage resources, inventory, and personnel.
Resource Manager Software
The backbone of PinPoint’s system is their resource manager software. The individual components of a RTLS system, the tags, antennas, and cell controllers, are all tied together in the resource manager. The software can provide the end-user only the information that he has requested, through a "publish / subscribe" architecture and series of proprietary NT services, greatly reducing network traffic. The PinPoint resource manager can deliver data to any PC, handheld, or WAP device.

PinPoint offers third-party developers a completely open software platform, which allows for the creation of custom applications for specific markets and industries. On November 29, 2000, PinPoint announced a strategic agreement with RF Code. The goal is to provide organizations with the ability to gather real-time location information of assets throughout a facility.

RF Code, Inc.
RF Code, Inc. is a leading developer of Radio Frequency Identification (RFID) technologies. Established in 1996, they provide advanced RFID and tracking solutions to the express delivery industry. RF Code has as their mission to become a leading provider of high volume asset tracking and identification systems.

The Spider system is a 303.8 MHz RFID portable asset tracking solution, which features small, long-range tags and readers. Tags can be read up to 400 feet while localizing position to within 20 feet through an attenuation process.

Spider Tags (Active Beacon)

The Spider tag (figure 6) is a unique RFID tag that provides long range or short-range identification. These small tags, (1.2” x 2.4”), can be identified at distances up to 300 feet from the reader with optional antennas. They were originally designed for the infant security market, and provide high volume identification. The Spider system is suitable for
pallet and rolling stock management, hospital asset tracking, personnel locating, and security and warehouse management.

The Spider's unique collision avoidance system provides read capability for up to 500 tags at a standard 7.5 second beacon interval, and up to 1,000 tags at a 15.4 second interval.

**Spider Reader**

The Spider reader (figure 7) is the component of this RFID system that provides configurable long-range or short-range identification of RF Code Spider tags, at a range of up to 300 feet. Through a process of modifying attenuation, the readers are able to localize a tag's position to within 20 feet of the reader, as well as inform the host computer whenever something changes. For example, when a tag enters or leaves the range of the reader, an alert will sound notifying the system of a change in tag location.

Some benefits of the Spider readers include:

- A small footprint – the reader can be mounted just about anywhere,
- Compatibility with multiple communication options including wireless – giving the system the flexibility to operate in virtually any environment,
- Ability to acquire, identify, and track up to 1,000 spider tags – the reader utilizes a state-of-the-art anti-collision communications protocol,
- Rechargeable batteries – for mobile operation of the reader, and for uninterrupted stationary operation even during a power outage.

PinPoint has integrated RF Code's Spider products with its Mobile Resource Manager software platform. The Spider readers connect to the PinPoint resource manager via a wired or wireless local area network (LAN). The Spider tag's small footprint and three to five year battery life, permit them to be mounted just about anywhere. The readers also support a mobile mode through a rechargeable battery, enabling mobile, wireless asset management applications.
(Note: As the research for this report was being carried out, PinPoint Corp. met the fate of numerous dot.coms companies, with millions of dollars of venture capital yet never turning a profit. Pinpoint Corp. filed for Chapter 7 bankruptcy protection on March 29, 2001, after defaulting on a loan to a secured creditor.)

WhereNet

WhereNet systems have been developed specifically to manage inventory, track containers, locate property, monitor job orders, ensure quality processes, connect wireless call systems, and provide personal safety. When used with containers, pallets, parts, and equipment, the system streamlines production staging, inventory control, and finished goods put away and retrieval.

WhereNet has extensively developed its RTLS. The RTLS is configured as a local positioning system, and works in tandem with wireless local area networks and bar code data capture products, to provide information from a single, integrated tracking system.

The WhereNet RTLS enables real-time management of assets in locations requiring local area coverage, by utilizing a combination of hardware and software. The hardware of the system consists of a communications infrastructure of read/write RF tags, fixed-position antennas, location processors and hand-held tag-communicator terminals.

WhereNet has developed software to support and manage tracking assets, and integrates the hardware into the system. By customizing their software packages, several industrial applications have arisen from the RTLS system. WhereNet products have been developed for high-end, asset-rich customers, and they have succeeded in producing very sophisticated local positioning system applications for several industries. Bringing such a system to an operation does require significant financial investment.
The Market for RFID

The global market for conventional Radio Frequency Identification (RFID) is presently a several billion dollars industry, and growing 20 - 30 % every year. These RFID tags typically cost dollars to tens of dollars each. However, there are now many new inventions of RFID tags, which are promised to cost a dollar or less. It is generally agreed that these lower priced tags will create even bigger markets, than those specialized markets for conventional RFID systems. This can primarily be attributed to the fact that these tags can now be considered single use or disposable. One application for these low-cost single use tags is for luggage identification in the travel industry. This topic is discussed in further detail in Chapter 11.

RFID technology provides in-transit management capabilities, as well as performance reports and access to real-time data via company networks and the Internet. Chapter 4 presents the specific model simulation for a shipboard RFID application, which was chosen as the focus for this research.
Chapter 4: Description of Vessel Loading Process

This thesis examines the suitability of AIT onboard naval and commercial ships. While there are conceivably unlimited potential applications for which RFID technology could be applied, (Chapter 10 will examine them in more detail) it is necessary to focus on only a few processes, in order to gain insight into a more thorough investigation. For this research, it was decided to examine the process of loading a vessel.

The framework for the analysis of the different scenarios is essentially a variation of the same theme: materials tagged with RFID transponders are transported from a warehouse (or other shore-based facility) onto a vessel into storerooms onboard. Figures 8 and 9 show typical loading scenes of stores for passenger ships.

The current system used at most ship terminals to record assets being loaded, is a manual, paper-based system. As materials are delivered by tractor-trailer truck, longshoremen unload the truck, and then place them on the pier where ship’s personnel walk around and identify them. This process can be time consuming, costly, and labor intensive.
Once identified, an officer will sign off that the items indeed have been delivered. Figures 10 and 11 show typical loading scenes of stores for passenger ship. Once received, the pallets of materials are then loaded onto the vessel and left in a staging area, where they are later distributed to various storerooms around the vessel.

![Figure 10: Longshoremen unloading truck pier-side](source: Author's Photos)

![Figure 11: Officer checking delivery](source: Author's Photos)

The introduction of an RFID system offers relief to such problems, while requiring only a modest investment in equipment. With such a system, RFID tags can be used to tag just about anything which needs to be identified as it is loaded onboard; such as spare parts, boxes of food, people, their luggage, etc.

The model framework developed for analysis of this generic situation includes the following processes. Items are taken from shore side locations on the pier. These items are then loaded onto the ship. Once onboard, the items are placed in the various storerooms located all around the ship. The idea is that RFID will provide information on the flow of the material, permitting their location to be tracked and recorded automatically. Chapter 8 provides more specifics on the model framework developed.

To assist in showing how the RFID technology can be effective and useful when applied to shipboard applications, and to determine that RFID technology can even function
effectively in a marine environment, several small-scale practical “proof of concept” demonstration were performed as part of this research.

The MIT research team, led by Professor Henry S. Marcus, contacted ship operators, RFID manufactures, and software developers to solicit their participation in these demos. Michael McGurl and William Walker from Harbor Express, Robert Gordon from Ocean Development Company, and Steve Awtrey of PinPoint Co./ RF Code all generously offered their time and facilities to MIT for these demonstrations.

The specific RFID Proof-of-Concept demonstrations performed by MIT and the other team partners are described in Chapter 5.
Chapter 5: Proof of Concept Demonstrations

In order to show the effectiveness and usefulness of using RFID technology onboard ships, several small-scale practical demonstrations were performed. The theme of these “Proof-of-Concept” demonstrations was the same; items being loaded & unloaded off a vessel are registered and tracked using RFID tags.

These demonstrations provide a “real world” simulation on how an RFID system could assist ship operators with tasks such as inventory management and control. They also helped identify factors that need to be considered when applying RFID technology in a marine environment.

As mentioned previously, RFID radio signals are subjected to the same physical phenomenon that affect normal electromagnetic radio transmissions. This includes the lack of ability to penetrate metal. Since most ships are constructed primarily using metal, this was thought to be a concern heading into the demonstrations.

A commuter passenger ferry and a cruise ship were selected as appropriate test vessels for these demonstrations.

Harbor Express, Quincy, Massachusetts – Commuter Ferry

Harbor Express operates two 25-meter catamaran ferries on commuter service between Quincy, MA, Downtown Boston, and Boston’s Logan International Airport. The vessels (figure12) were built during the 1990’s at Gladding-Hearn Shipbuilding in Somerset, MA.

The management at Harbor Express was interested in finding an efficient inventory tracking system, to help them keep track of exactly what is leaving their storerooms shore-side, being loaded onboard their vessels, and when it is being loaded.
After several preliminary meetings with the officials at Harbor Express and an initial site visit, a demonstration was held on Saturday, February 17, 2001 at Harbor Express' Quincy terminal. In attendance were representatives from MIT, Harbor Express and PinPoint Corp. An RF Code Spider Tag system was used, including a portable Spider reader interfaced with a Palm Pilot Vx personal digital assistant (PDA) (see figure 13), and 10 active Spider tags.

