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Microcircuit Technology in Logistic Applications Radio Frequency (MITLA/RF): an analysis of radio frequency identification and tracking to support logistic operations

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THESIS

MICROCIRCUIT TECHNOLOGY IN LOGISTIC APPLICATIONS RADIO FREQUENCY (MITLA/RF), AN ANALYSIS OF RADIO FREQUENCY IDENTIFICATION AND TRACKING TO SUPPORT LOGISTIC OPERATIONS

by

Edwin T. King

March 1995

Thesis Co-Advisors: Keebom Kang
Myung W. Suh

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This thesis is an analysis and evaluation of Microcircuit Technology in Logistics Applications. (MITLA/RF) Under the MITLA initiative the Department of Defense (DoD) is testing, evaluating, and developing asset tracking devices to increase readiness and responsiveness while reducing the overall costs of providing logistic support. The underlying goal of the MITLA initiative is to increase readiness through improved asset visibility on a global scale. The primary focus of this thesis is to underscore the current mission requirements and the need for introducing MITLA/RF into military logistic operations. A background analysis of the capabilities and functionality of the system components is presented. Strong emphasis is placed on the digital wireless network and its role in the expeditious environment of military logistics. Automated logistic system interoperability, migration and the technology to dollar tradeoff is discussed. This study provides insight that if properly used, will help logistics policy makers introduce a sound high-tech solution to successfully track and support Marine Corps logistic efforts well into the next century.

TABLE OF CONTENTS

LIST OF ACRONYMS

ACE	Air Combat Element
ACK	Acknowledgment
AIS	Automated Information System
ANSI	American National Standards Institute
ASCII	American Standard Code for Information Exchange
ATLASS	Asset Tracking for Logistics and Supply Systems
bps	bits per second
C^4I^2	Command, Control, Communications, Computers Intelligence & Information
CALM	Computer Aided Load Manifesting
CAMES	Computer Aided Embarkation Management System
CCITT	Consultative Committee for Intergrated Telegraphy and Telephony
CEUCE	Common End User Computing Equipment
CMS	Classified Material Storage
CSMA/CD	Carrier Sense Multiple Access/Collision Detect
COE	Common Operating Environment
CPU	Central Processing Unit
CSS	Combat Service Support
dBm	Decibel Poewr level related to 1 mW
DES	Data Encryption Standard
DMS	Defense Messaging System

DoD	Department of Defense
DOS	Disk Operating System
FCC	Federal Communications Commission
FDX	Full Duplex
FM	Frequency Modulation
FMF	Fleet Marine Force
FTP	File Transfer Protocol
GCCS	Global Command and Control System
GCE	Ground Combat Element
HDX	Half Duplex
HTTP	Hyper Text Transfer Protocol
IBV	In the Box Visibility
IEEE	Institute of Electrical and Electronics Engineers
ITV	In Transit Visibility
JMCIS	Joint Maritime Command Information System
JOPES	Joint Operations Planning and Executing System
Kbps	Kilo bits per second 10^3
KHz	Kilo Hertz
LAN	Local Area Network
LED	Light Emitting Diode
LOG-AIS	Logistic Automated Information System

LOGMARS	Logistics Application for Marking and Reading of Symbols
MAGTF II/Log AIS	Marine Air Ground Task Force Logistics Automated Information System
MAGTF	Marine Air Ground Task Force
MCTSSA	Marine Corps Tactical Software Support Activity
MEB	Marine Expeditionary Unit
MHz	Mega Hertz (10^6)
MIS	Management Information Systems
MITLA	Microcircuit Technology in Logistics Applications
MITLA/RF	Microcircuit Technology in Logistics Applications Radio Frequency
MPF	Maritime Prepositioned Force
MPS	Maritime Propositioning Ships
MRE	Meal Ready to Eat
NIST	National Institute of Standards and Technology
OMFTS	Operational Maneuver from the Sea
OSE	Open Systems Environment
OSI	Open Systems Interconnection
POSIX	Portable Operating System Interface
RDBMS	Relational Data Base Management System
RF	Radio Frequency
RFID	Radio Frequency Identification
RISC	Reduced Instruction Character set

RTT	Recording and Tracking Technology
SAVI	Savi Technology, Inc., of Mountainview, CA
SDK	Software Development Kit
SMTP	Simple Mail Transfer Protocol
SQL	Structured Query Language
TAFIM	Technical Architecture Framework Information Management
TC AIMS	Transportation Coordinators' Automated Information for Movement System
TCP/IP	Transmission Control Protocol/Internet Protocol
TDS	Tactical Data Systems
UB	Unified Build
VAC	Voltage Alternating Current
VDC	Voltage Direct Current

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I. INTRODUCTION

A. OVERVIEW

This thesis focuses on two distinct disciplines: Logistics and Information Technology. The technology discussed in this thesis has enormous logistic potentials. At the same time there are many information technology issues that must be addressed in order to make the system a valuable logistic tool. The Marine Corps, in its never ending quest to make itself more efficient while maximizing its limited pool of research dollars, has begun to foster one of the most exciting logistic innovations in recent times. The innovation that we will be analyzing throughout this thesis comes under the broad heading of Microcircuit Technology In Logistics Applications/Radio Frequency (MITLA/RF). Through the use of Radio Frequency Identification (RFID) Tags and other related equipment the Marine Corps and other Department of Defense (DoD) agencies are striving to obtain more efficient and more accurate asset control. Recent Marine operations have brought to light the need for better control over our equipment and supplies. We must make more efficient use of our operational budget dollars. Operation Desert Shield/Storm exemplifies how poorly our currently deployed asset control mechanisms are. When equipment and supplies are deployed as part of a large scale joint operation, control and accountability of these assets quickly degrades. This loss of asset accountability limits the operational commanders' combat effectiveness. Today's battlefield requires the logistician to rapidly track and locate assets throughout the area of operations and get them quickly to the war fighter. The MITLA initiative is looking at commercially developed radio frequency tags, interrogators, wireless networks and eventually satellites to track assets on a global scale. The goal of the MITLA/RF initiative is to provide both planners and war fighters with the capability to maintain real-time global asset visibility.

This thesis is an analysis of one of the components that make up the asset tracking system, the digital wireless network. The wireless network is the first significant step to the expeditious environment of military logistics.

This is the second in a series of theses to come out of the Naval Postgraduate School concerning MITLA/RF. The first thesis by Captains R. Amirante and G. Baker analyzed the feasibility of using MITLA/RF to support equipment maintenance. (Amirante and Baker, 1993) This thesis focuses on the operational logistics aspect of asset tracking and accountability. It specifically looks at asset tracking equipment and connectivity via digital wireless networks.

B. RESEARCH OBJECTIVE

This thesis analyzes the current family of asset tracking devices currently being developed for DoD by SAVI Technology, Inc., of Mountain View, CA. The main objective of the thesis is to answer the following questions regarding the wireless local area networks and radio frequency identification and tracking assets.

- What are the capabilities and limitations of the distributed wireless network proposed by SAVI Technology, Inc.?
- How will this technology interoperate with existing Marine logistics systems?
- How will this technology help enhance Marine Expeditionary Brigade (MEB) equipment accountability and combat effectiveness while reducing and streamlining the logistics tail?
- How could the manpower configuration of the MEB be transformed by implementation of this system?

C. SCOPE AND LIMITATIONS

1. Scope

The primary focus of this study is to conduct an analysis of the distributed wireless network currently under development for the Marine Corps as part of the MITLA/RF initiative. The thesis will focus on three areas of interest:

a. The Distributed Wireless Network

1. Capabilities
2. Limitations
3. Range
4. Security of data

b. System Interoperability

1. Interoperability of MITLA/RF wireless network with existing and future Marine logistic tools
2. Integration with the functional areas of embarkation, supply and operational planning

c. Anticipated Benefits of the System

1. Equipment accountability
2. Increased productivity
3. Operational reconfigurations
4. Potential cost savings

2. Limitations

This thesis has been constrained by a number of factors. The first is the realization that MITLA focuses on emerging technologies. Design specifications and capabilities are constantly changing and improving. The second constraint is the lack of actual field or operational use data. Exercise Agile Sword 94 is the only known demonstration of the wireless RFID technology in an actual operation. It was conducted using many but not all of the components described in this thesis; but was an excellent representation of the functionality and capabilities that can be achieved through the use of this technology.

As technology moves forward, the system components described in this thesis will change. They will no doubt become smaller and more powerful. Nonetheless, the underlying principles and objectives outlined in thesis for asset tracking will remain sound. The strategic objective for asset tracking in the Marine Corps will be founded on the technological advances we make today.

D. METHODOLOGY

The primary method of obtaining research material was through a review of existing literature. Additional research material was obtained from actual system performance evaluations. These included laboratory tests and a proof of concept field demonstration. Additional performance data was obtained from the exercise Agile Sword 94 which was a Maritime Prepositioned Force (MPF) off-load demonstration in Camp Lejeune, NC that made extensive use of MITLA/RF assets. Meetings and interviews with the manufacturer and system developers were conducted throughout the research phase. The meetings and demonstrations allowed a more thorough understanding of the design requirements, and the current system capabilities and limitations.

These research techniques combined to provide a balanced, objective and comprehensive analysis of the asset tracking system components. The extensive meetings and phone conversations with key representatives from Headquarters Marine Corps, Marine Corps System Command, Naval Facilities Engineering Command and SAVI Technology were the principal sources of research material for this thesis.

E. THESIS ORGANIZATION

This thesis is divided into six chapters. The first chapter, as an introduction, provides a general overview. Chapter II looks at why we in DoD are investing in new logistic tracking technologies. Chapter III is a detailed analysis of the current asset components and their capabilities. The wireless network is analyzed in great detail in this chapter. Chapter IV looks at the issue of system interoperability. Current trends for common operating environment are analyzed. Chapter V presents an comparison of existing technologies and MITA/RF technologies in an actual amphibious operation. The final chapter contains the conclusions, recommendations and final remarks. A list of acronyms is provided on page xi.

II. WHY IS THE MARINE CORPS INVESTING IN RFID TECHNOLOGY ?

A. GENERAL

There are a number of reasons why the Marine Corps and the DoD are investing a substantial amount of time and financial resources to the improvement of asset tracking and accountability. First, the post-Cold War shift in US military posture from forward deployed ground and air elements in Europe to a US-based, force projection is dramatically changing the logistics planning process. Secondly, with the advent of the new naval service strategy published in "From the Sea" and its complement "Operational Maneuver from the Sea (OMFTS)," the Marine Corps must redefine its concepts for deploying, sustaining and re-deploying Marine Air Ground Task Forces. (MAGTFs). (Schindler, 1993)

The expeditionary focus of this new strategy is to forward operate and respond swiftly on short notice. The Marine Corps and the rest of DoD are facing constrained fiscal and manpower resources. At the same time the operational requirements continue to broaden in scope and number. To meet these challenges, the Marine Corps must begin to examine new options that will enhance combat logistics and maintain its combat capabilities. The employment of technology is one solution that will help compensate for the reduction in manpower and fiscal resources. However, improvements in technology are not without cost. Advanced technology designed into our new equipment has substantially increased our firepower and mobility, which has caused a ripple effect necessitating greater logistical resources in the area of ammunition and fuel replacement. (Tusa, 1994) The challenge in this argument is to strike a balance between the combat arms and the combat support arms. These two fundamental elements of warfighting can never be thought of as separate entities: without effective and responsive combat logistics the ground operations will grind to a halt. It is hoped that through the implementation of RFID technology that we can increase not only our asset accountability but our logistic responsiveness. The challenge is set for the logistician who must support modern combat operations. They must be able to provide supplies in greater quantities, in less time, using fewer people.