The experiment took place using the vessel FLYING CLOUD, along side at the Harbor Express terminal. Personal flotation devices, or lifejackets, were used in the experiment to simulate miscellaneous spare parts. Spider Tags were attached to 10 lifejackets (figure...
14), and then they were placed in the storage lockers beneath the seats. Within a few seconds, the portable reader was able to detect all 10 tagged items. This was possible despite the fact that the storage lockers are constructed of aluminum. There was enough of a gap between the seat for the radio signal to penetrate, and reach the reader.

![Figure 14: Lifejackets with Spider RFID Tag Attached](Source: Author's Photo)

Next, the tagged items were moved to different locations around the vessel, including above and below the passenger deck. Again, after a few minutes the reader, still located on the passenger deck, detected all of the tags. The tags placed on other decks, especially the one brought down into the engine room, did take longer to receive a read than the ones still located on the passenger deck, but they were read by the reader.

After achieving successful results onboard the vessel, the system was next tested at the Harbor Express warehouse, a group of five 20 foot marine containers located behind the terminal, several hundred feet away from the vessels. These containers hold engine spares, oil, deck stores, and concession items. Again, tests of reads through the steel container walls were a success. Most likely the radio signals were able to “escape” through air gaps and gasket around the container doors.
These tests suggest that an RFID system could function in the environment found at Harbor Express. Some potential applications of RFID technology were identified together with the Harbor Express officials.

Officials at Harbor Express reported that, typically it takes two of their staff, \( \frac{1}{2} \) a Saturday (approx. 5 hrs), to manually check all of the equipment onboard the vessels. If these items each had an RFID tag attached to them, theoretically, a complete inventory could be obtained in just a few minutes with a quick walk through of the vessel.

Another task that may be suitable for RFID is the voyage passenger count. The US Coast Guard requires that a headcount of all “Souls onboard” be taken and recorded, before being allowed to depart. Currently, passengers are manually counted by a crewmember, using a “click-counter” as they board the vessel (figure 15)

With an RFID system in place, passengers would be counted automatically upon boarding the vessel. This is achieved by the fact that their ticket would contain a RFID tag embedded in it, which would be detected by the readers located at the entrance of the vessel. These tickets could potentially be reusable (in a style similar to the boarding passes used by Southwest Airlines).

The following is a short list of some potential applications of RFID tags at Harbor Express, which were identified during the demo:

**POSSIBLE APPLICATIONS FOR USE OF RFID AT HARBOR EXPRESS**

- Tracking of Engine Spare Parts and Tools
- Tracking of Provisions – Snacks, Ship Service Items
- Bar Stores
  a) Bottles
  b) Cases of Beer and Soda
- Luggage & Baggage
- Revenues
  a) Parking
  b) Multi-ride electronic ticketing
- Safety, including:
  a) Maintenance of Lifesaving Equipment
  b) Count & tracking of children onboard

A more detailed description of RFID applications onboard ships is presented in Chapter 10.

**Ocean Development, Jacksonville, Florida – Cruise Ship**

A second demonstration showing the proof of concept for the use of RFID technology onboard ships was performed on July 20, 2001 at the Atlantic Marine Shipyard located in Jacksonville, Florida, onboard Ocean Development’s new vessel, cv CAPE COD LIGHT.

The vessel is being built for Ocean Development’s new Delta Queen Coastal Voyages (DQCV) cruise line brand. The vessel is a sister-ship to the DQCV recently completed vessel, the cv CAPE MAY LIGHT, for a new niche market of coastal cruises along the Eastern and Western coasts of the United States.
Figure 16: The CAPE MAY LIGHT (Left) and CAPE COD LIGHT being fitted out at the Atlantic Marine Shipyard
(Source: Atlantic Marine)

Every new vessel experiences, during the final stages of construction, a process known as the Initial Load Out. This process is essentially the loading or stocking of the vessel, with a reasonable amount of spare parts and inventory of consumables, before the vessel officially enters into service. Probably at no other time is there a better opportunity to obtain an accurate count of the inventory onboard the vessel, than during this time.

Figure 17: cv CAPE COD LIGHT
(Source: Author’s Photo)
Vessel Characteristics: CAPE COD LIGHT

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
<td>300 feet (91.4 m)</td>
</tr>
<tr>
<td><strong>Breadth</strong></td>
<td>50 feet (15.2 m)</td>
</tr>
<tr>
<td><strong>Draft</strong></td>
<td>12.5 feet (3.8 m)</td>
</tr>
<tr>
<td><strong>Passenger Capacity</strong></td>
<td>220 (double occupancy)</td>
</tr>
<tr>
<td><strong>Speed</strong></td>
<td>13 knots</td>
</tr>
<tr>
<td><strong>Propulsion</strong></td>
<td>Twin Z-drives</td>
</tr>
<tr>
<td><strong>Materials (Hull/ Superstruct.)</strong></td>
<td>Steel</td>
</tr>
<tr>
<td><strong>Gross Tonnage</strong></td>
<td>1,580 GRT</td>
</tr>
<tr>
<td><strong>Naval Architect</strong></td>
<td>Guido Perla and Associates</td>
</tr>
</tbody>
</table>

While the vessel is being completed by the shipyard, Ocean Development has purchased all the inventory for the hotel spaces of the vessel. The hotel spaces are all the other areas on the vessel that do not fall under the category of deck or engine department spaces, which include all the technical and mechanical spaces onboard. While the two vessels have been under construction at the Jacksonville facility of Atlantic Marine, Ocean Development has been keeping the inventory for the two vessels at a warehouse owned by ICS Logistics, some 15 miles west of the shipyard.

On Friday July 20, 2001, a site-visit was made to tour Ocean Development’s operations in Jacksonville, FL. In attendance were the author and Professor Henry Marcus from MIT, Mr. Robert Gordon from Ocean Development Company, Janne Meinertz from TransGroup Worldwide Logistics, Ocean Development’s logistics handler, and Steve Awtrey from RF Code.

First the team visited the ISC Logistics warehouse, to view how the inventory for the vessel was being stored. The inventory, including everything from television sets for the cabins to chairs and jars of preserves for the dinning room, was placed on wooden pallets, and stored on metal racks (see figure 18). All items were labeled, marked with an identification number and the vessel’s name.

A portable Spider Tag system, similar to the one used at Harbor Express, was again used in this demonstration, to observe how an RFID system could function in these
environments. The warehouse consisted of several large storage and handling rooms, separated by steel reinforced concrete walls. Tags were moved around the warehouse, to test the equipment's readability. With only one antenna reader, there was some difficulty reading tags placed in the other rooms. The test equipment achieved positive reads, when used as a portable device and moved around the warehouse. However, a fixed installation would likely require multiple readers, installed in the different rooms.

After completing the test at the ICS warehouse, the team then traveled to the vessel, located at the outfitting pier of Atlantic Marine Shipyard. There, the vessel is nearing completion, and is expected to enter cruise service in several months time. A tour of the vessel was conducted, and potential applications and reader installation spots were identified.

Following the tour, the RFID demo system was tested in the vessel’s laundry room. The environment was typical of many of the spaces found onboard, surrounded by metal. As is the warehouse, the reader was able to detect tags located in the same room, but had
difficulty detecting tags removed from the room. Again, a shipboard application would require multiple readers to be installed in order to obtain full detection coverage.

These “Proof-of-Concept” demonstrations helped to show that RFID technology does in fact work onboard a ship. While some of the readings were hampered due to the highly metallic environment found onboard a vessel, overall the tests were a success.

The next step is to examine a typical shipboard process, which is part of ship operations, and a candidate for an RFID system. Purchasing & inventory control of stores and spare parts is such a system, and the current process is described in Chapter 7.
Chapter 6: Description of Current Processes

Modern Supply Chain Management techniques emphasize the importance of such activities as purchasing, transportation planning, inventory control, and warehousing. Some of the important aspects to consider when examining an organization’s system are lead-times, holding and shortage costs, and the structure of the inventory system.

When researching potential applications for RFID technology onboard a ship, it is necessary to focus on a discrete process, in order to perform an analysis on the benefits of implementing a RFID system.

Purchasing & Inventory Control

The purchasing & inventory control process is one of the most important tasks in successful maritime operations. Efficient operations here can influence the smooth operation of a vessel, avoiding the situation of running out of inventory at an inopportune time. The challenge is to find the right balance between holding and shortage costs. Changes in the structure of the inventory system and shorter lead-times can also give considerable cost reductions. This is where an RFID system can provide some benefit.

Typically, purchasing of materials and supplies, involves a multi-step process:
1. Requisitions for spare parts are prepared by officers onboard, to record materials required by a vessel. 2. These are then sent shore side, to the main office where ship superintendents review the requests. 3. Next they are consolidated and passed on to the purchasing department of the shipping company, where they are sent out for bids from vendors. 4. Once an acceptable bid is received, a Purchase Order (PO) is issued to place the actual materials order with the vendor.

Inventory control tracks equipment, parts, and consumable items through various locations along the material supply chain, including onboard each vessel of a fleet, and at shore-side facilities.
To assist with the purchasing and inventory control process, ship operators often use a computer software package to track inventory and issue requisitions and purchase orders. These systems share information between ships and the office, allowing on-board personnel to plan and manage maintenance and stores.

**Marine Maintenance Management Systems**

On July 15, 2001 the author met with Haavard Ramsoy, Chief Officer on the cruise ship, ms NORWEGIAN MAJESTY. The meeting took place onboard the vessel, during one of her weekly calls to Boston, Massachusetts. Norwegian Cruise Line, the owner of the ms NORWEGIAN MAJESTY, used a computer based software system called AMOS-D for their inventory and purchasing tasks.

**AMOS-D (Administration, Maintenance, Operating, Spare parts - Database)**

AMOS-D is a computerized vessel information system, used for planned maintenance, spare parts control, surveys, certification handling, and purchasing. The program provides the essential reports and statistics for shipboard management and safety.

The AMOS-D system has facilities for the requisitioning of spare parts, including purchase order handling, quotation comparison, and transportation document preparation (consolidated consignments). The system also provides some inventory control capabilities, such as printing of bar code labels and inputting of goods received onboard.

SpecTech a.s., a Norwegian based company, supplies the marine industry with AMOS, a leading maintenance management system. More than 10,000 ships are managed on a daily basis using AMOS maintenance systems. AMOS systems combine planned maintenance with spare parts control (figure 19).
A typical AMOS system consists of two distinct types of installations, each with different levels of access to the system:

- Shipboard users (Captain, Chief Officer, Chief Engineer, all other officers and personnel)
- Office users (Ship Superintendents, purchasers, etc.)

Norwegian Cruise Line uses the AMOS system for purchasing & inventory control onboard their entire fleet of cruise ships, and in their main office in Miami. NCL is experiencing a period of expansion, which includes the addition of three new vessels over the next 18 months. The new vessels will be equipped with the latest version of AMOS, AMOS for Windows. The original DOS-based AMOS-D system is still in use onboard the six NCL ships currently in service.

Component Numbering System

Any materials management system must have a database, in which the individual items or components are defined and described.

The AMOS-D numbering system used on the MAJESTY is build up as follows:
The “51” at the beginning identifies the ship (in this case the NORWEGIAN MAJESTY, which is identified as ship 51 in the NCL fleet). The “10” identifies the department onboard (“10” means Deck Dept., “20” means Engine Dept.)

AMOS uses a 10 digit (3.2.2.3) identification system for spare parts. The first 7 digits identify the component involved, and the final 3 digits are the actual spare part #.

The first digits (505 in the example above) are the system classification number, taken from the Norwegian Shipping Research Institute numbering system, SFI system, since AMOS is a Norwegian program originally. (505 represents Portable Fire Fighting equipment.) The next 2 digits identify the type of component, and the third 2 digits are the sequence number or subtype.

An example:

- 731.48.01 731 in the SFI system is 7=System for machinery
- 73= Air Compressor system
- 731=Starting Air System
- 731.48 = Starting Air System, Compressor
- 731.48.01 = Starting Air System, Main Air Compressor #1

Spare parts for this compressor would then follow as: 731.48.01.001 for part #1.

The MAJESTY tries to keep an inventory of between 5 and 10 spares per item (typically) which are manually registered in the AMOS system. Then each time a part is used, the officer manually enters it into the AMOS system, and a reminder to reorder the part comes up when the inventory level drops below the minimum. NCL operates with an eight week requisition cycle for regular maintenance and consumable parts. The vessel's requisition requests are sent to the cruise line’s main office in Miami, where all requisitions fleet wide are collected, and then sent out for bids from a minimum of three vendors.
**ABS SafeShip**

The American Bureau of Shipping (ABS) offers an integrated management product for ship owners who have vessels built to the ABS SafeHull design criteria. The SafeHull criteria has been adopted as a condition for ABS Classification and Rule Requirement for container ships, tankers, and bulk carriers. The criteria are based on thorough and easy-to-apply engineering analysis techniques, enhancing safety of ship structures and leading to improved reliability.

SafeShip is ABS' total vessel integrity management program that follows the life cycle of a SafeHull ship from the design and construction stages, through service and survey periods. The Windows-based program assists ship owners to improve operational efficiency and ship safety.

ABS SafeShip brings together several components including:

- ABS SafeHull – addressing the design and construction phases
- ABS SafeNet – addressing delivery and in-service vessel operation

**ABS SafeNet**

A shipowner with a complete suite of SafeNet modules can handle most aspects of operational management - from payroll, to regulatory requirements, and to planned maintenance programs. The modules are fully integrated, eliminating the need for repetitive data entry by sharing information, allowing rapid movement from one module to another.

All shipowners of ABS classed vessels can receive the following two SafeNet modules:

- Marine Information
- Survey Status

Full ABS SafeShip clients will receive three more modules:

- Hull Maintenance
- Maintenance & Repair
- Vessel Drawing Storage
Figure 20 shows a typical screen view of ABS SafeNet’s Purchasing & Inventory module.

![Figure 20: ABS SafeNet - Purchasing & Inventory](source: ABS Nautical Systems)

These computer material management systems help to ensure that the data used for ordering spare parts and stores is always correct. So when a spare part is ordered, the PO will have the correct part number and equipment details, which results in saving money on the common problem of incorrect part-ordering and delivery.
Both the AMOS-D and SafeShip systems require manual data entry by the officers or shore side personnel assigned to these tasks.

These materials management systems are seemingly ideal candidates for incorporation with an RFID system. As described in Chapter 3, RFID systems typically require a software component, with a database containing the detailed information of the item tagged. The material management systems mentioned above already contain this information. Thus it would seem that the added capability of real-time part and material tracking would be an attractive addition to these otherwise static programs.

**RFID Systems and Naval Vessels**

Martinez Consulting and Computer Services, Incorporated (MCCS, Inc., see Chapter 11 for more information) has been selected by the US Navy to conduct a comprehensive review of the facilities at Naval Station Mayport, Florida. MCCS is evaluating the facilities, both shore side at the naval station and onboard a Navy vessel homeported at Mayport, for all physical and technical aspects of implementing automatic identification and data collection (AIDC) into the Mayport HAZMAT supply process.

MCCS, Inc. carefully considered the placement of RFID equipment, to both insure that it met the needs of the project while not interfering with normal operations. They performed an extensive study of commercial off the shelf (COTS) RFID tags available on the market, to determine the best tags to be used in the Mayport environment.

Part of the project involved MCCS developing the functional logic for the software that will pass data from the RFID readers to the server. They were also responsible for identifying the data elements that need to be passed to the existing Navy inventory systems.

**Systems Interfaces**

The US Navy Destroyer, USS THE SULLIVANS, currently uses two separate inventory systems.
1. The Shipboard Uniform Automated Data Processing System (SUADPS) is used for control and visibility over all supplies for the ship, and
2. the Hazardous Inventory Control System for Windows (HICSWIN) is used for hazardous substance management.

Shore-side, the Navy uses the Hazardous Substance Management System for control and visibility of HAZMAT. At the present time, these systems do not interface with each other another. All of them would be good candidates for modifications to interface with an RFID system.

The result of MCCS, Inc’s work at Mayport will be a comprehensive systems design architecture, showing all subsequent actions necessary to have a fully operational and functioning RFID system to track the Navy’s HAZMAT material.

The actions addressed in their study include: the functionality of the software which resides between the antenna/readers and the server where data is stored; a plan for interfacing/updating the existing Navy inventory control systems with the information collected from the RFID; and drawings of the USS THE SULLIVANS and the shore-side HAZMAT storage facility, showing portal design and locations, equipment requirements, and placement of antennas/readers.

**RFID Systems Used Onboard Cruise Ships**

While it is the goal of this thesis to present viable RFID shipboard applications, it is interesting to note that at least one RFID system is already being used onboard cruise ships.

The ms NORWEGAN MAJESTY uses an RFID system in their night security patrols around the vessel. As night watchman makes his rounds, he using a hand held scanner to scan passive tags, which are installed at set checkpoints around the ship. Upon completing the round, he returns to the navigation bridge where the data from his reader is downloaded to a PC, and a record is produced.
Also, most cruise ships offer gift and duty-free shops for their passengers. As with their shore side counterparts, these shop use EAS systems to protect against shoplifting, as described in Chapter 2.

Chapter 7 will present a proposed RFID System implementation onboard ships, to aid with materials management.
Chapter 7: Description of Proposed RFID Process

The process of loading vessels is inherently an attractive candidate for an RFID tracking system. Numerous items are loaded onto a vessel, passing through one of only several openings in the side of the ship, and then distributed to a variety of storerooms and other locations. Much of this is palletized, and is delivered by a number of different delivery trucks.

The basic operations (package identification, receiving, loading, and storing) remain the same as before. But they will be supported by state of the art RFID technology, which will improve the throughput accuracy and timeliness of the operation, and reduce manually intensive tasks associated with product identification, storage, and tracking.

Before the installation of any RFID system, it is important to conduct a site visit, to determine the physical constraints, equipment requirements, portal design, antenna mounting, and reader placement. It is important that the readers are positioned optimally, to insure 100% readability of all incoming-tagged materials.

The following is a description of a typical shipboard process, with an RFID system installed.