We have been forced by Congress to reduce our force structure. In complying with the down sizing initiative, we as Marines must fight to retain our combat effectiveness in-spite of the smaller size. To maintain the combat effectiveness and the force structure of the Ground Combat Element (GCE) we need to focus on introducing technology innovations in the area of logistic support. This is not to say other technological improvements can not be made to the GCE. In fact the logistic improvements that will be discussed in this thesis transcend all elements of the Corps. Exploring non-logistic technological options for the GCE is beyond the scope of this thesis. The Marine Corps Combat Service Support (CSS) structure, principles and doctrine have been validated for the near term and for the majority of possible scenarios. (Schindler, 1993) However, there is much that can be done to optimally improve the effectiveness and responsiveness of the current CSS system. The increased operational tempo, mobility, and over-the-horizon maneuver warfare have outpaced the development and implementation of modern logistic systems. (Michon, Gunderson, and Torres, 1993) In order to remain responsive to the CSS needs of the GCE and the Air Combat Element (ACE) there must be significant improvements in the way we currently track and account for supplies and materials. If properly employed, technological advances in logistic systems can be an effective force multiplier. Future conflicts will be fought with fewer support personnel, although fewer in numbers these Marines will be required to provide better and more responsive support to the war-fighting effort. The implementation of technology in the area of combat service support is a vital and cost effective proposition that will help preserve the combat effectiveness of the Corps in these times of diminishing resources.

The purpose of this chapter is to outline one of the technological innovations that is being considered by the Marine Corps to improve the efficiency and effectiveness of logistic and CSS operations. New technologies are required to quickly process the unprecedented quantities of CSS data necessary to support the logistic aspect of emerging command and control concepts. (Michon, Gunderson, and Torres, 1993)

The emerging operational hypothesis of OMFTS, which requires sea-basing, will further complicate the CSS function. (Michon, Gunderson, and Torres, 1993) Recent deployment of Marine Corps forces in Operation Desert Storm and Operation Restore Hope resulted in logistics support falling short of expectations. Hard work by well-trained Marines assured that no operations were jeopardized, and all mission objectives were achieved. In both operations logistic support proved to be an expensive, labor intensive, and cumbersome process. (Michon, Gunderson, and Torres, 1993) As stated above, this is a concern because the Marine Corps is getting smaller in both personnel and fiscal resources. In order to continue to provide responsive CSS, changes in the way we conduct business have to be implemented.

In August of 1982 the Microcircuit Technology in Logistics Applications (MITLA) was founded "to rapidly introduce and foster inexpensive, portable, state of the art automated devices to improve logistical performance throughout DoD." (Durham, 1993) An underlying goal of the MITLA initiative is to provide accurate and timely asset information to the force commanders.

Improved asset visibility is both a wartime and a peacetime concern. In peacetime, it is a key planning tool that can help ensure effective logistic support in times of diminishing financial resources. Improved asset visibility will enable DoD and the Marine Corps to reduce inventory stockage levels and make better use of our financial resources. Better asset visibility will allow us to maintain a cost effective peacetime material readiness level. In a wartime situation, total asset visibility will prove to be an invaluable operational resource. It will enable the operational commander to make quick and accurate decisions concerning the level of logistic support available for operations. It will also provide logistic officers with the information needed to make cost-effective decisions concerning the positioning and movement of materials. The improved accuracy of asset information will help reduce the submission of duplicate orders which intern degrades the efficient use of our supply and transportation assets.

In summary, MITLA through the implementation of advanced technologies is concerned with the development of logistic tools that will significantly improve material tracking and accountability. To date, numerous efforts to improve asset tracking have been made. Most of these however have become fragmented and very service specific. This has caused wide spread inefficiencies in logistic support. This is especially true in times of joint operations. Without a common logistic architecture, each service operates its logistic effort independently. Service specific logistic systems causes inaccuracy and inefficiency throughout the entire national logistic system. The current goal being supported by MITLA and DoD is to effectively integrate the total DoD logistic picture across all service lines to improve operational support and reduce inventory stockage levels.

B. EXISTING DOD ASSET TRACKING DEVICES

One of the first asset tracking and accounting technologies to be employed by the MITLA initiative is signal dimension barcodes. These barcode systems are currently used on Maritime Prepositioning Ships (MPS). They are also utilized during large scale exercises to aid in the manifesting and control of assets.

Bar coding is a low-cost, accurate solution that is widely utilized by many industry groups. As mentioned above, barcoding schemes are either one or two dimensional. A one dimensional barcode has the ability to encode small amounts of data (i.e., 82 characters). Two dimensional barcode is the multi-row, continuos variable length, structured data encoding symbology that can encode 2800 characters. (Smith, 1986, MILSTD-1189)

The 39 barcode is the most popular barcode technology used in DoD for inventory and tracking purposes. It is a variable length, discrete, self-checking, bi-directional, alphanumeric barcode. Its character set contains all the letters from A to Z (uppercase), 0-9, $, %, +, -, and space. The asterisk (*) is reserved for start and stop bar. The full 128 lower case ASCII characters can be represented by combining two characters. For example, "a" is represented by "+A". (MILSTD-1189, Whiting, 1994) Each character has a total of nine elements (bars and spaces) called modules, of which three are wide (hence the name Code 39). Code 39 symbols can be recognized by their distinctive start and stop bars, represented by an asterisk (*). The pattern of code 39 is shown in Figure 2-1 has the following sequence: narrow bar, wide space, narrow bar, narrow space, wide bar, narrow space, wide bar, narrow space, narrow bar. Code 39 has the ability to incorporate an optional check digit to ensure data integrity. (Whiting, 1994, Flynn, 1994)

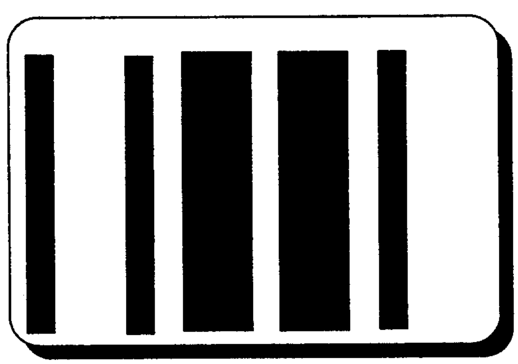

Figure 2-1 Code 39 Barcode (Whiting, 1994)

The success of barcoding can be credited to its simple design. To read a barcode, a scanner, either fixed or handheld, moves a beam of light of a specific frequency over a series of dark bars that vary in width. Light reflected from the spaces between the bars is read by the scanner and converted to a digital signal by a microprocessor. (Smith, 1986) This simple design has allowed barcode technologies to be incorporated in many industries. The chief advantages of barcodes are speed and accuracy. High rate scanners can read bar codes at a rate of 500ft/min about 5.8 miles per hour. (Smith, 1986) Barcodes have the ability to store a fairly large amount of information in a small space. The cost is inexpensive and the number of applications that can take advantage of bar codes is growing all the time. There are many types of scanners available in the market: from light pens that contains light emitting diodes to fixed station scanners.

Scanning devices although accurate and inexpensive have some distinct limitations that make them ineffective for use in expeditious environments. The principal disadvantages of barcoding are:

- Limited scanning distance/range.
- Scanner to barcode orientation.
- Limited memory.
- Each barcode must be individually scanned.
- Susceptible to environmental conditions.
- Data is fixed. (write once read many devices)

We will now discuss in detail the characteristics of these limitations to barcode technology.

a. Limited Distance and Range

The average range of a barcode scanner is between 6 and 18 inches. In order to read the encoded information on a barcode, the user must get the scanner within the effective range in order to capture the encoded data. There are barcode scanners available on the market that will read bar codes at distances up to 6 feet; yet these scanners are larger, heavier and more expensive than the wand type scanners. (Smith, 1986) Such scanners are designed for fixed facility tracking operations like postal and manufacturing, and cannot be considered for use in expeditionary operations due to their size.

b. Scanner to Code Orientation

In order to read the encoded information on a barcode label, the scanner must be able to see the barcode label. Correct positioning and orientation between the barcode label and the scanner is vital for the data capture. If a barcode label is inverted or mis-oriented, the scanner cannot read the encoded information. In a fast paced logistic operation this is a serious handicap. Containers and trucks are usually loaded with multiple items. There is no way of accurately capturing all the data associated with these assets. There is too much human intervention in the process and the margin for obtaining incomplete and inaccurate information is high.

c. Limited Memory

Limited memory is acceptable for certain applications such as coding pallets of ammunition, MREs and similar items. But when you consider all of the information needs for a full operational deployment the memory available on the average barcode is not sufficient for all applications. Currently deployed barcode applications have only memory space for 82 characters. (MILSTD-1189)

d. Each Barcode Must be Individually Scanned

In order to retrieve the information contained in a barcode label it must be scanned by a barcode reader. To obtain an accurate inventory of every item in a given location each barcode label at the location must be individually scanned. This can be a labor intensive and time consuming task. Chances are considerably high that some of the barcode labels will be overlooked when this type of collection process is used. This will lead to an inaccurate and incomplete representation of the assets available at the scanned location. During the buildup of forces this inaccurate information will eventually cause the ordering of unneeded supplies and equipment. During retrograde operations the inaccurate information could adversely affect the lift requirement. In either instance, inaccurate logistic data does not make efficient use of our limited resources.

e. Susceptibility to Environmental Conditions

Barcode equipment performs best in an environmentally neutral condition. Extremes of and kind have the potential to degrade the performance of the barcode system. Some of the more common elements that will degrade the performance of the barcode system are: bright sunlight, dirt, rain, snow, and ice. (Michon, Gunderson, and Torres, 1993,; Micron Communications Inc.,

1993) All these meteorological factors can degrade and adversely affect the performance of the barcode. All of the elements mentioned above are found in environments where military logistic operations take place.

f. Data is Fixed (Write Once, Read Many Devices)

Barcodes are passive devices. Information can only be written one time to the barcode. A barcode label can be read an infinite number of times however, once written the information is fixed and it can not be updated or changed. Barcodes are useful when you need to gather several small pieces of data. To obtain large descriptive pieces of information more versatile technologies must be employed. (Michon, Gunderson, and Torres, 1993, Micron Communications Inc., 1993)

C. WHY RFID ?

Realizing some of the weaknesses associated with barcoding systems, MITLA began to look into Radio Frequency Identification Tags (RFID) as an alternative tracking solution. This initiative and divergence from the barcoding systems was not seen as a necessary by many within DoD until 2 August 1990, when the Iraqi military forces launched a surprise attack against Kuwait. On 7 August 1990, the US military began sending enormous quantities of supplies, equipment and personnel to the Saudi Arabian peninsula. (Levin, 1991) The accessibility of excellent Saudi Arabian sea and airport facilities (far greater than their needs) eased an expedited unloading of supplies and equipment. The speed and sheer volume at which equipment, supplies and materials arrived in the country overwhelmed and crippled the barcoding methods of asset tracking. It was during the initial build up of forces that the severe limitations and shortfalls of barcoding systems came to light. Logisticians from all branches of the service stated they were unable to maintain visibility over equipment/supplies arriving in the theater. Logisticians operating the ports and airfields further stated that they generally knew when a ship was going to arrive but only had a general idea about the type of cargo that it contained. It was not uncommon for ships or aircraft to have incomplete or inaccurate manifests, mislabeled containers, or generic cargo descriptions. The contents of shipments remained a mystery until the aircraft or ship was completely off-loaded. Even after the off-load was complete it was often necessary to open the containers and sort through the contents to find a single item. (Michon, Gunderson, and Torres, 1993), For example, the US Army reported that during Desert Storm/Shield 25,000 of the 40,000 shipping containers sent to the theater had to be opened and hand sorted to identify the contents. (Michon, Gunderson, and Torres, 1993)

The magnitude of items arriving in the theater during the initial buildup overwhelmed staging areas, warehouses and the barcode system at all points of debarkation. (Levin, 1991, Michon, Gunderson, and Torres, 1993) Also during this time accurate accountability and control of assets also suffered. According to supply officers, many of the combat units arriving in theater obtained their equipment and supplies and departed to forward-operating locations before logistics personnel could accurately record the transaction. (Levin, 1991) Many of these units acquired assets that were far in excess of their needs. This caused critical shortfalls in equipment and supplies for units arriving in country at later dates. There were other problems with accountability; for example, the Army lost track of almost all of its containerized cargo sent to the Gulf. As a result, DoD had to pay $50 million in late container charges. (Haseley, 1992) A number of factors caused this delay in container return. The primary cause was poor or nonexistent manifests and inadequate container documentation. Secondly, the number of containers sent to support Desert Storm was large enough to fill more than 500 ships and 10,000 aircraft. Many of these supplies were untouched during the ground war. (Haseley, 1992) This left DoD with the task of returning about 35,000 containers to various locations throughout the United States and Europe. The lack of documentation did not end when the containers were returned to the depots. Officials at the depots did not know how many containers to expect, what was in them, or when they would arrive. Without this information, the depots could not control the flow of material. All of these factors contributed to the $50 million late container charge.