Pre-encoded RFID tags are placed on a variety of pallets of goods to be loaded, on the pier side. These goods are then loaded onto the vessel in the normal manner by the longshoremen. As these tagged items pass through the readers, located around the loading doors of the vessel, an electronic manifest
will immediately be captured, containing a listing of all of the items on the pallet. This list will appear instantly on the vessel’s inventory computer next to the loading area onboard, as well as on the computer screens of the various department heads onboard who are expecting to receive stores. It is important to note that this list can also be compared (electronically) to the goods actually ordered, to show if there are any discrepancies.

Then, as the goods are re-distributed around the vessel, these various department heads who are receiving stores can use a handheld reader to see exactly what they are receiving on each pallet, and more effectively distribute the stock into their storerooms onboard.

Such a system could use inexpensive passive RFID tags (figure 22). The tags would be stimulated by the readers, either by the fixed reader antennas mounted at the loading door and storeroom entrances, or by the handheld readers.

Figure 22: Various Smart Tags In-lays  
(Source TI*RFID)
The tags could be embedded into the shipping label by the vendor. Figure 23 shows the labeling found on a typical box of stores for a cruise ship. One box will have a variety of identification labels attached to it, with an "alphabet soup" assortment of serial numbers and ID codes. Many will also have numerous bar codes affixed to them. It is not immediately clear which label or barcode is the relevant one to the end user.

With a passive RFID tag embedded into a label, the box will automatically be registered as it passes through the doorway.

An RFID system would permit simultaneous identification of the items, and the whole process would occur passively, without requiring any human labor. Not only does RFID speed up data collection at the acquisition point and improve the accuracy of information, it also contributes to the optimization of manning both aboard the vessel and ashore.
Automatic Requisitions

In the previous chapter inventory control programs were discussed, and it was mentioned that most of these systems presently require manual data entry, performed by the officers or shore side personnel assigned to these tasks. Since most ship operators, from cruise lines to the US Navy, use a computerized inventory control, these systems are ideal candidates for incorporation with RFID technology.

An onboard RFID system provides a vessel with real-time asset and inventory monitoring capabilities. Plus, when tagged materials are removed from a storeroom, the event will automatically be registered in the inventory control program. Once a minimum inventory level is reached, this action could automatically trigger a draft requisition to reorder replenishments.

To aid in the examination of the benefits RFID technology offers for shipboard applications, a computer model was created, to permit simulations of the loading process. The purpose of this computer modeling is to provide quantitative data on the current practices, as well as after modifications, to simulate the addition of RFID technology to the process. Chapter 8 contains a description of this process model.
Chapter 8: Description of Model Framework

To assist in the analysis of the impacts an RFID system implementation will have onboard a ship, a model framework of a typical operation was created. This generic model can be applied to situations found at a small commuter ferry operation, at a cruise line, or in the US Navy, despite the fact that conditions are different. The model is used to help identify the “weak” points of a process, those that are candidates for improvements. The model also provides the input necessary for a financial analysis.

One can not assume that skills of the people performing the work, or what can be expected from them, will improve. Thus, it is necessary to explore technological aids. RFID technology provides such an aid. As described in Chapters 2 and 4, the weakest link in the loading process of a vessel is the identification of materials being delivered and stored. RFID can remove the manual, time consuming, and costly process currently required, of ship’s personnel having to identify the materials. With an RFID system, the identification process occurs automatically as items are loaded and placed in the onboard storerooms.

While the specifics of the situations vary, be it the commuter ferry operation, at a cruise line, or in the Navy, the general scenario is similar. Items are transported by truck from the warehouse to the pier. There they are unloaded by forklift and set down. Next longshoremen load the items onto the vessel, and place them in the staging area, where crew distribute the items to the various store rooms onboard. The Provision Master checks the items being loaded. Should any item be missing from the delivery, the purchasing department at company headquarters is notified, and the items are sent to the vessel by air. Figure 24 shows a graphical representation of the model.
This thesis has identified many of the benefits from implementing RFID onboard ships. However, for an organization to consider acquiring such technology for their operations, financial considerations must also be addressed. RFID, compared with other tracking technologies such as barcodes, has some significant initial investment requirements. An analysis of the initial capital costs associated with an RFID implementation, including a calculation of the investment payback period and net present value, is helpful in determining the soundness such an investment.

The cost of a shipboard RFID system depends on several factors, including the application for which it is being applied, which system is selected (a passive, an active, or combination of the two), and the physical environment to which it is being installed. These factors vary from installation to installation. Chapter 9 presents the results of a financial analysis for a proposed RFID installation in a typical shipboard application.
Chapter 9: System Costs and Analysis

While the motivation for considering an RFID system may differ, whether you are the management of a commuter ferry operator, a cruise line, or the US Navy, the benefits are similar. Using a scenario taken from the model framework present in the previous chapter, the financial impact of a simple RFID onboard a ship will be determined.

Inventoring an Aircraft Carrier Storeroom
Lieutenant Dan Feliciano, an Afloat Stock Control Officer in the US Navy, informs that a typical Aviation Stores Division (S-6) carries approximately 8,000 repairable assets, maintained in 15 - 20 storerooms onboard. A complete, wall to wall, inventory will take eight personnel working 8 hour days, 1 working week (5 days) to complete, or a total of 320 hours. This is strictly time used for counting, and does not include any additional time for reconciling differences, which could take four crewmen, anywhere from one to eight weeks to complete.

Salary of US Navy Sailor
According to Arthur J. Clark, in his 2000 MIT master thesis, the average yearly cost of a lowest paid sailor in the United States Navy is $75,000. Each sailor’s typical shipboard employment, including time for leave, is 11 months per year. It was estimated that the average sailor works 50 hours per week, resulting in 2,393 hours of work during an 11-month period. Using this estimate together with the above salary, results in an hourly wage for a Navy sailor of $31.34.

Calculation of Inventoring Costs
Cost of labor required to taking of inventory:

\[
8 \text{ hr/day} \times 5 \text{ days} \times 31.34/\text{hr navy sailor cost} \times 8 \text{ sailors} = 10,028.80
\]

Cost of additional check for reconciling differences (labor cost only):

\[
8 \text{ hr/day} \times 5 \text{ days/working week} \times 4 \text{ weeks (avg.)} \times 31.34/\text{hr navy sailor cost} \times 4 \text{ sailors} = 20,057.60 + 10,028.80
\]
Total cost of current inventorying process = $30,086.20

According to Lt. Feliciano, the average time required for inventorying will vary somewhat from ship to ship, depending on several factors, including availability of personnel, availability of barcode scanners, if the assets are bar-coded, system access, and the ship's schedule.

**RFID**

An RFID installation for use in shipboard storerooms could be a purely passive tag system providing in- and out-data, an active tag system providing “live” updates, or a combination of the two. With RFID in place, inventory can be taken with increased speed and accuracy. Depending on the system used, the total time required could be just a matter of minutes. For the sake of comparison, it is estimated to take 30 minutes.

**Cost of RFID System**

The cost of an RFID system varies, depending on the application and the information capabilities required. Typically passive tags cost about a $1.00 or less, depending on data storing capacity of the tag, and the volume ordered. The cost of the simplest active tags ranges from around $8 to $25. The more complex active tags used for RTLS, capable of broadcasting large quantities of information, generally cost more than $25 a piece.

Based on this research, a shipboard installation will likely require readers to be located in each storeroom, if separated by steel bulkheads, due to radio wave interference. Passive tags, active tags, or a combination could be used.

**RFID Equipment costs:**

Cost of RFID Readers:

Assuming an average of one fixed reader per storeroom,

\[18 \times \$1,600 \text{ RFID reader with antenna} = \$28,800\]

Several portable handheld readers,

\[3 \times \$1,000 \text{ RFID reader with antenna} = \$3,000\]
Cost of RFID Tags:
Using only passive tags:

\[ 8,000 \text{ Repairable Assets} \times 0.65 \text{ cost of passive RFID tag} = \$5,200 \]

Using both passive and active tags:

\[ 4,000 \text{ Repairable Assets with active tags} \times \$10 \text{ cost of active RFID tag} \times \\
4,000 \text{ Repairable Assets with passive tags} \times 0.65 \text{ cost of passive RFID tag} \]

\[ = \$42,600 \]

Using only active tags:

\[ 8,000 \text{ Repairable Assets} \times \$10 \text{ cost of active RFID tag} = \$80,000 \]

Cost of Computer Hardware:
A computer with monitor and printer is required to run the reader software and maintain the tag relational database

\[ \text{= \$1,500} \]

Total RFID system costs:

\[
\begin{align*}
\text{Using only passive tags -} & \quad \$38,500 \\
\text{Using both active and passive tags -} & \quad \$75,900 \\
\text{Using only active tags -} & \quad \$113,300
\end{align*}
\]

This estimate does not include additional expenses such as installation costs, training costs, or maintenance and repair costs.

Financial Analysis
The time savings achieved by using an RFID system for taking inventory was projected to be 319.5 hours, not including time required for additional searching. With the given wage for a Navy sailor at $31.34/hr, a savings of $10,013.13 is yielded per procedure. When the saved additional search time is include, to total saving amount to \$30,070.73.
Payback Period
The payback period is the length of time necessary to recover the initial investment. For a passive RFID system the payback period is 1.3 inventory takings, and for an active system it is 3.8 inventory takings. A combined active and passive system would have a payback period of 2.5 inventory takings. It should be noted that these payback periods have been calculated based on full inventory taking procedures. An RFID system offers the additional benefit of always keeping the inventory readings up to date.

Present Value
The present value is the total amount that a series of future payments is worth at present. The present values for investing in an RFID system onboard an aircraft carrier, calculated over a five-year period with a discount rate of 8.5% and assuming a complete inventory is taken every six months is:

\[ \text{\$197,305.00} \]

Net Present Value
The net present value is calculated by subtracting the initial investment from the present value of future cash flows. If the net present value is positive, then the investment is considered attractive.

The net present values for the investments in the three RFID systems onboard an aircraft carrier, assuming a complete inventory is taken every six months, and calculated over a five-year period with a discount rate of 8.5%, are: \text{\$158,805} for the passive tag system, \text{\$121,405} for the passive-active system, and \text{\$84,005} for the active tag system.

These values help to determine whether an RFID system implementation provides financial benefit. A comparison of the resulting NPVs, of when the frequencies of inventory taking varied, can be found in the appendix.
Other Operating Costs
As mentioned above, there are typically other costs associated with operating RFID systems. Estimates provided in the U.S. Transportation Command Automatic Identification Technology Integration Plan, estimate these costs to be:

- Training - 4% of site investment
- Infrastructure maintenance - 5% of site investment
- Hardware and Software maintenance - 13% of site investment
- Systems Administration - 5% of site investment

These costs may vary depending on the system selected, and the complexity of the site. They have not been included in this analysis.

Potential Cost Benefits
Implementation of RFID technology greatly reduces the time required for inventorying, and eliminates the need for allocation of additional time for an extra search, as currently performed. This time savings results directly in a monetary savings of paid wages.

In addition, with an RFID system in place there is less of a chance that misplaced items will be lost. Inevitably assets will be misplaced. When the search time for these items become too long, either replacement parts are used or the item is reordered. This represents an additional cost, which is avoided if the misplaced item can be located using RFID.

While the example given is for an aircraft carrier implementation, there are benefits for using RFID systems on commercial ships as well. This model framework, of an onboard storeroom, can also be used for a cruise ship and the storage space of a commuter ferry operation as well.

Certainly on a cruise ship for example, labor cost of crew (especially on foreign flag vessels) is significantly lower than that of a Navy sailor, the impact of missing stores, spare parts, and other equipment crucial to ship operations could have far greater financial implications than in the Navy. If a scheduled cruise is delayed, or worse
cancelled, huge financial liability can result. Missing provisions and supplies result in a lower level of service offered to the passengers, an important measure in the highly competitive cruise vacation industry. Critical items necessitate an emergency air shipment to the next port of call, an expensive endeavor, which potentially could be avoided with an RFID system in place.

The question is then, what is the value of the asset information, which the RFID system provides? Clearly a higher priced active RFID system using tags in the $10 range, does not make economic sense for a tracking a commuter ferry passenger’s luggage. However, such a system might make sense as a “man-over-board” system for the ship’s personnel. With the ferry operating at a top speed of 30 knots (about 34.5 miles per hour), the chances of locating and recovering anything that has fallen off the vessel is difficult. The RFID system could provide real time location information of the asset while onboard, and trigger an alarm when removed from the vessel. The system could also provide data on the last registered location of the assist, and if integrated with the vessel’s GPS satellite positioning system, assist the vessel determining where to recover the lost asset.

Once an RFID system is implemented onboard for a specific suitable application, and the supporting infrastructure is in place, the system has the potential to be expanded to include other applications, without requiring the same initial investment. Depending on the extent of the supporting infrastructure (the location and type of the RFID antennas and readers) all that would be required for expansion are more RFID tags and possible modifications to the supporting software and database.

Having demonstrated with this storeroom inventory example, that an RFID implementation should be within a financially sound envelope for a ship operator, Chapter 10 will examine some additional potential shipboard applications for RFID systems.
Chapter 10: Potential Applications for RFID Onboard Ships

There are numerous potential applications for RFID technology onboard ships, whether they be commercial or naval vessels. RFID systems can be retrofitted into an existing vessel, or incorporated during the design process of a new ship. Once an RFID supporting infrastructure is installed onboard a ship, it is easily expandable and upgradeable.

RFID technology can effectively be applied to a variety of tasks onboard vessels. These systems have the potential to assist in ship operations of vessels ranging from small commuter boats to the largest of aircraft carriers. The following sections present some of the applications for which an RFID system could provide benefit.

Inventory Methods and Tagging
On most ships, both commercial and naval, materials are tagged with barcodes, and stowed throughout the ship in various storerooms. These stowage locations are often in harsh environments that can degrade the paper barcode labels. Since RFID tags are less prone to degradation in such adverse environments, and since reading of these tags does not require a line-of-sight path, it is likely that the taking of inventory can be done much more efficiently, and that inventory accuracy will be higher. The benefits of using an RFID system for inventory management include fewer man-hours being required for inventory taking, and less material replacement costs.

Figure 25 shows a typical (empty) storeroom found onboard a cruise ship. Note the wire cage type bulkhead, separating the storage space. This
could be used to separate valuable stock such as bar stores, from other hotel stores, or for personal safety reasons such as paint or chemical stores. An RFID equipped system for inventory would permit walk-by scanning of the material, through this wire bulkhead, and without requiring direct access to the tagged materials.

**Inventory Tracking Methods**

As described in previous chapters, inventory-tracking methods on most ships today are manual and with barcodes. RFID provides a hands-off system, making data entry errors far less likely to occur compared with existing methods.

As Gary Dunlap suggests in his 1999 MIT master’s thesis, a question which needs to be considered is how to differentiate between what material can reasonably be tracked at an item level with an RFID type of scanner, and which must continue to be tracked by some other means.

Generally the frozen and cool storerooms are well stowed to permit easy inventorying, and could support any method from manual checking, to barcodes, to RFID tags. The same is true for Engine Storerooms, where there is also often an engine storekeeper or supply officer assigned.

Often storerooms found on ships are not organized, and items are just placed (or tossed) into them. Taking an accurate inventory of these types of storerooms is very time consuming and difficult. Certainly if all items had RFID tag labels on the them, the taking of inventory would be greatly simplified, saving both time and effort. Few errors would occur, improving accuracy and reducing cost associated with double ordering of inventory, because the original item was “lost.”

RFID could also offer great benefit during the Initial Load Out process of a vessel, described in Chapter 5.
Passenger Commuter Ferries

According to Consolidated Laws of New York State, the term "passenger commuter ferry" means a vessel providing mass transportation service. Passenger commuter ferry services can be found in many metropolitan areas located on water. One such operation is Harbor Express in Boston, MA, presented in Chapter 5.

While typical voyage lengths are less than 45 minutes, often the turn-around time between voyages is no more than 15 minutes. During this brief time passengers are disembarking the vessel, some with luggage, trash is sent ashore, fresh supplies and sometimes spare parts are loaded, and finally the new passengers board the vessel. These vessels generally also carry only a minimum of crewmembers, the base amount required by the Coast Guard, who are responsible for the safe and smooth operation of the ship.

Due to the relatively short time in port, RFID could offer a commuter ferry operation some relief in the tasks that have to take place during this time. Some of the potential applications appropriate for RFID technology, onboard passenger commuter ferries, include tracking of the following:

- **Spare Parts & Equipment**, including:
  - Engine Parts
  - Deck Parts
  - Safety Equipment (see description of Demonstration in Chapter 5)

- **Loading/unloading of Concessionary Items** – Inventory control, automatic issuing of requisitions for stock replenishments

- **Loading/unloading of Passengers’ Baggage** - "Smart" baggage tags. For an airport commuter service such as Harbor Express, an RFID system for baggage could be installed at the embarkation terminal, allowing travelers to check-in their luggage already before boarding the ferry, avoiding the long lines and hassle at the airport. Their luggage could then be scanned upon
arrival at the airport, and automatically sent to the correct departing flight. (See discussion in Chapter 11.)

- **Uses in Multi-ride Electronic Ticketing - RFID systems streamline ticket issuing and validation. They also serve to minimize losses from ticket fraud. Tickets can be created on demand with RFID-enabled bar code printers; Multi-ride tickets, consisting of RFID card transponders, can be issued to individual frequent ride customers and enabled for specific time periods; and tickets can be read remotely to increase throughput at entrances and gates.**

- **Safety Equipment, including:**
  a) **Maintenance of Lifesaving Equipment –** inspection history and physical presents and condition information. The USCG requires that the number of personal flotation devices (PFD) for children carried onboard be 5% of the total passenger capacity. At Harbor Express, they experience a dramatic increase in the number of children carried during school vacation periods, and when sailing with school field trip to Boston. As the vessels do not have storage capacity for a full load of both adult and children’s PFD, extras are kept in large yellow bags, which are loaded onboard when large numbers of children are expected. Occasionally, to help calm nervous children, PFDs are removed from these bags for them to don. An accurate count of the PFDs in each bag must be taken regularly. With active RFID tags attached, real-time count information would be accessible continually.
  b) **Maintenance of Fire-fighting Equipment –** inspection history and physical presents and condition information

- **Safety (Other), including:**
  a) **Accurate count of “Souls onboard” for departure condition –** USCG requirement, Info received from RFID tickets
  b) **Count & tracking of any children onboard –** Adult vs. Child RFID tickets
Cruise Ships

RFID systems could be applied to many applications found onboard cruise ships. Some of these potential applications were presented in some of the earlier chapters.