As you can see from these examples, barcoding and manually derived paper manifests are inefficient and expensive ways of controlling the assets required to support the rapid deployment of forces. Property management for equipment and containers as it moves from ship to shore is currently a paper process that is manpower intensive and receives little attention during training exercises and even less attention during a conflict. The various "automated information systems" (AIS) that are used to track materials belonging to the Marine Air Ground Task Force (MAGTF) are actually manual systems that store data in an electronic medium. (Michon, Gunderson, and Torres, 1993) The information flows from the Unit level to the Command level using these systems require the constant reformatting and translating of the information content. The term *automation* is stretched to its limit when you examine the family of logistic tools that were used to support the Gulf conflict.

Despite the AIS shortfalls, the Marine Corps has consistently met the logistic challenge, moving all necessary supplies and materials when required, and has effectively executed the assigned mission. This has been accomplished, however, at a significant time and manpower cost which can be directly attributed to current logistic practices, procedures, and equipment. The most important element to the success of Marine Combat Service Support (CSS) is the training and attitude of the individual Marine. (Michon, Gunderson, and Torres, 1993) CSS cannot continue to be responsive to combat elements when faced with the increased operational tempo, mobility, and distances associated with the emerging concept of stand-off operations. New technologies and processes need to be developed and fielded to meet the emerging logistic challenges that face the Marine Corps in the years ahead.

To meet the future challenges of Marine logistics, the Marine Corps has teamed with MITLA and has began to take a serious look at alternative Recording and Tracking Technologies (RTT). The current intent and focus is to take the current RFID technology and enhance and improve it so that it can be incorporated into the family of Marine AIS. The goal is to field logistic tools that will enhance the Corps ability to plan for and deploy on multiple fronts and handle rapidly changing scenarios.

The MITLA team realized that the capabilities of RFID far exceed those of conventional barcodes. RFID tags have the ability to add new information, change existing information, and respond to queries. The placement of the tag on an asset is completely flexible. Unlike barcodes, the orientation of the tag has no impact on the tag's ability to transmit its stored information. All of the tags developed by SAVI have omni-directional antennas that allow them to be accessed independent of the tags orientation to the interrogator. There is no line of sight requirement between the user and the tag. The information contained on a tag cannot be erased by strong magnetic fields. (Micron Communications Inc., 1993) Dirt, paint and other substances that degrade barcodes do not affect the reliability of an RF tag. (Micron Communications Inc., 1993) RFID tags use wireless technology to monitor, track and locate assets and to remotely control operations in both industry and military environments. (Durham, 1993)

As a result of the findings that have been published concerning Gulf War accountability and tracking of assets the interest in RF tag technology is extremely high. The remaining chapters of this thesis are devoted to the development of automated identification technologies and their intergration into the Marine Corps inventory of logistic assets.

III. ANALYSIS OF THE SAVI RADIO FREQUENCY (RF) NETWORK

A. SAVI'S BASIC ASSET TRACKING SYSTEM

This chapter describes in detail the digital Radio Frequency (RF) link that is being developed by SAVI Technology Inc. of Mountain View, CA. The RF link concept will allow SAVI Interrogators to be linked as part of a wireless network. The basic network will consist of RF link units, interrogators and computers. The development and implementation of a wireless RF link will be the first significant step in making RFID technology a viable expeditionary asset for the Marine Corps. Before we discuss the merits of the digital RF network, we need to outline and review the basic components that make up the SAVI asset tracking system. The reader needs to understand the basic system and its capabilities before they can try to analyze the more complex operations of the wireless system. The description that follows is designed to be a basic overview. It is written to help the reader understand the essential components that make up the SAVI asset tracking system. It is not intended to be a detailed technical evaluation of the system components.

1. System Components

- SAVI Tag (s)
- SAVI Fixed Interrogator (s)
- SAVI hand Held Interrogator (s)
- System Software

These components comprise the basic SAVI asset tracking system. (SAVI Technology (a), 1994) The SAVI Tag described above has the ability to store, transmit and receive data commands to and from either the SAVI Fixed or Handheld Interrogators. SAVI Tags and Interrogators communicate with each other using a proprietary radio communications protocol. This batch collection process will be explained in greater detail in the later section of this chapter. The SAVI batch collection algorithm allows for simultaneous communication between an interrogator and multiple tags. Without the batch collection technique, the existence of more than one tag in a given environment would confuse the system. This would happen because all tags respond to Interrogator commands at the same time and multiple responses from the tags would cause collisions and disrupt the flow of data in the system. By employing the batch collection process, an Interrogator can communicate with an almost unlimited number of tags as long as they are within the usable range of the Interrogator. The batch collection algorithm also allows the user to single out specific tags to receive information or respond to a specific query. (SAVI Technology (a) 1994, Lawlor, 1993) A Fixed Interrogator can store data from all of the SAVI Tags within its range. The Fixed Interrogator can then relay the data to the system computer either by a real time command or on a per-arranged schedule. (SAVI Technology (a), 1994) Interrogators can be linked together to increase system range and coverage. The Hand Held Interrogator performs the same functions as the Fixed Interrogator but it is mobile and has a reduced range. The following is a more detailed description of the system components and their capabilities.

a. Seal Tags

Seal Tags are a small 4.5" x 5.5" x 2" battery powered radio transceiver which has the ability to store user-defined information in non-volatile read/write memory. Current Seal Tag configurations have 256k bytes of standard memory. An additional 128k bytes of extended memory are available for mass data storage. (SAVI Technology (a), 1994, SAVI Technology (b), 1994) The tags are normally in an battery conservation mode "sleep," which helps to extend the battery life. Current battery life of the SAVI Seal Tag is approximately 5 years based on average usage. A signal from the Interrogator wakes up the tag. Once awaked, the tag can be read, written to or an audible location beeper can be activated. The Seal Tag also has an infra-red wake-up capability for use with the Hand Held Interrogator. (SAVI Technology (a), 1994)

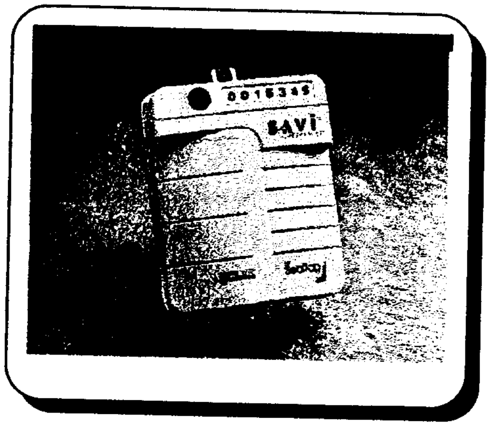

Figure 3-1 SAVI SealTag

The design charistectics and the general operating specifications of the SAVI Seal Tag are outlined below.

- Rugged/Waterproof
- Read-write capability
- 9600 baud two way communications
- 256k bytes of standard memory,
- up to 128k of extended memory
- FCC Part 15, unlicensed operations (less than 1W maxium output power)
- 433 MHz
- Serial data interface port

b. SAVI Radial Tag

SAVI is in the process of developing a tag designed to be affixed to pallet-sized assets. It is intended to be a low cost device that will facilitate the tracking of palletized items like ammunition and MREs. This device is still in the design process, and no specific information is available. It is mentioned here to show the reader the future direction for these assets.

c. SAVI Fixed Interrogators

Designed with an omni-directional antenna and range up to 600 feet. (SAVI Technology (a), 1994) These items were initially designed for operation in permanent or semi-permanent sites. The Marine Corps deployment plan for the SAVI Fixed Interrogator is to use them in a both permanent and expeditionary sites such as warehouses, ports, airfields and beach support areas. The Interrogators may be networked together to provide coverage of nearly unlimited size. Currently networking of Interrogators can be done in two ways. First, through the use of a hardwire connection. This connection is made with RS-232 or RS-485. This configuration is usually employed at fixed sites. The second method of networking Interrogators together is through the SAVI RF link. The RF link is the vehicle that will do away with the hardwired connections and make this system more expeditionary. After we complete the discussion on the basic SAVI components we will discuss the wireless RF link. Each Interrogator has 64k bytes of memory for interim data storage. Interrogators can be powered from 110/220 VAC or 5-16 VDC. A solar power unit is also available. (SAVI Technology (a), 1994)

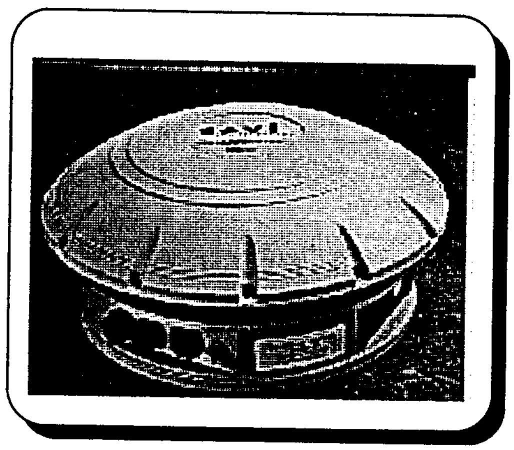

Figure 3-2 SAVI Fixed Interrogator

d. SAVI Hand-Held Interrogators

These are hand-held portable, rechargeable battery-powered units that have the same functionality as the fixed Interrogator. The Hand-Held unit has an omni directional range of up to 300 feet. The Hand-Held also supports a infra-red wake up of the SAVI Tag. This feature allows the operator to communicate with a Seal Tag when the tag identification number is not known. Data collected by the Hand-Held Interrogator are stored in the unit and may be displayed and/or transferred to the system computer depending on the desires of the operator. The SAVI Hand-Held Interrogator supports a variety of external data interfaces, including a direct barcode input port. (SAVI Technology (a), 1994)

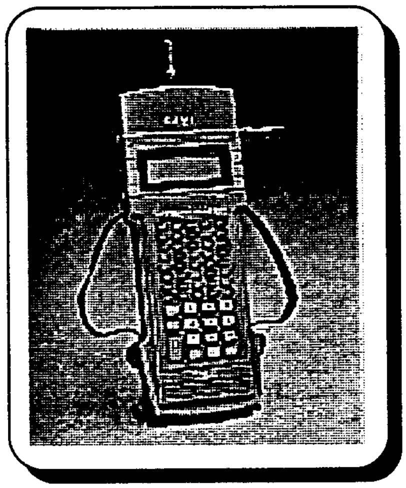

Figure 3-3 SAVI Hand Held Interrogator

e. System Software

The System Software allows the operator to interface with the system and control the SAVI Interrogators. SAVI has developed a number of software packages. They are outlines in the paragraphs below.

(1) **TagOS**. This is a software package that operates in the Microsoft Windows environment. It provides the user with a graphical based asset management and tracking system using a relational data base.

(2) SAVI **Interrogator Network Controller (SINC™).** This software provides the low-level control needed to communicate with and operate SAVI Tags and Interrogators.

(3) SAVI **Software Development Kit (SDK™).** This software package is available to customers who have specific operational needs that are not adequately addressed in the software applications described above. The SAVI

SDK allows system designers to customize the system to meet their specific operational requirements. (SAVI Technology (a), 1994)

2. Need for RF Links

The items described above make up the basic SAVI asset tracking system. Implementation of this system requires a physical hardwire connection between the system computer and each of the Interrogator units. There is no physical link between the Interrogator and the individual tags. The hardwire connection is a definite limitation to the employment of this system in a expeditionary environment. As anyone who has been at a point of embarkation or debarkation can attest that the addition of wires for the establishment of a network is at best a counterproductive effort. Military points of embarkation/debarkation are unfamiliar places to the Marines who use them. No matter how well you plan the layout of your network, in the fast paced, highly mobile environment that abounds during unit deployments, something or someone will disrupt your connection. A disruption in the flow of communications will degrade the accuracy of your logistic data. Perceived material shortfalls caused by inaccurate information will turn into unnecessary requests for supplies. Supplies which you actually have on hand will not be accounted for because of the disruption in your information flow. The requisition of extra supplies will add an additional strain to the already overburdened supply and transportation system. The key point here is that a hardwired system is not a reliable choice for use in an expeditionary environment. Most readers of this thesis, Marines in particular will understand first hand the problems caused when vehicles drive over communications links. The communications reliability degrades and is often totally disrupted by vehicles severing vital communication lines. If the Marine Corps is going to achieve Total Asset Visibility, the SAVI RF link is going to play a major role. The RF link has the potential to transform and improve the logistic capabilities of the Marine Corps. In the section following we will describe the SAVI RF link in detail.

B. WIRELESS NETWORKS AND RADIO FREQUENCY SELECTION

1. Background

Wireless networks for data communications continue to establish themselves as viable alternatives to hardwired systems. This is becoming especially true in the world of military logistics. As stated in the above sections, hardwired systems have their place but they also have some inherent problems. A major limitation for a cable-based logistic tracking networks is the environment in which they must operate. Time is never on the logisticians side; a wireless network can be established in far less time and with fewer people than a hardwired network. There are no cables to route or connect. These two factors make the implementation of wireless networks a very attractive Marine logistic solution. A misguided vehicle operator or a poorly placed container cannot cut your network cables causing a disruption in the flow of information. A wireless network can be dismantled, transported and easily reconfigured at a new location. Ease of set-up, transportability and an adaptiveness to changing locations are key success factors in the world of logistics. They are also the underlying reasons why a wireless network is preferred over a hardwired network for logistic applications.

Wireless networks are not without some limitations. The major drawback of the wireless network are the data transfer rates at which they currently operate. In almost all cases they have slower data transfer rates than hardwired network systems. (Leonard, 1992) However, for logistic radio frequency tracking applications, the data transfer rates provided by the current family of spread spectrum radio products is sufficient for the logistics applications. The spread spectrum radio technology will be thoroughly discussed in a later section. We now focus the discussion on the selection of radio frequencies used by the wireless system and the reasons why these frequencies were chosen.

2. Radio Frequency Selection

The FCC regulates all commercial radio communications within the United States. This includes both licensed and unlicensed communications. Licensed communications requires the granting by the FCC a specific radio channel to a specific user for a specific purpose. (SAVI Technology (c), 1991) The FCC controls the power output and resolves interference problems. The major advantage of licensed communications is the increased range. The disadvantage is the regulatory control imposed by the FCC for each user and each site. Unlicensed communications are governed by Part 15 of the Code of Federal Regulations (Ref. 7) Part 15 of the Code of Federal Regulations allocates three frequency bands for unlicensed communications within the United States. They are: 260-470 MHz (UHF), 902-928 MHz ("915") band and the 2400-2484 MHz ("2450") band. (SAVI Technology (c), 1991) In these frequency bands the FCC severely limits the transmitter operating power. This reduced output power limits the range of the transmitter. However, for RFID applications the reduced range is not a significant problem. The benefits of unrestricted use at multiple locations more than justify operating in the unlicensed portion of the frequency spectrum.

a. Interrogator/ Tag Range Limits

The maximum range of a radio system is defined by the equation:

$$R_{max} = \left\{\frac{P_T G_T G_R \lambda^2}{[4\pi] S_{min}}\right\}^{1/2}$$, where

P_T = transmitted power (in watts)

G_T = antenna gain, transmitter

G_R = antenna gain, receiver

S_{min} = minimum detectable signal (in watts)

λ = wavelength (in meters)

Using this equation it can be shown that the theoretical limit for unlicensed communications is about 1500 feet. (Kasmir, 1991) Man-made interference and atmospheric conditions often reduce this theoretical range. SAVI Interrogator to SAVI Tag normal operating distances are between 250 and 350 feet. Greater operating ranges have been demonstrated by this equipment. However, under normal operating conditions, the 250 to 350 foot range ensures sufficient data accuracy and robustness. A Tag can respond to any Interrogator that is within its operating range on the network. By employing a cell topography (see Appendix xx) the range of the system as a whole can increase or decrease depending on the needs of the mission that the system is supporting.

SAVI Interrogator and SAVI Tag communications are accomplished in the 260 to 470 UHF frequency band. Some of the underlying reasons SAVI choose this band for Tag to Interrogator communications are as follows:

- The 2450 band is considered unacceptable because it is the international frequency band for household microwave ovens. Using this frequency could cause interference with the operating performance of the system.
- The UHF band is less congested and has less manmade interference.
- The UHF band overlaps with many international unlicensed channels which leads to the possibility of developing an international tag for civilian applications. (SAVI Technology (c), 1991)

b. Modulation

SAVI Tags and Interrogators incorporate Frequency Modulation (FM). FM modulation was chosen because it offers better signal quality, which results in better data transfer reliability. FM is also less susceptible to the effects of the environment. (i.e. electrical storms, auto ignitions etc.) FM is also the industry standard for items like cordless phones, FM radios, and walkie-talkies. Since FM components are currently being produced in large quantities, economies of scale in the manufacture of components for this system can be realized. (SAVI Technology (d), 1991)

C. SAVI RADIO FREQUENCY (RF) LINK 1.0

1. Functional Description

The SAVI RF link is a device that enables a SAVI Interrogator to become part of a wireless network. The RF link serves as the physical link between the central computer and the interrogators. The network can consist of one or more computers and/or interrogators. The minimum wireless network consists of one computer, two RF link units and one Interrogator. Multiple RF link units can be used to add wireless connections between other networks, stand-alone Interrogators and individual computers.

The SAVI RF link ensures seamless communications across both wired and wireless connections. (SAVI Technology (e), 1994)

Before we continue to describe the networking capabilities of the SAVI RF link, we need to describe the components that comprise the RF link unit. This will give the reader a better understanding of the capabilities of the system. The SAVI RF link is composed of five individual components which are linked together in a sealed weather proof housing. The five components are: LED Display, RF link Interface Board, Power Supply, Spread Spectrum Radio Transceiver and the Antenna. (SAVI Technology (e), 1994)

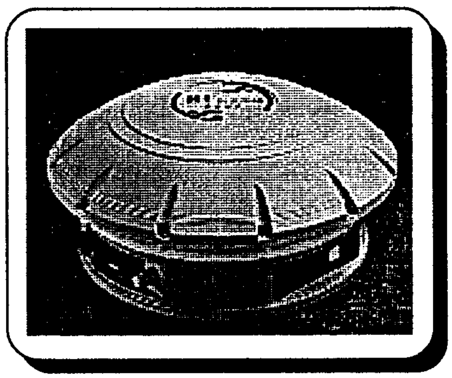

Figure 3-4 SAVI RF Link

a. LED Display

The two LED displays on the side of the RF link provide the user with the following information:

- Power on/off
- RF link ID number
- RF link serial number
- Transmitting data indication
- Manual reset button.

b. The RF Link Interface Board

This board contains the main intelligence of the RF link. The board, as its name implies, interfaces with the radio transceiver, wired network or host and the LED display. The Interface Board is responsible for implementing the RF link protocol for message routing. The Interface Board also contains the ports for the RS-232 and RS-485 connections. These ports provide the physical link between the computer and the RF link unit. The SAVI RS-485 Network Protocol will be described in more detail in a later section of this thesis.

c. Spread Spectrum Radio Transceiver

The RF link incorporates a spread spectrum radio transceiver that is manufactured by Digital Wireless Corporation of Atlanta, GA. (Digital Wireless Corporation, 1994) This component of the RF link allows one SAVI RF link unit to communicate with either a SAVI Interrogator or another SAVI RF link unit. Recent changes to the FCC regulations have fostered commercial development of spread spectrum radios in the "915" UHF frequency band. The changes to Part 15 of Title 47 of the Code of Federal Regulations are written to help foster the development of low power telecommunications systems. The only underlying restriction is that the devices operate in the UHF frequency band 902 to 928 MHz. Devices operating in this frequency band cannot interfere with and must live with interference from licensed users in the frequency band. (SAVI Technology (c), 1991)

The transceiver developed by Digital Wireless Corporation employs proprietary 900 MHz Recombinant spread spectrum technology. Spread spectrum was chosen for the following reasons:

- Mulitpath rejection: This radio can isolate and or reject a mulitpath signal from a direct path signal.
- Improved frequency utilization: Spread spectrum improves the utilization efficiency of the channels. In some cases, it is possible to communicate on top of existing channels.
- Anti-jam: Spread spectrum makes it very difficult to corrupt communications signals by intentional jamming. The radio is capable of providing up to 19200 bps in the full duplex mode and 51200 bps in the half duplex mode. (Digital Wireless Corporation, 1994)

The general specifications of the WIT-915 Radio as outlined by the manufacturer are outlined below:

- Frequency agility automatically seeks a clear channel
- Fade-resistant Spread Spectrum technology
  (903.0 MHz to 927.0 MHz)
- Maximum power allowed for FCC Part 15 unlicensed operations.
- 4 transmit power levels, from 1 mw to 1W.
- Adaptive transmit power control, conserves power
- Low-power sleep mode.
- Data squelch mutes noise when no noise is present
- RS-232 compatible signal set
- supports point to point or CMSA multi-point applications.
- Digital addressing with over 8 x 10^6 possible IDs.
- Single serial port for both data and control.
- Built-in data encryption.
- Nonvolatile memory, stores configuration when power is off.
- Supports asynchronous and synchronous data formats.

(Digital Wireless Corporation, 1994)

Spread spectrum is a communication technique by where the transmitted signal is spread across the entire frequency bandwidth. The signal is spread across the available bandwidth using a coding technique. This is often called a spreading signal. (SAVI Technology (d), 1994, Freeman, 1991) In order to use the coded information the receiver needs to know the unique code that the original signal was spread with. Without the code the original signal cannot be properly interpreted. The benefit of employing this approach is improved frequency utilization. By utilizing spread spectrum, system developers are able to achieve reliable communications at power levels at or below 1W. (SAVI Technology (f), 1994) Specific details of the radio transceiver as it is employed in the SAVI RF link are as follows:

- **Spread spectrum technique:** direct sequencing for unlicensed operations (FCC part 15.247)
- **RF Bandwidth:** 700 KHz21 communication channels
- **Outdoor range:** line-of-sight up to 5000 feet (normal logistic operating conditions 1/4 mile)
- **Range indoor:** Warehouse: 800 feet, Office: 300 feet
- **Receiver sensitivity**: -90 dbm

d. Power Supply

The power supply for the RF link allows for three different types of input power: 90-132 VAC (nominal 120 VAC), 180-264 VAC (nominal 240 VAC), and 5.4-16 VDC (nominal 6.4 VDC). (SAVI Technology (e), 1994)

e. Antenna

SAVI has developed an omni-directional antenna for the RF link. It consists of a quarter wavelength stub centered on a horizontal ground plane. A horizontal element has been added to the top of the stub to achieve polarization diversity. (SAVI Technology (e), 1994) The antenna is contained in its entirety within the housing of the RF link.

D. SAVI WIRELESS NETWORK

The SAVI wireless network is really a combination of two networks. Both networks will be discussed in detail in a later section of the chapter. In this section we present a brief overview of two types of networks employed by SAVI. The first type of network is the RS-485 network. This is the hardwired portion of the network. In many applications there is no need for a wireless network (e.g., in a warehousing environment.) Some mission requirements call for a combination of both wired and wireless communications (e.g., warehousing/flightline or warehousing/pier operations.) The configuration of the network will be strongly influenced by the mission and the assets available to support that mission. The SAVI family of products are extremely flexible, and support numerous RS-485 network combinations.