The busiest time for a cruise ship is turn-around day, the day on which a scheduled cruise ends and the next cruise begins. This day is also know as embarkation day in the cruise world. In the space of typically 10 hrs or less, all of the passengers, their luggage, and garbage generated during their cruise must be offloaded from the vessel. This can first occur once the ship has been cleared by customs (for cruises with international itineraries) and must be completed early enough to allow passengers to make connecting flights home. Next the ship must be thoroughly cleaned by the crew, and all cabins turned over with new linens. Often there is also a change of several dozen crew, and their belongings. Fresh provisions for the cruise and spare parts and supplies must be loaded onto the vessel, before a new load of passengers and their bags arrive. These bags must be correctly distributed to their owner’s cabins before dinnertime if possible. Prior to departure, a mandatory US Coast Guard passenger boat drill must be conducted, and then the vessel is underway.

The provisioning process alone can involve hundreds of pallets of goods being delivered to, and loaded onboard, the vessel. Usually this is done by an team of longshoremen, working in concert with each other, and personnel from the ship. Pallets must be loaded onto the vessel in a continuous stream, as there is time pressure, both due to the limited time in port, but also due to union requirements. The goal is to get all materials loaded onboard, so that the vessel can depart on time. While it is the intent that these items are locally distributed to their appropriate storeroom locations onboard during this process, many times store are first taken from the staging area to their storerooms after departure. This allows little room for error, as if any items are missing, it is too late to do much about it. Either it is necessary to wait for the follow week’s embarkation day to reprovision, or for crucial items, an emergency shipment to the next port-of-call must be made. This process is clearly a good candidate for an RFID system, as previously described.
The following is a list of tasks found onboard cruise ships, during vessel storing and operation, for which RFID systems could be applied:

**Materials Management: Vessel Storing** – as described in previous chapters
- Tracking of Spare Parts & Equipment
  - c) Engine Parts
  - d) Deck Parts
  - e) Safety Equipment
- Tracking of Provisions – Fruits & Vegetables, Dairy Products, Fish & Meats
- Hotel Stores
  - c) Hotel Dept. office supplies
  - d) Gift Shop stores
  - e) Beauty Spa stores
  - f) Photo Dept. stores
  - g) Dinning Room stores
  - h) Bar stores
  - i) Casino stores

- Luggage & Baggage
  - a) Embarking & Disembarking passengers (with Deck and Zone #/Cabin #)
  - b) Crew Personal effects

With the largest cruise ships sailing with well over 2,000 passengers a voyage, a lot of luggage is handled. Typically, cruise lines assume 3.5 pieces of luggage per passenger. That results in more than 7,000 bags being moved on and off a vessel during an embarkation/disembarkation day. Putting RFID tags on baggage would allow a cruise line to better inform passengers of the status of their missing bags.

A simple system could be similar to the storing system, the attached tag tells the system that it has been loaded and is aboard the vessel. Then the crew would know
where to look for the lost bag onboard, or contact the airline or pier side personnel. A more advanced system might be capable of reporting where the bag is. These systems could also be integrated with smart airline baggage identification systems. (See Chapter 11)

- Waste Handling and Disposal – RFID could be used to register safe disposal of:
  a) Garbage
  b) Plastics
  c) Glass
  d) Engine Room waste
  e) Deck & Hotel waste
  f) Bio-hazardous waste (Medical, Photo, Engine)

An RFID system could be used to support the vessel’s official entries in the Garbage Record Book, required by the International Convention for the Prevention of Pollution from Ships (MARPOL). In accordance with regulation 9 of Annex V of the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 (MARPOL 73/78), a record is to be kept of each discharge operation or completed incineration. This includes discharges at sea, to reception facilities, or to other ships. To aid in documenting these actions, an RFID system could provide supporting data showing that proper (or in some cases improper) handling occurred.

**Vessel Operation**
The following applications would be suitable for RFID technology in vessel operations:

- Safety Equipment, including:
  a) Maintenance of Lifesaving Equipment – RFID tags affixed to lifesaving equipment, such as lifejackets and life rings, could provide a “man-overboard” information feature. Should these items fall off the ship, an alarm would be triggered, informing of their disappearance, and providing “last detected” location information. They could also supply valuable physical presence information, informing the ship’s master that the proper amount of lifesaving equipment is
onboard. This would be particularly helpful for tracking of inflatable life rafts (see figure 26). Especially on ships with a complement of dozens or more rafts, where they are continually being offloaded for scheduled servicing and “loaner” rafts are supplied, having an RFID tag attached to the raft container would assist in identifying the number and type of raft.

b) Maintenance of Fire-fighting Equipment – Handheld Fire-fighting equipment could be tagged to automatically check that it is present. Service and inspection information could be tied into the tag database, and alarms set to warn of overdue servicing.

Figure 26: Promenade Deck Lifesaving Equipment, including Lifeboats and Inflatable Rafts (Source: Author’s Photo)

Safety (Other), including:

a) Accurate count of “Souls onboard” for departure condition – (see previous discussion)

b) Count of children and disabled persons onboard – an accurate count of all children, disabled people, and anyone else requiring special assistance during an emergency would be beneficial, as specific crew members are assigned to these tasks as a part of their emergency duties. A simple passive RFID tag system, with tags embedded into boarding passes, would allow for this counting.
A more advanced system using active RFID tags could be used in a RTLS setup. Children could be issued with a special cruise line watch or bracelet (figure 27), giving them say free soft drinks during their cruise, which is actually a transponder, broadcasting their location on the vessel. Parents could then go to computer kiosks around the ship and locate their children at any time. This unobtrusive system would provide the children with the sense of being more independent of their parents, while giving them a sense of security. It would also be of great assistance in finding and matching children with parents, should an actually emergency occur.

Security, including registration:

- Authorized passengers and crew onboard – RFID encoded boarding cards and crew identification cards, to ensure that all “heads” are aboard prior to departure.
- Guests and visitors, contractors, longshoremen, etc. - RFID encoded visitor and vendor passes, to ensure that these people have disembarked the vessel before departure.
- Tracking of children around the vessel – as discussed above

**Naval Vessels**

In research previously performed at the Massachusetts Institute of Technology, the use of RFID technology showed great benefits when applied to laundry operations onboard naval aircraft carriers. The study showed that when an RFID system was installed, there was a significant reduction in man-hours and thus substantial monetary savings, as compared with the Barcode technology that is currently being used. The full examination of this RFID application can be found in Arthur J. Clark’s 2000 MIT master thesis, “The Application of Radio Frequency Identification Devices Onboard Naval Ships.”

**RFID and the Navy**

The Office of Naval Research has several ongoing research and development (R&D) projects involving RFID systems. The work is being conducted by the Naval Surface
Warfare Center, Indian Head Division (NSWC IHD). They are currently investigating the development of RFID systems to support ordnance and other classes of supply management, through two major efforts.

1. Advanced Technology Ordnance Surveillance (ATOS) - The goal of this program is to demonstrate the use of RFID tags combined with Micro Electo-Mechanical Systems (MEMS) sensors, to perform inventory management of ordnance afloat and ashore.

   The RFID tags will allow real time inventory management of ordnance, and the MEMS sensors will monitor the environment the ordnance is exposed to. This information is then used to determine the current condition of the munitions.

   The NSWC has been working on this effort for several years to ensure the safe use of RFID tags in the highly restrictive environment on board Navy ships and ordnance, and examine the compatibility with Navy ship board systems, and International regulations.

2. Afloat Supply Department of the Future (ASDOF) Smart Storeroom - The ASDOF Smart Storeroom project is an effort to use RFID systems afloat to improve the management of inventories of other classes of supply. In October 2000, the first phase of the effort successfully demonstrated the use of RFID tags to track the issue of Depot Level Repairable (DLRs) materials from the Rotatable Pool (the vessel’s supply department) on board the naval vessel, USS Harry S. Truman. The demonstration showed the RFID systems could be used onboard a ship while underway at sea.

   Phase one of this project tested seven RFID/RFDC systems and has demonstrated that such devices can effectively operate in a challenging afloat environment.
Phase two of the project will demonstrate automated receipt, issue, and inventory control processes and pass supply data into a stand-alone integrated barcode system to validate database transfer interoperability.

- **Tracking of Spare Parts & Equipment** – as suggested on commercial ships:
  a) Engine Parts
  b) Deck Parts
  c) Safety Equipment
- **Tracking of Provisions** – Fruits & Vegetables, Dairy Products, Fish & Meats
- **HAZMAT Material tracking** – (See chapter 11 for a detailed discussion)
- **Weapon systems** - Some weapons systems are maintained in a rotatable pool, available for temporary installation on various deploying ships and permanent installation on certain amphibious and auxiliary ships, patrol craft and Coast Guard cutters. These systems could be potential candidates for RFID tracking
- **Tracking of Officers and Crewmen** – RTLS systems, tags affixed to personnel badges or embedded into uniforms permitting locatability.
- **Tracking of Officers’ Uniforms**

It would seem clear that there are many benefits to be had from the use and integration of RFID systems on Navy ships. According to data presented in the Dunlap thesis, there is room for improvement in the receipt process of onboard aircraft carriers and submarines. These improvements could include using automated tagging schemes such as RFID in the inventorying process.

**Other Potential Applications of RFID**

The following is a short list of other potential shipboard applications:

- Tagging of laundry items, including table and bed linens - to support better distribution and minimize effort spent sorting.
- Tagging of tools or special equipment - to permit an automated inventory process, could also be used as a security measure, with an alarm sounding if taken off of the vessel by unauthorized personnel.
- Security system - using a combination of RFID and an Electronic Alert System (EAS).
- Tagging of Safety Equipment - should the equipment/person fall overboard, the location and other vital statistics.

There are clearly many other appropriate applications not listed here. The purpose of listing all of these applications is to demonstrate that RFID systems can be a great tool when applied in a shipboard environment. As the cost of RFID technology drops, and the need for real-time asset and inventory monitoring increases, the possibilities of employing this technology are limitless.

This chapter has attempted to identify many of the potential applications of RFID technology onboard naval and commercial ship. A discussion of the benefits RFID has to offer when applied on ships would not be complete without looking shore side, at land based applications, which support ship operations. Chapter 11 contains this discussion.
Chapter 11: Synergy with Shore-side Activities

In addition to the significant benefits RFID technology offers when implemented with naval and commercial shipboard applications, one should really look at the whole process and include shore-side operations as well.

As discussed in preceding chapters, materials management is an important aspect of any organization involved with logistics in some way. In addition, RFID offers many advantages when used in supply chain management. Fully integrated RFID systems provide airlines and freight forwarders with a proactive shipment control solution through real-time locating systems. The United States military is also interested in the benefits that RFID technology has to offer.

Defense Logistics Agency

The Defense Logistics Agency (DLA) is the US military’s logistics combat support agency, whose primary role is to provide supplies and services to America's armed forces worldwide. DLA's mission includes managing over four million consumable items and processing more than 30 million annual distribution actions. The DLA must continue to help the US military maintain its readiness, at reduced cost, and sustain current and future deployed operations.

The Defense Logistics Agency is examining the benefits of RFID technology through a series of initiatives. The DLA has assumed the role of executive agent of the Department of Defense’s (DoD) Automatic Information Technology (AIT) concept of operations.

The concept of operations outlines key actions, specifying how AIT should be used in deployment, redeployment, sustainment and retrograde activities. This according to a memorandum by Jacques S. Gansler, under secretary of Defense for Acquisition and Technology, who says "In today’s global environment, commanders must know exactly where their assets are located and be able to act on this information."
As executive agent, DLA is responsible for implementing AIT standards across the entire Department of Defense (DoD). AIT includes the hardware and software required to create the storage devices, read the information stored on them, and to integrate that information with other logistics data. Information on each device can range from a single part number to a self-contained database.

**Hazardous Materials (HAZMAT) Management**

The capability to automatically identify and track HAZMAT materials, from their source of supply to the DLA receiving site, and ultimately to the end-user customer, will greatly reduce the personal risk to DLA personnel.

As described in Chapter 6, Martinez Consulting and Computer Services, Inc. (MSSC, Inc.) has been contracted by the Defense Supply Center Richmond (DSCR) to conduct several studies of automatic identification and data collection and tracking technologies. The contracts called for the researching and analyzing, designing and installing of an AIT system for tracking DLA products as they traverse the DLA supply chain.

One contract had MCCS review the HAZMAT supply process at Naval Station Mayport, in Florida. As part of this contract, a “proof of principal” test was successfully completed using RFID technology in a DoD distribution center environment.

Martinez Consulting and Computer Services, Inc. is located in Chambersburg, PA, and concentrates on system design, development, training, and implementation. MCCS, Inc. services include business process analysis, requirements analysis, systems design, and software engineering. They apply standard methodologies to ensure comprehensive testing and evaluation of systems.

On Thursday, February 22, 2001, a meeting was held in the Ocean Engineering Conference Room at MIT, between the author and Professor Henry Marcus from MIT, and Dennis Feldman, Joseph Jones, and Tom Cromack from MCCS, Inc. At the meeting,
the team from MCCS described several of the projects that MCCS has been working on for the DLA, including AHRIST and MICLOG.

**AHRIST**

AHRIST stands for Advanced HAZMAT Rapid Identification, Sorting and Tracking. It is the initiative for the application of AIT to hazardous materials management.

The AHRIST effort was set forth to determine whether AIT and ADC (Automatic Data Collection) could solve an ongoing problem of the identification of hazardous material at the DLA Depots.

Thousands of packages arrive daily at DLA Depots. Packages containing regulated hazardous materials (HAZMAT) are received simultaneously with common, non-hazardous supply items. Currently there is no system in place, which consistently and accurately alerts the personnel, or notifies the DLA Automated Information Systems (AIS), of the arrival of HAZMAT products.

DLA personnel can not confidently differentiate common, non-hazardous supplies from those containing potentially unsafe and environmentally dangerous materials and chemicals.

Despite the requirement that most of the chemical products received must have a Material Safety Data Sheet (MSDS) available to employees, as this document is not a shipping document, it is not required to accompany the material or products to the DLA Depots. As a result, the product and the critical technical and safety information are separated while passing through the supply chain. This means that personnel can be at an increased risk when handling these items.

The AHRIST initiative was undertaken by DLA Headquarters together with MCCS, to assist DLA depot personnel in rapid identification of items with regulated hazardous
material content. Environmental and safety compliance can be improved, and value-added information services can be provided to DLA management and customers.

**MICLOG**

MICLOG stands for Microchip Logistics, and is the name of the project MCCS is conducting to determine the operational capabilities of radio frequency (RF) product identification, receiving, handling and storage alerts, expiration date alerts, and tracking along the supply chain. Part of this project involves the running of an Operational Prototype (OP), with the goal of determining how well RFID technology works in an operational environment.

**MICLOG Operational Prototype**

The purpose of the MICLOG Operational Prototype is to evaluate if chemicals, packaged in various boxes, cartons, and containers, each labeled with a three-part composite RFID enabled tag, can be successfully identified and tracked as they move along the supply chain, from manufacturer through distribution centers, to the end consumer.

There are three identification segments on the composite label: a text segment, a linear and 2D (PDF417) bar code segment, and an RF-enabled microchip tag. The primary focus of the prototype is to evaluate the performance of the RF component of the label, in a commercial, operational environment, subject to handling, transportation, storage, and environmental conditions.

Using URS corporation’s Total Chemical Management (TCM) Hub in Salem, the OP was conducted using RFID portal readers (see figure 28), installed at three commercial sites. The sites represent a manufacture, distribution center, and end customer of a typical supply chain. The readers are connected to a networked computer architecture, designed to collect, manage, and display information acquired from the composite RFID tags/labels.
MCCS constructed a shipping portal at the manufacturer's (appli-tec) site located in Haverhill, MA. The manufacturer's portal will be used to encode the RFID tag memory chip prior to shipment to the URS TCM Hub in Salem, MA in addition to triggering the advance shipment notification to the MICLOG server in Salem, MA and the remote MCCS EC/XML global server MCCS headquarters in Chambersburg, PA.

The portal at URS is used to read incoming products with the RFID tag attached at the manufacturer’s site, and to encode the RFID tag memory chip prior to shipping the product to the URS customer (Raytheon) located in Andover, MA. Incoming receipt information and outgoing shipping notification is also sent to the remote MICLOG global server.

A receiving portal was set up at the customer's (Raytheon) site in Andover, MA, a DoD prime contractor for Hawk and Patriot missile systems maintenance. The chemicals received from the URS TCM Hub would automatically provide receipt confirmation, and complete the tracking process.
The RFID tags created at the URS Salem Hub, pass through the receiving portal at the Raytheon facility, and generate an electronic transaction (receipt confirmation notification) via the local server. These electronic transactions are sent to both the URS TCM Hub in Salem, MA and the remote MICLOG EC/XML server in Chambersburg, PA.

MCCS has used the OP to effectively demonstrate the value of RFID in identifying and tracking products as they move along the supply chain. The OP has also identified limitations of the technology, including difficulty reading through liquid chemicals.

These projects help to establish what RFID technology can offer, when applied to the management of HAZMAT. These benefits can also be realized when used on board ship, as was demonstrated onboard the US Navy Destroyer, USS THE SULLIVANS. (See Chapter 7.)

Source Tagging
Source tagging involves the embedding of disposable RF security labels into items, either at the point of manufacturing or packaging. It has proven successful in the packaged products industry, and retailers, such as discount chain giant Target, are starting to use source tagging on various merchandise such as apparel, shoes, sporting goods, batteries, videocassettes, audiotapes, computer software, electronics, and earrings.