To establish a wireless expeditionary network there needs to be at least one RS-485 connection between the PC and the RF link unit. This connection will establish the foundation for the wireless mode of operations. More RS-485 connections are possible but the minimum for wireless operations is one RS-485 connection. (SAVI Technology (e), 1994) Wireless network configurations are designed based on the needs of the user and the mission being supported. The wireless portion of the network uses the X.25 protocol for all free space communications on the network. As stated earlier, the RF link unit is the centerpiece that allows SAVI Radio Frequency Identification and Tracking products to become part of a wireless network. The RF link unit supports the combined use of both wired and wireless links within the network. Some of the more common types of network configurations are diagrammed in Appendix # 1.

RF link units are designed so that the Interrogators do not have to be aware of there presence for them to become part of the network. (SAVI Technology (f), 1994) An RF link unit may be connected to a wired or wireless network in any number of ways.

- As a network node, positioned anywhere in the network.
- To a computer via an RS-232 or RS-485 direct link.
- As a stand-alone repeater. (SAVI Technology (f), 1994)

The network can be configured to handle multiple computers, multiple Interrogators, and multiple RF Links. However, RF link units cannot be directly connected to each other. A direct RF link to RF link connection will cause the network to fail. (SAVI Technology (f), 1994)

1. Network Configuration and Routing

The RF link employs a dynamic routing algorithm that handles the processing of all the messages that pass between any two nodes in the wireless network. A node on this network is defined as an Interrogator, computer, or a RF link unit. The algorithm also configures the RF link to work in the repeater mode of operations. The routing algorithm does not require any prior knowledge of other RF link units that may be part of the network. It self-configures the network to successfully route all message traffic to the desired destination. As the network becomes more established, the algorithm gains knowledge about the network configuration. It employs this knowledge to optimize message routing over the network. The dynamic algorithm can also respond to changes in network configuration. If a node is added, removed, or its location is changed, the algorithm responds. Without any user input it properly reconfigures the network to ensure the most efficient message delivery times. (SAVI Technology (f), 1994)

The SAVI RF link is a wireless packet based switching network. The primary function of a packet switched network is to accept packets from a source station and deliver them to the specified destination station. (Stallings, 1994, p.288) The major appeal of a packet - switched network comes from their flexible multi-point connection capabilities. Nodes in different operating locations operating at different signaling rates can exchange data with a central computer or each other.

To ensure proper and timely delivery of packets on the network a routing function must be performed. The routing must be robust enough to deliver packets in the event of a localized failure or overload. The network should be able to deal with these types of problems without the loss of packets or a break in the virtual circuits.

Packet switched networks have a number of advantages that make them well suited for the type of application we are discussing here. They are:

- ***Increased line efficiency*** - A node to node link can be shared by many packets. The packets are queued and transmitted as rapidly as possible across the line.
- ***Accepts multiple data rates*** - Nodes on a packet switched network with different operating signaling rates can exchange packets. This is possible because each station connects to the node at its proper data rate data is buffered to accommodate for the differences in signaling rates.
- ***Continuous communications*** - During times of heavy use, packets are not blocked from entering the network. Thus providing a continuos communication ability. Delivery of packets may in times of extreme usage will become slower but entering packets onto the network will not be blocked.
- ***Priority sequencing*** - If the user desires, Packets can have a different priorities depending on the importance of the information. Thus packets with a higher

priority can be transmitted first. The higher the priority of the packet the lower the delay in transmission delivery. (Stallings, 1994, p.274)

2. Network Protocols

As was already mentioned, the SAVI wireless network incorporates two types of network protocols the X.25 and the RS-485 protocols. The system is also capable of RS232 connections. The capabilities of RS-485 are better than those of RS-232. In this chapter we will consider only the RS-485 network.

a. X.25

Probably one of the best known and most widely used protocols is X.25. This protocol was initially approved in 1976. It has been revised four times. Once in 1980, 1984, 1988 and again in 1992. X.25 specifies a standard interface between a host system and a packet switched network. X.25 has three layers of functionality; they are physical layer, link layer, and network (packet) layer.

These three layers corresponds to the lower layers of the Open Systems Interconnection (OSI) Model. (Stallings, 1994, pp.226-228) Compliance with the OSI reference model is an important feature of the network design. OSI compliance will allow the SAVI network to connect with and share information from other OSI vendor compliant networks. The importance of vendor network interoperability cannot be over emphasize. Without network interoperability, the SAVI network would be operating as a stand-alone network. Stand-alone networks do not get the information to the decision makers and users in a efficient or timely manner. The Marine Corps cannot afford to operate or procure systems that are not interoperable with the existing family of networks or logistic systems. If the information contained on the SAVI network is to be of any value to Marine decision makers, it must be seamlessly and efficiently transported across a wide variety of heterogeneous networks. Developing a network that complies with the open systems architecture is most efficient way to ensure compatibility between heterogeneous networks.

b. SAVI RS-485 Network Protocol

The RS-485 protocol is a packet based protocol which allows communications between computers, Interrogators, RF link units and other RS-485 compatible products. Each node on the RS-485 network is considered to be a unique and separate node. Each node has a unique 16-bit address and a 8-bit node type. (SAVI Technology (g), 1994) Packets transmitted on the RS-485 network contain the following fields:

HEADER $AAAA (2 bytes)	SRC (2 bytes)	DST (2 bytes)	PACKET TYPE (1 bytes)	INFO (zero to 241 bytes)	SEQ# (1 bytes)	CRC CCITT (2 bytes)

Table 3-1 Packet Description

- **HEADER** A "unique" 2 byte sequence ($AAAA) indicates the beginning of a packet.
- **SRC (source address)** 16-bit sender ID. Most significant byte first.
- **DST (destination address)** A 16 bit receiver ID. Most significant byte first. For example, an address which reads 0xFFFF is used to broadcast a message to all nodes on the network.
- **Packet Type** This byte indicates the packet type. Valid packets are data packets, reset packets, connect packet, hello packet, sleep packet, wakeup packet, and hello acknowledgment packet.

The values for each of the packets is shown in Table 3-2.

Packet Type Value	Packet Type
$00	Data
$02	Reset
$03	Connect
$04	Close link
$10	Hello
$11	Sleep
$12	Wakeup
$80	Acknowledgment
$81	Busy Acknowledgment
$83	Connect Acknowledgment
$84	Connect Negative Ack.
$90	Hello Acknowledgment

Table 3-2 Packet Types

- **Sequence Number** This is an 1 byte value that is used to recognize duplicate packets. A sequence number is maintained for each direction of communication and for every connection between two network nodes. The sequence number is incremented after every successful exchange. By checking the sequence number, the receiving node can determine whether a packet is new or a duplicate and respond accordingly.
- **CRS-CCITT** To ensure data integrity for each packet, a 2-byte Cyclic Redundancy Check (CRC) is included that is calculated on all of the previous bytes of the packet except for the header. (SAVI Technology (g), 1994)

E. TRANSFERRING DATA ACROSS THE NETWORK

1. Passing Information on Savis Network

The sequence of actions for passing a message from node "A" to node "B" is outlined below.

1. If a link has not already been established between nodes "A" and "B," then "A" will send a Connect packet to "B". If "B" can support the link then it will respond to "A" with a Connect packet. If "B" cannot support the link it will respond to "A" with a

Connect Negative Acknowledgment. The number of links that a node can support at the present time is as follows:

- **Interrogator** - 5 Links at a time.
- **RF Link Unit** - 5 Links to the RF link unit.
- **From the RF Link unit** - Not yet specified, anticipate about 200 links.
- **Personnel Computer** - Software dependent, limit has not been specified, anticipate a minimum of 200 links.

2. After the link has been opened, "A" sends a data packet containing the message and the current transmission sequence number for the link "A" to "B".

3. If "B" receives the packet without errors, it responds with an Acknowledgment packet. This indicates to "A" that the sequence number has been received. "B" checks the sequence number of the received packet to determine if it a duplicate or a new packet. If "B" receives the packet and there are errors there is no response from "B".

4. If "A" does not receive an Acknowledgment packet in T_1 units of time, it re transmits the same packet. If the number of re-transmissions is greater than M, the communication between "A" and "B" is broken. "A" should then attempt to reconnect to "B" by sending a connect packet.

5. If "A" is finished communicating with "B", then "A" sends a Close link packet to "B". Node "B" responds with an ACK. (SAVI Technology (g), 1994)

2. Batch Collection of Network Nodes

A powerful feature of the network protocol is the ability to collect the network ID's and device types for all other nodes on the network. This process was described earlier in the chapter. To help further clarify the point a brief example of the batch collection process is provided. The collection process uses the Hello, Hello Acknowledgment, Sleep and Wakeup packets in the following manner:

1. The connecting node broadcasts a Hello packet with the broadcast destination ID (OxFFFF). The OxFFFF is a broadcast address that represents all nodes on the network. The collecting node also broadcasts the length of the collection cycle.

2. All receiving nodes that are awake respond with a Hello ACK after a random delay within the collection cycle. The Hello ACK indicates the node ID and device type. Nodes that are asleep do not respond.

3. At the end of the collection cycle, the collecting node sends a Sleep packet to every node that responded during the collection cycle.

4. The collecting node rebroadcasts a Hello packet, gathers incoming Hello Acknowledgments, and sends a sleep packet to all responding nodes. This process continues until no nodes respond to the Hello. It is then assumed that all nodes have been collected and are now asleep.

5. The collecting nodes sends a Wakeup packet to every node that was put to sleep during the collection process. Nodes will respond with a ACK when they receive the Wakeup packet. (SAVI Technology (g), 1994)

3. Merging RFID and the Wireless Network

To capitalize on the benefits provided by both radio frequency asset tracking and wireless network technology, these two technologies must be deployed as a unit. The SAVI solution to achieve wireless asset tracking in a localized area combines the functionality of the fixed Interrogator and the wireless RF link unit. These two SAVI components are combined together on a pedestal platform. In this configuration the Interrogator communicates with both the RF link unit and all the Tags that are positioned within its range. The RF link Unit provides the network connectivity and the Interrogator provides the functionality of asset tracking and accountability. Utilizing this configuration virtually any number asset tracking pedestals can be deployed to meet the mission needs at the operational location. The pedestal unit is designed for rapid setup and dismantling. This makes it an ideal logistic tool for use in expeditious environments. The photo in Figure 3-5 shows the RF link Unit and the Fixed Interrogator deployed together on the pedestal platform with solar panels attached .

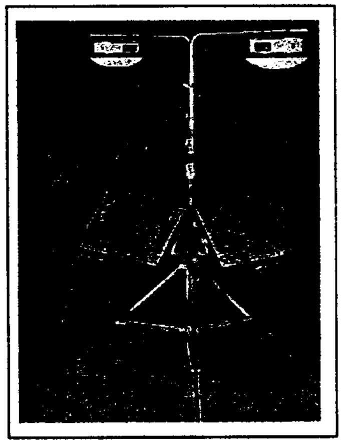

Figure 3-5 SAVI RF link Unit

4. Untapped Capacity of the SAVI Wireless Network

The SAVI wireless network has been designed so that asset tracking and accountability can be accomplished in expeditious environments. The network design has some inherent excess capacity that if exploited can enhance not only our asset tracking capacity but our logistic communications as well. This is especially true during the early stages of amphibious operations when the more reliable communication assets are not yet established. Currently, the deployment and implementation of our communication assets takes not only careful planning but an extensive number of man hours. Nowhere is this more evident than in the establishment of expeditious electronic networks. These networks and communication enhancements are historically established long after the off-loading of the ships and aircraft. This leaves the logistician who must operate efficiently during the early stages of the operation with very limited communication options. The communication assets that are normally available during the initial phases of any operation are the man-packed VHF radios and messenger. Current operational procedures only provide the logistician with limited communication assets during the initial phases of the operation. There are no communication networks and the communications that are provided often lack the robustness to perform the required logistic functions.

a. Wireless Electronic Mail

One way to increase the robustness of our communications during the critical initial phase of an amphibious operation is to exploit the excess capacity of the SAVI wireless network. Asset tracking although a vital and critical aspect of logistic applications is not going to be a continuos process. There will be times during the off-load and on-load phase when the network will remain idle. During these idle times, there is a window for the transmission of electronic mail. This window opens up communication potentials for the logistician that have never been before been available. A logistic electronic mail network can be established concurrently with the establishment of the asset tracking network. They utilize the same physical assets. The only addition to the system would be the software required to handle the mail traffic. Logistic communications and responsiveness would be significantly enhanced through the incorporation of an electronic mail interface on the SAVI wireless network. Real time requests and information sharing could be conducted between and within operational sites. Information sharing and the transmission of real-time information will enhance the effectiveness and responsiveness of our logistic system. Isolated Logistic sites could be kept updated. Situational awareness updates could be easily transmitted to all logistic sites within the amphibious operations area. The wireless network operates at 51200 bps. This data rate is fast enough to send revised situtional maps and photographs to the logistician. The more information the logistician has about the battlefield and the forces they are supporting the better the support will be.

Currently the SAVI wireless network does not have an electronic mail interface. An electronic mail interface was not part of the initial product development specifications. However, electronic mail would not be not be a difficult addition to incorporate into the system software. The enhanced connectivity provided by the incorporation of a electronic mail protocol would greatly enhance the responsiveness of the logistic system.

5. Interconnecting With Other Networks

a. Background

As soon as their equipment is off-loaded; communication personnel will begin to establish more robust communications. In a typical amphibious operation it is not uncommon to eventually see the implementation of extensive telephone, radio and computer networks. It is at this point in the operation, when the logistic network needs to be interconnected with the other networks being established in the amphibious operations area. The goal is to interconnect all of the various networks so that all stations can communicate and utilize the expanding networking capabilities.

b. Goals of Internetworking

- Provide a link between networks. At minimum, a physical and a link control connection is needed
- Provide for the routing and delivery of data between processes on different networks.
- Provide an accounting service that keeps track of the use of various networks and gateways and maintains status information.
- Provide the above services in such a way as not to require any modifications to the network architecture. This means that the internetworking facility must accommodate and compensate for the differences between the various networks.

Some of the more common network differences that must be identified and resolved through internetworking are outlined below:

(1) Different addressing schemes: The networks may use different addressing and maintenance schemes. Some form of global network addressing must be provided.

(2) Different maximum packet sizes: Packets from one network may have to be broken up into smaller packets inorder to be transmitted over another network. This process is called segmentation.

(3) Different network access mechanisms: The network access mechanism may be different from one network to another.

(4) Different time-outs: Networks may have different time-out periods. In order to achieve successful connection of multiple networks there must an established timing procedure. An established timing procedure will allow the successful transmission of data and avoids unnecessary re-transmissions.

(5) Error recovery: The degree of internetworking error recovery depends on the needs of the user.

(6) Status reporting: Different networks report status and performance differently. The internetworking facility must be able to provide such information to authorized processes.

(7) User access control: Each network will have its own user access control technique. These processes must be invoked by the internetworking facility as needed. Additionally, a separate internetworking access control technique may be required.

(8) Connection, connectionless: Individual networks may provide connection oriented or connectionless service. It may be desirable for the internetwork

service not to depend on the nature of the connection service of the individual networks. (Stallings, 1994, pp.471-473)

c. Intermediate Systems

The goals of internetworking are fairly well defined. In this section we will look at some of the devices available to connect individual networks together. Intermediate systems are the devices that are used to connect separate subnetworks together to form an Internet (network of networks). Intermediate systems (IS) provide a communications path and perform the necessary relaying and routing functions so that data may be exchanged between subnetworks on the Internet. (Stallings, p.471)

To meet the communication requirements for an amphibious operation we need to install a Intermediate system between the SAVI wireless network and the conventional hardwired computer networks that are added to the command structure as the operational timeline progresses. The three most common types of IS are outlined below:

- Repeaters: Probably the least expensive device for connecting two segments of a network. In fact the SAVI RF link can be configured to operate in the repeater mode extending the range of the wireless network. A repeater retimes and regenerates the digital signals on the network and sends them on their way again.
- Bridges: A bridge is used to connect two networks that use identical LAN protocols, the bridge acts as an address filter picking up packets on one network that are intended for a destination on another LAN and passes them on. The bridge does not add or take anything away from the packet.
- Routers: Use to connect two networks that may or may not be similar. The router employs an Internet protocol present in each router and each host of the network. Many modern routers are multiprotocol routers. Routers strip off the outer layers of data before they send a packet from one LAN to another. By doing this they reduce the total number of bits that are passed across the network.

d. Summary

Which intermediate device will be used to connect the SAVI wireless network to the other networks in the Marine inventory is not important at this stage in the product development. What is important for product developers to realize is the potential that exists for connecting the SAVI wireless network to the existing wired networks used by the Marine Corps. Providing this connectivity to the logistician will increase logistic responsiveness and accuracy. The entire networking can be setup and dismantled in a modular form. Starting with the asset tracking/e-mail network and growing as the operational needs dictate. When the operation is over and the retrograde begins the network can be dismantled in a reverse modular fashion leaving the logistician with the functionality of the asset tracking and e-mail. The other networks can be dismantled and retrograded. As the asset tracking requirements during the retrograde become less the SAVI wireless network can be dismantled. At this point in the operation any asset tracking could be accomplished with the hand held interrogator and a lap top computer.

F. SECURITY OF INFORMATION OVER NETWORKS

1. History of Logistic Information

Logistics information has historically been an unclassified entity within DoD. For some reason we do not feel the need to safeguard logistic information the way we safeguard operational plans and ship movements. Logistic data can provide a accurate picture of the enemy force structure. This was proven during Desert Storm. As we analyzed the size and frequency of the Iraqi resupply convoys, we could determine with some accuracy the strength and the preparedness of their forces to fight.

With the eventual employment of highly accurate asset tracking devices, the potential for data compromise is real. An adversary tapping into our logistic data stream can obtain a very accurate picture of our force structure and its sustainment capabilities. It is imperative that we begin to take a hard look at the value of logistic information. A potential compromise of highly accurate logistic data could erode away the tactical advantage and allow the enemy to better prepare himself to meet the threat.

There are a number of security methods that can be employed to safeguard the integrity of logistic data. Probably the best way to accomplish this is to identify the potential weak areas and protect them. The potential weak spots in this system is in the transferring of data from one location to another. At a point of embarkarion/debarkation this is not a great threat because these areas are usually secure. However, the potential for a sophisticated adversary to try and intercept our data transmissions does exist. The greater potential for data intercept exists when we connect the logistic network to other theater networks and start passing data in the clear. A potential adversary could intercept our data stream and gain access to highly accurate logistic data. It is time we think about protecting our logistic data. There are many encryption methods on the market today that could make this a transparent yet powerful tool for ensuring the security of our logistic data.

2. Possible Security Weaknesses

Security issues arise because information traveling on the Internet usually take a circuitous route through several intermediary computers to reach any destination computer. The actual route your information takes to reach its destination is not under your control. As your information travels on Internet computers, any intermediary computer has the potential to eavesdrop and make copies. An intermediary computer could even deceive you and exchange information with you by misrepresenting itself as your intended destination. These possibilities make the transfer of all information that travels across networks susceptible to interception or abuse by the enemy. The threat of information misuse is even greater when we start to send data via wireless networks. A adversary who gets in between two nodes on a wireless network could intercept all of the information that passes between the nodes. This interception of data could go undetected indefinitely.

When we talk of network security we are talking about three key points:

- You are certain whom you are talking to (server authentication)
- Your conversation with the server is private (privacy using encryption)
- Your conversation cannot be interfered with (data integrity)

These three basic properties which are not intrinsic to networks provide what is being called Internet Data Security. (Pfleeger, 1989) To ensure the security of our logistic data there are a number of possible solutions that could be effectively employed.

Researching the network security options and offering a possible solution to the problem is beyond the scope of this thesis. Security options for DoD networks is currently in a state of transition. It would be best for MITLA system developers to wait and see what standard DoD adopts for network data security and then incorporate that standard into the architecture of the MITLA system.

The developers of the Defense Messaging System (DMS), for example, are looking at network security as part of the scope of there initiative. Eventually a solution will be implemented to secure network communications within DoD. What technical aspects of the implemented solution are not important. What is important is the recognition that all data that traveling across our networks (including logistic information) is vital and should be safeguarded with some type of robust network security measure.

IV. SYSTEMS INTEROPERABILITY

A. BACKGROUND

The objective of this chapter is to analyze how the MITLA/RF family of products should be structured and designed so that they can seamlessly interoperate with the next generation of Marine Logistic Automated Information Systems (Log-AIS). To better understand the importance of system interoperability we need to briefly examine the history of information systems within DoD. We then need to look at the system architecture changes proposed by DoD that require all services to migrate to a standard information system and Common Operating Environment (COE).

The majority of information systems currently deployed throughout DoD are service-unique and "stovepiped" systems. In their current configuration, these systems are costly to maintain and operate. (Marine Corps Point Paper (a), undated) Each of these systems possesses its own unique migration path towards an open system with little regard to system interoperability. Additionally, under the current budgetary conditions it has been projected that post development software support requirements for Marine tactical systems will rapidly outpace available funds. This in itself necessitates the need to institute an application streamlining strategy. The Marine Corps has adopted a Naval strategy to support and migrate its Command and Control infrastucture. (Marine Corps Tactical Systems Support Activity, 1994) Under this strategy, the Marine Corps will migrate its systems to the Joint Maritime Command Information System (JMCIS) platform. The JMCIS platform is the Navy's concept for managing its key C4I systems to the Global Command and Control System (GCCS) (Van Riper, 1994) The foundation of the JMCIS migration is the incorporation of an architecture known as the unified build. The unified build consists of a set of common core segment applications. These applications are designed to support the seamless integration of functionally separate C4I applications into an integrated C4I systems environment. There are many similarities between the

JMCIS architecture and the proposed GCCS Common Operating Environment (COE). (Van Riper, 1994) This is one of the key reasons JMCIS was chosen as the migration system. The incorporation of JMCIS into the Marine Corps GCCS migration strategy makes sound economic and operational sense. It gives the Marine Corps a flexible, comprehensive strategy for managing its stovepiped systems to the COE.

B. DISCUSSION ON OPEN SYSTEMS

Analysts in industry and in DoD agree that the theoretical concept of open architecture is well defined. However, they emphasize that, in the real world, a wide variety of vendor implementations and user expectations make a explicit working definition of the term "Open System" virtually impossible. Although the exact details concerning the definition vary somewhat; the fundamental concepts of an open system provide two primary capabilities.

- Users can seamlessly move applications from one platform to another, either at the desktop or at the server.
- Secondly, users can easily communicate information from one system to another because the communications and application interfaces are clearly defined and well accepted. (Jordahl, 1993)

In the truly open environment software could be written in any language and could run on any available piece of hardware. Currently this capacity does not exists, software is written for specific operating platforms. To help us achieve consistency within a operating environment we have adopted standard operating systems and standard software languages. Our programs are either written for a standard operating platform or database in a variety of languages. (Jordahl, 1993)

In order to achieve an open system environment, industry experts agree that there must be well-defined and accepted information architecture or framework. The framework must coexist with other systems that the organization is running. DoD has recognized this and has established a set of technical standards that are mandatory for all

DoD information systems. The standards are outlined and detailed in the Technical Architecture Framework Information Management (TAFIM)

The TAFIM is a eight volume series of documents that provide the enterprise guidance for the evolution of the DoD technical infrastructure. Its framework guidance is independent of any mission specific applications. The TAFIM outlines an information systems technical infrastructure based upon an architecture that supports portability, scaleability, and interoperability of the information system. (Defense Information Systems Agency, 1993) The TAFIM uses Federal and National standards (NIST, IEEE; OSE, POSIX, APP etc.) which have been adopted as standards by industry and are accepted worldwide by US allies. The guidelines in the TAFIM show technical managers and developers how to create profiles of standards to meet specific mission area architectural needs. (Marine Corps Point Paper (a), undated) The TAFIM also provides guidance for the transition of existing systems to the target open operations environment.