Many of these items may find their way onboard ships, either in the supplies for a ship’s crew, or to the gift shops onboard cruise ships. A shipboard RFID installation could take advantage of these items having been source tagged.

Another application is in the air travel industry, incorporating RFID tags into the baggage tags applied at check-in or even being embedded directly into the luggage. The International Air Transport Association (IATA) is examining various technologies for improved baggage management, to reduce the growing problem of mis-directed or lost
luggage, and address security issues. Also, the IATA has been looking to establish a standard RFID system frequency, which will not interfere with the safe operation of other aircraft systems.

As many of the voyages taken onboard ship often include air travel (commuter ferry service to the airport, transportation to and from a cruise, crew deployment, etc.), integration with the airline RFID baggage systems potentially offers many benefits.

**Smart Baggage Tags**

It's known as the "smart" baggage tag. It looks like the normal luggage tag issued at the check-in desk. However, in addition to the printed bar codes and destination and flight information, the tag has a passive RFID transponder embedded, which can be delivered through existing bag tag printers, without occupying additional space at the check-in desk.

By using smart RFID labels, airlines will have a highly reliable, economical baggage identification and tracking solution for positive passenger-to-baggage verification and reconciliation. An RFID system can be integrated with existing technology, including baggage tags, check-in desk printers, and sortation equipment.

The present system, used at most of the airports of the world, relies on barcoding of bags. All that the barcode contains is a unique ID number for the baggage. The data about the bag is stored on a network, which therefore also needs to be available at the arrival airport, for the tag to be successfully read there. An RFID embedded tag provides extended data storage capability without increasing the size of the label. This RFID tag contains key elements of the baggage source message (BSM), so that there is no need to reference a database to handle and route the bag.
As traveling by air typically involves several connecting flights to get to one’s final destination, baggage is often sorted several times. According to one source, about 30 - 40% of barcodes wear out during multiple sorting, and are un-scanable. An RFID enabled baggage tag system also permits the ability to redirect luggage automatically, if a flight plan is changed, without having to issue new tags.

According to a study conducted at the Department of Industrial Engineering and Management of Helsinki University of Technology, if all airlines implemented RFID systems for baggage services, there would be an estimated savings of $6 - $12 billion, from reconnecting errant bags to their owners. The operational costs of the tags for such a system are estimated to be $0.6 - $1.2 billion.

Luggage can be automatically scanned in groups, no matter the orientation of the bag or whether it is overlapped with others. The system has a reliability rate of over 99%. The small 1% failure rate is caused by luggage containing metal especially the new metallic bags, camera cases, etc. These types of bags often cannot be properly scanned, because the RF waves are unable to penetrate them.

**Smart Baggage Tag Trial**

In 1999, British Airways conducted trials of smart baggage labels at Heathrow Airport on the high volume travel routes from Manchester, UK and Munich, Germany. The trials involved over 75,000 smart bag tags on passenger luggage.

The field trials have shown RFID to be more robust and reliable than the existing barcode system in identifying and tracking baggage. BA has openly shared the trial data in an effort to accelerate the adoption of RFID technology. Following these trials, the IATA voted to formally adopt the 13.56 MHz RFID ISO 15693 standard, as a recommended practice for identifying airline passenger baggage electronically.
BlueTag and Bluetooth Technology

One new patent pending technology is the BlueTag Travel tag. The philosophy behind this product is to equip baggage with an reusable intelligent tag, combining several new technologies, to provide a more RTLS type of system for baggage tracking.

The BlueTags system consists of a smart wireless tag, based on Bluetooth and RFID technology, which is radio based technology allowing users to make effortless and instant connections between various communication devices.

Bluetooth is a short-range wireless technology, designed to enable electronic devices to communicate with each other without the need for cables. This relatively new technology uses frequency-hopping, spread-spectrum (FHSS) communication, operating in the 2.4-GHz bandwidth. This frequency is one in which unlicensed devices are permitted to communicate in most countries of the world, and makes a robust link, even in noisy radio environments.

The name Bluetooth, trademarked by the Swedish company Telefonaktiebolaget LM Ericsson, comes from Harald Bláþland (Bluþooth), a Danish king from the 10th century, who united the Danes under Christianity.

The BlueTag Travel tag can either be embedded in or attached to the object to secure, track, and monitor. Possible objects for tagging include suitcases, handbags, and laptop cases.

At the other end of the system is the next generation of Bluetooth enabled mobile phones or PDA's. The BlueTags can also be read and tracked by Bluetooth enabled scanners. The mobile phone or scanner will serve as the surveillance monitor, and the tag will be the monitored object.
Travellers who use the BlueTag system register personal information, such as e-mail, address, etc. in the BlueTags Database before using the tag for the first time. Then, when taking a trip, other relevant information such as travel itinerary and destination, is downloaded to the BlueTags Database, to achieve full functionality of the tag.

The developers of the BlueTag Travel system claim that their tags will simplify the entire baggage identification and tracking process, from the electronic check-in process, to security, tracking, arrival notification, and confirmation.

Luggage handling is not only a logistical issue for air-travel, but also a major issue for the cruise industry. With the largest cruise ships sailing with well over 2,000 passengers a voyage, a lot of luggage is moved.

Typically, cruise lines assume 3.5 pieces of luggage per passenger. That results in more than 7,000 bags being moved on and off a vessel during embarkation/disembarkation day for a ship with 2000 passengers.

**Other Shore-side Applications**
As mentioned in Chapter 3’s discussion on manufacturers of smart RFID systems, RFID is being used in the automobile manufacturing industry, healthcare environments, car rental companies, and railcar and transportation companies.

Another attractive shore-side candidate for RFID systems is shipyards. This application has been examined in great detail in two MIT master theses; Chel Strogren’s 2000 thesis “The Use of Automatic Identification Technology to Improve Shipyard Material Handling Processes”, and Matthew Barlin’s 2001 thesis “Implementing Automatic Identification Technology to Improve the Construction of Naval and Commercial Ships”.
Chapter 12: Conclusions

“Radio Frequency Identification is revolutionizing the automatic collection of data in the supply chain from suppliers to manufacturers, warehouses, and retailers” according to Josef Schuermann, Chairman of the SubGroup on Regulatory Matters of the International Organization for Standardization (ISO).

The same revolution could occur in the marine field, if RFID technology is adopted and applied to shipboard processes. This thesis has presented some of the potential applications for RFID systems onboard naval and commercial ships, and supports the conclusion that RFID technology does offer significant benefits when implemented with shipboard applications.

While this thesis presents a number of potential applications for RFID technology onboard ships, a ship owner should still consider some of the risks associated with using this technology for these applications. Some of the risks include:

- **Lack of standardization** – While there are many manufactures of RFID systems, most of these are proprietary, and lack standardization. Both the Uniform Code Council (UCC) in the United States, and the ISO internationally, are working towards establishing certain standards for RFID technology applications. In the aviation industry the FAA and IATA are also attempting to find an appropriate frequency which RFID can use onboard airplanes. Until such standards are set, and until there is agreement amongst manufactures for cross platform or cross system readability, it is doubtful that this technology will see its full acceptance.

- **Application of the RFID tag** - One challenge of any RFID system, is at what point should the tags be applied to the items to be tracked. Source tagging is one option, applying the tag at the point of manufacturing. Another is having the tags placed on the items, boxes, and/or pallets at the freight consolidators. When it comes to
baggage, using a similar system to the airlines allows the same tag to be used for identification onboard the ship as on the aircraft.

- **Active RFID tags limited by battery life** – The length of the battery life (typically between 2 and 5 years) can be a limiting factor in the applicability of active RFID tags for certain purposes, based upon maintenance cycles. Part of the scheduled maintenance should include battery replacement, to ensure uninterrupted service.

As technology progresses, these risks will be mitigated, and solutions found, making RFID even more attractive. With the continued demand for more accurate data collection and monitoring, RFID will play an increasing important role onboard ships.

This thesis has successfully addressed many of the challenges and potentials for the application of RFID technology to improve various systems and processes onboard naval and commercial ships. The research has shown that RFID can greatly improve the accuracy and speed of materials and inventory management, and that RFID has broad applicability in many other areas aboard ships.
References:


References: web-sites


Bar Codes


**RFID in Baggage Tags**


**Web Search Engines**

*Google.com*, July 2001, Google Inc. “Search 1,346,966,000 web pages”  
<http://www.google.com/>

Appendix

Net Present Value Calculation of RFID Systems When Implemented Onboard a US NAYY Aircraft Carrier’s Aviation Storeroom

![Net Present Value vs. Frequency of Inventory Taking Comparison of RFID systems](image)

<table>
<thead>
<tr>
<th>Total times inventory is taken</th>
<th>Inv./Year</th>
<th>NPV of RFID System Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Passive</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>$79,998</td>
</tr>
<tr>
<td>10</td>
<td>2</td>
<td>$158,805</td>
</tr>
<tr>
<td>15</td>
<td>3</td>
<td>$211,214</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
<td>$246,069</td>
</tr>
</tbody>
</table>

These are the net present values, for investing in an RFID system onboard an aircraft carrier, calculated over a five-year period with a discount rate of 8.5%.