C. MARINE CORPS SYSTEM MIGRATION STRATEGY

The current Marine strategy for migrating to an open system is to capitalize on the core services provided by the Joint Maritime Command Information System (JMCIS). By capitalizing on the existing core services; the Marine Corps plans to transition 13 systems to the JMCIS platform. The common core services provided by JMCIS will eliminate redundant functionality and allow mission specific source code to reside at the applications layer. This will reduce the need for post development software resources and reduce the number of lines of code to be maintained by the Marine Corps by an average of 63%. The JMCIS approach is considered an ideal technical step for facilitating the migration of MAGTF C4I family of systems to the target GCCS common operating environment. (Marine Corps Point Paper (a), undated, Van Riper, 1994)

To achieve the migration to the Common Operating Environment the Marine Corps has established the following guidelines:

- All automated systems will be developed considering their deployability in support of a MAGTF.
- The common architecture for the Marine Corps.
- The Marine Corps intends to migrate all of its MAGTF automated support systems to the GCCS COE. When direct migration to GCCS is not desired or is impractical, the JMCIS COE will be used as the intermediate migration path to GCCS.
- All systems that support a MAGTF will operate on the family of Common End User Computing Equipment (CEUCE) which is planned to include both DOS/WINDOWS based hardware platforms as well as UNIX based RISC workstations.
- All systems will be developed to complement the results of the functional process improvement studies for the functions supported.
- All data will comply with data administration procedures and standards set forth in DoD 8320.1.
- The Commanding Officer, Marine Corps Tactical Software Support Activity (MCTSSA) will provide guidance on specific software development matters and assist developers in resolving technical issues relating to the migration to JMCIS/GCCS COE.

1. Marine Information Systems Classification

The Marine Corps has classified its information systems into two broad categories: (1) Migration Systems and (2) Legacy Systems. These classifications define the alternative development tracks for the information systems. "Migration Systems" are defined as existing or planned and approved systems that have been officially designated as the single system to support a standard process for a function. Migration Systems are those existing systems whose development life can be extended through modification. These systems will become an integral part of the GCCS COE. The Marine Corps regards Legacy Systems as systems that duplicate the support services and functionality of the Migration Systems. Over time the Marine Corps intends on terminating all of its Legacy Systems. (Van Riper, 1994)

2. Migration Timeline

The projected migration timeline for the transition to JMCIS/GCCS starts in 1994 and is projected to be completed during 1997. The transition to JMCIS is being strongly influenced by the TAFIM. By following the common conceptual framework, vocabulary and base standards the Marine Corps hopes to increase commonality and interoperability with in the Marine Corps and throughout DoD. Figure 4-1 shows the Migration timeline and the significant milestones associated with the transition to JMCIS.

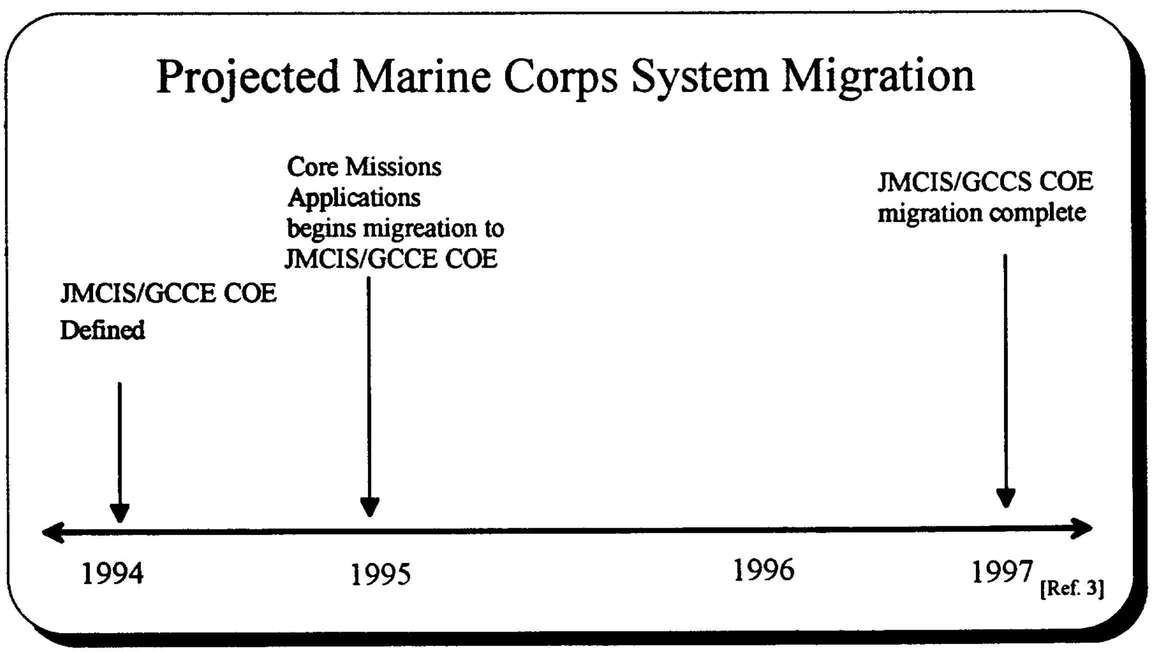

Figure 4-1 Marine Corps Migration Timeline

D. PROBLEMS WITH MIGRATION TO JMCIS

1. General

The TAFIM, JMCIS and GCCS all require a POSIX Operations System (such as UNIX), and a Structured Query Language (SQL) interface to the Relational Data Base

Management System (RDBMS). While the TAFIM does not specify RDBMS, both JMCIS and GCCS only support two Data Base Systems: Oracle and Sybase and they only support two POSIX-compliant Operating Systems: SunOS and HP-Unix. (Marine Corps Point Paper, *(b), 1994*)

2. Marine Corps Information System Environments

The Marine Corps has two distinct End Using Computing Automated Information System (EUC AIS) environments. One for Tactical Data Systems (TDS) and another for Management Information Systems (MIS). Contained in the difference between these two architectures lies some of the major challenges and obstacles concerning the migration to open systems.

In the TDS arena, there are a relatively small number of high-powered expensive workstations. On the MIS side there are a large number of comparatively cheaper Intel based personnel computers. Both JMCIS and GCCS are predicated on the Unified Build (UB) concept. The UB is a set of standard software modules (programs). Designed to provide a common interface, integrated applications, data sharing and reduce redundant functionality. JMCIS incorporates a Applications Programmer Interface (API) to provide the core programs to perform these functions.

Table 4-1 outlines the differences between the two current Marine operating environments and the near-term GCCS (target) architecture. As you can see from the table there is not a significant difference between the Near-term GCCS system and the current TDS family of systems. There is however a major difference between the current MIS family and the proposed GCCS environment. The major problem with the UB as it relates to the Marine Intel-based systems is that the core software modules will only run on either a SunOS or HP-UX operating system. Both of these operating systems require a RISC-type CPU in order to run. The more prevalent Intel-based machines that run all of our logistic systems will not run the UB operating system. (Marine Corps Point Paper, *(b)*, 1994)

	Near-Term GCCS (Target)	Tactical Data Systems	Management Information Systems
Hardware	None Specified	Sun 4/300 (DTC-II) with 32MB RAM, 500MB HDD and HP-730 (TAC-3) with 32MB Ram and 1.2 GB HDD	80/486PCs with 8MB RAM, 500MB HDD
Operating System	Sun-Solaris ver 2.3	SunOS and HP-UX (UNIX)	MS-DOS
User Interface	X- Windows System	X- Windows System and Motif	MS-Windows
RDBMS	Oracle and Sybase	Oracle and Sybase	WATCOM SQL, Paradox,Clipper, dBase, etc.
Language	Ada, C	Ada, C, C++	Ada,C, C++, Power Builder
Data Management Interface	SQL	SQL	SQL and DBMS-specific
Network	TCP/IP	TCP/IP	NetBios

Table 4-1 Current Marine Corps Operating Environments

3. JMCIS and LOG-AIS

The problem with migrating the current family of MIS over to JMCIS are monumental. Two key issues concerning the migration of the MIS to JMCIS stand out. First, there is an age old Marine Corps question; money. We do not have the funds to replace every Intel-based information system to meet the architectural requirements of JMCIS. Secondly, the Marine Corps needs to adopt a FMF standard operating system. One that closes the gap between the MI systems and the near-term GCCS. JMCIS

One possible solution to the hardware problem being evaluated by the Marine Corps is the Marine Common Hardware Suite (MCHS). The MCHS is a set of tactical computers which are scheduled to be bought during FY 96. Currently there are a four separate classes of the identified for the MCHS they are:

- Class A: A UNIX based machine with 64+Megabyets of RAM and a 2 Gigabyte hard drive. This machine is a practical JMCIS platform that allows some room for future expansion. This is a high end system that can provide multiple computing and network services.
- Class B: Also a UNIX based machine that has 32+ Megabytes of RAM and a 1 Gigabyte hard drive. This system is designed to operate as a workstation. The platform currently offers adequate an capability for running JMCIS software programs.
- Class C: This is the DOS/ Windows legacy machines. There are numerous configurations and variations of these machines scattered throughout the Fleet Marine Corps. Capabilities range from 286 based machines to 486 based machines.
- Class D: Pocket Tactical Computer. A cargo pocket sized computing device for which there s no current contract or hard specifications.

The premise of the MCHS system is to field a family of systems that will support either DOS or UNIX and is X windows compatible. There is still some question as to whether all of these machines will have the power to run JMCIS. (Wartick, 1994) We need to take a hard look at the future software and system requirements not only from a Marine Corps perspective but from a DoD perspective. We need to start fielding computing equipment that will run not only today's software applications but the next generation of software applications.

How does all of this relate to the interoperability of MITLA with LOG-AIS? To be a functional asset to the Marine Corps, MITLA needs to interoperate with all of the systems that comprise LOG-AIS. The LOG-AIS family of systems is starting its migration to JMCIS in January of 1995 with the release of version 4.0 of MAGTF II. Version 4.0 is not written to JMCIS standards but is a first migration to a COE and common data structures. As MAGTF II continues its migration towards JMCIS the asset tracking and asset visibility functionality of MITLA must also migrate to the JMCIS platform. In the next few sections we will discuss the latest version of Marine LOG-AIS. These are the programs that will eventually be migrating to the JMCIS platform. This is also the LOG-AIS family that MITLA must initially support and must operate with. If MITLA is going to augment and enhance the logistic planning process it is imperative that it seamlessly interoperate with the MAGTF II LOG-AIS family of automated logistics systems.

E. MAGTF II/LOG AIS SYSTEMS

The Marine Corps has developed a family of coordinated mutually supporting, automated logistic systems: Marine Air Ground Task Force Logistics Automated Information Systems (MAGTF II/LOG-AIS). It is a family of microcomputer-based systems designed to provide operating forces (active and reserves) with the necessary tools to support operational and logistics planning for deployment and employment of MAGTFs. As a system, MAGTF II is a family of coordinated, mutually supporting PC-based systems. The system is designed to run on 386/486 microprocessors that have at least 4Mb of RAM, DOS 5.0 and a 100 MB Hard Disk. MAGTF II is composed of a series of individual programs that have a common and data structures and are designed to run in a common operating environment (Windows, DOS). Each of the Subprograms that make up MAGTF II is capable of operating independently and performing its own discrete functions. However, the power of MAGTF II/LOG-AIS is its ability to link all the subprograms together for an seamless and accurate sharing of logistic information.

MAGTF II is designed to assists the commander in the development, souring and refinement of operational plans in independent, joint and combined operations. It is a tool that is equally valuable during both deployment and re-deployment. When fully fielded, the MAGTF II/LOG AIS family of systems will provide the commander with the tools to perform the following tasks.:

- Rapid planning and force deployment

- Support Maritime Prepositioned Operations
- Maintain accountability of all assets
- Provide supply support for deployed forces.
  (McCormick, 1994)

1. The Following Systems Comprise the MAGTF II/LOG AIS Family

a. MAGTF II Warplanning Model

This system allows Marine planners to select and tailor a MAGTF for an operation or deployment. Required lift, sustainment and supportability estimates can be calculated using this system. Lift requirements and deployment data can be transmitted to the Joint Operations Planning and Execution System (JOPES). MAGTF II provides the interface between the Marine Corps and JOPES.

b. Transportation Coordinators Automated Information for Movement System (TC AIMS)

This system provides an automated capability to plan, coordinate, manage and execute MAGTF deployments of US forces from point of origin to point of embarkation, from point of debarkation destination.

c. Computer Aides Embarkation Management System (CAMES)

CAMES is an integrated database/graphics embarkation tool designed to assist in the embarkation personnel in planning and executing amphibious, MPF and Military Sealift command (MSC) load plans.

d. Computer Aided Load Manifesting (CALM)

CALM provides an automated tool to produce standardized aircraft load plans for C-130, C-141, C-5 and KC-10 aircraft. This system is similar to CAMES in that it is database/graphic driven. CALM is an Air Force project that is being rewritten to interoperate with Marine LOG-AIS.

e. Asset Tracking for Logistics and Supply System (ATLASS)

ATLASS provides a deployable supply system that will be used by unit supply accounts that comprise the MAGTF.

f. MAGTF Deployment Support System (MDSS II)

MDSS II is the hub of the MAGTF II/LOG-AIS family of systems. It is the unit level deployment planning and execution system. It is one of the principal systems that MITLA must be able to communicate with. MDSS II provides the MAGTF commander with the ability to build and maintain a database that contains the force and equipment data reflecting the configuration of the MAGTF. Data extracted from MDSS II provides the commander (MAGTF, JCS or National Command Authority) with an accurate picture of the MAGTF composition. By passing data from MDSS II to TC AIMS the commander can get an accurate lift requirement for the MAGTF. MDSS II is currently configured to interface and interact with all of the systems in the MAGTF II/LOG-AIS family of systems. Logistics Application for the Marking and Reading of Symbols (LOGMARS) has also been incorporated into MDSS II. If MITLA is going to become a viable logistic tool its functionality must also be incorporated into MDSS II. As a stand alone system MITLA no matter how functional, will not be supported by DoD or the Marine Corps under the new systems archirural concept. Figure 4-2 provides a graphical representation of how MDSS II serves as the bridge to the other MAGTF II/LOG-AIS family of systems.

g. MAGTF Data Library (MDL)

MDL provides a suite of microcomputer-based programs and files designed to provide source planning to the MAGTF II/LOG-AIS family of systems. It is a data quality engineering tool providing a source of quality control to ensure consistent and reliable logistic data. Data from both internal and external sources undergo an automated quality control process. These checks consist of edit checks, range and domain validations and other mathematical calculations which are designed to ensure that data errors are trapped and corrected before they reach the user.

h. Data Management and Standardization

Although not one of the systems components that comprise MAGTF II. The common data structures are a integral part of the systems functionality. By using common data structures information is seamlessly transferred from one component of the system to another. Data management and standardization provide a means to enforce data accuracy, currency, definition and naming standards for MAGTF II/LOG-AIS data dictionary.

Figure 4-2 is a graphical representation of MAGTF II LOG-AIS . It depicts the all the major logistic programs that comprise the system. At the center of the system is MDSS II the unit level deployment database. The common data structures and interface provided by MAGTF II version 4 allows the user to interact with all of the systems in the MAGTF II/LOG AIS family.

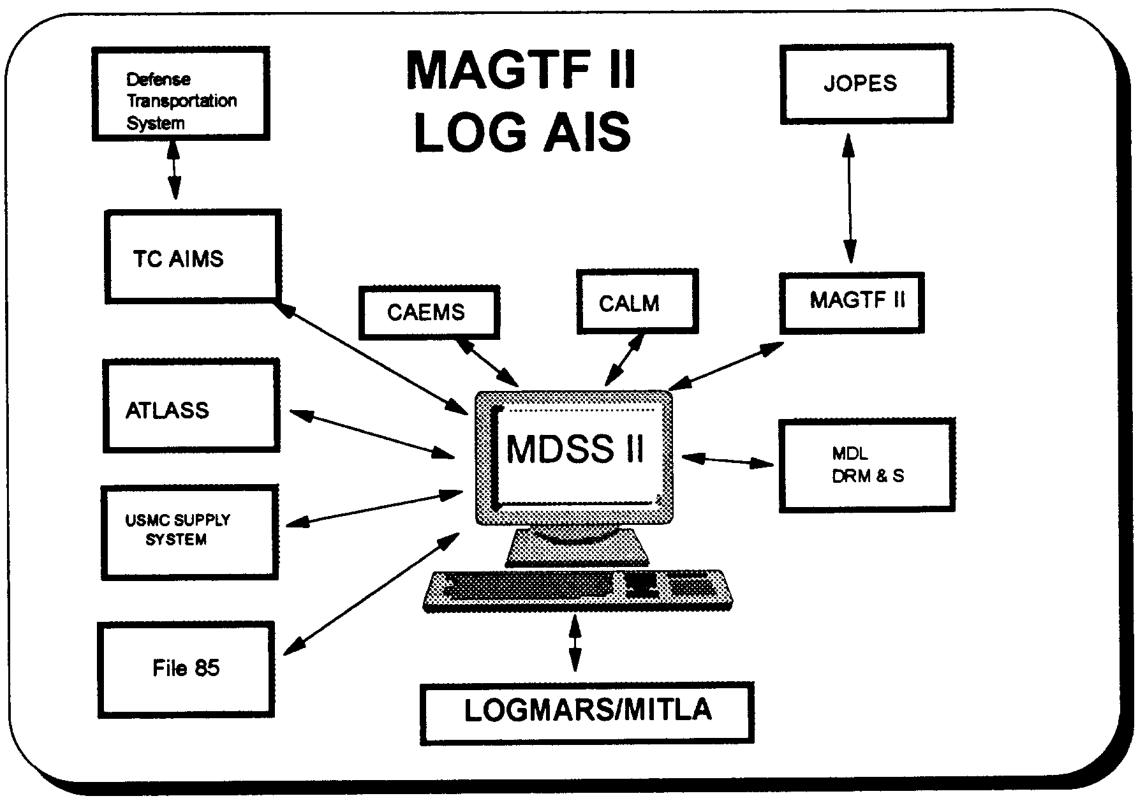

Figure 4-2 MDSS II (McCormick, 1994, Marchetti, undated)

F. MITLA AND MAGTF II/LOG AIS

1. Background

Currently MDSS II has a LOGMARS interface for scanning and collecting equipment data using barcode technology. As described earlier the linear barcoding system has a capacity of only 82 characters. This is the equivalent of one line of typed text on a standard 8.5 by 11 sheet of paper. Conversely, a SAVI Seal Tag has the capacity to store the equivalent of 96 typed pages of information. The capabilities of the two technologies are drastically different. In order to capitalize the full potential inherent to the SAVI family of tags a separate interface module must be developed to exploit all of the functionality associated with the SAVI family of asset tracking products.

a. Module design

The current MDSS II LOGMARS module has the following capabilities:

- Upload capacity: The ability of receiving barcode information from Radio Frequency (RF), Telephone Modem, or Portable Data Collection Device (PDCD).
- Label Generation: MDSS II has the ability to generate barcode labels from the internal unit equipment and supplies list, unit deployment list and the Alpha Roster.

The LOGMARS module only has the ability to update and read information from the pre-designated fields in the MDSS II database. Inorder to benefit from the additional functionality, flexibility and robustness of the SAVI Tags we need an additional more robust interface into MDSS II. The new module designed needs to handle the additional capabilities provided by the SAVI family of asset tracking devices. At a *minimum* the new module should provide the following functions.

- Write to tag: The ability to select user defined fields from the MDSS II database and write them to tags. The user should have the ability to select the desired database fields, desired records and associate them to one or more tags.

- Read Tag: The module should have the ability to interrogate, search, and read tags. It should also have the ability to interface with SAVI's digital wireless network.
- Update MDSS II database: The module should read tags and update the users' database fields within MDSS II. This update should be a seamless and transparent function that requires no additional user input.

There are many additional functions that could be incorporated into the module. For example, equipment maintenance information could be electronically stored in the excess memory on the tag and accessed through MDSS II or ATLASS. However, identifying and analyzing all of the possible additional uses for the excess memory capacity of the SAVI Tags is beyond the scope of this thesis. The key point of this section is to point out the drastic differences between capabilities of LOGMARS and MITLA/RF. Inorder to realize the benefits associated with the MITLA/RF family of products, careful thought and consideration needs to be given to the MDSS II interface. The interface should exploit all of the functionality of the MITLA/RF products.

V. BENEFITS OF EMPLOYING MITLA/RF TECHNOLOGY AN ANALYSIS OF EXERCISE AGILE SWORD 1994

A. BACKGROUND

This chapter is an analysis and evaluation of MITLA asset tracking devices during an MPF in-stream off-load. During the period 6 August to 23 August 1994 exercise Agile Sword 94 was conducted at Camp Lejeune, North Carolina. The exercise was a partial Maritime Prepositioning Squadron (MPSRON) offload. It involved one ship from the squadron of the MV 2nd Lt. John P. Bobo. The exercise scenario called for called for the off-loading of 447 Principle End Items (PEIs) and 80 containers (COTs) This exercise was the first and to date the only actual analysis of MITLA/RF asset tracking devices conducted by the Marine Corps. (Lundgren, 1994; Taylor, Lamont, Smith, Angel, 1995)

The evaluation of the MITLA assets centered on three areas of MITLA functionality.

- Documentation of the flow of equipment and provide a reconstruction of the offload.
- Analyze the accountability and tracking performance of MITLA.
- Determine any efficiencies provided by MITLA automated systems.

(Taylor, Lamont, Smith, Angel, 1995)

The following sections of this chapter give an overview of MPF operations, the MPF command structure, the importance of offload accountability and tracking and the physical layout exercise Agile Sword 94. These sections are provided to give the reader who is unfamiliar with MPF operations an overview of MPF operations.

1. MPF Overview

The MPF concept provides the Marine Corps with a force of 13 ships. These ships are preloaded with equipment and supplies and can be quickly be dispatched to a region of conflict. At the point of debarkation the supplies and equipment are married up with the Marines who would have flown to the conflict area. The flotilla of 13 ships is divided into three Maritime Prepositioning Squadrons. Currently these squadrons are stationed in Guam, Diego Garcia and along the East coast of the United States. (Taylor, Lamont, Smith, Angel, 1995)

2. MPF Command Structure

As with most amphibious types of operations an MPF operation has two chains of command. One for the Navy and another for the Marine Corps. The Commander of the Maritime Prepositioning Force is responsible for the seaward security and for getting the equipment ashore. The Marines take control of the equipment at the high water mark on the beach. In order to understand the flow of information in an MPF operation a few terms need to be described. The Landing Force Support Party (LFSP), the Arrival and Assembly Operations Group (AAOG) These two agencies are responsible for getting the equipment from the Navy and distributing it to owning units at locations called the Arrival and Assembly Operations Element (AAOEs). The entire process from offload to receipt by the owning unit is called reception and throughput. (Taylor, Lamont, Smith, Angel, 1995)

3. Offload Accountability and Tracking

Asset tracking and accountability during the offload stage of any operation is critical. It is important that all the equipment is accounted for, and properly distributed to the designated owning unit. This is one of the critical areas in which there was a break down during the Gulf Conflict. (Michon, Gunderson, and Torres, 1993) The AAOG is responsible to the MAGTF commander for the proper tracking and distribution of supplies and equipment.

Prior to the start of the exercise, Marines placed tags on all of the items that were selected for offload. These tags had been previously written and electronically formatted to contain the same information as the LOGMARS barcode. The identified fields were: Unit Identification Code, National Stock Number, Package ID, Description, and Major Subordinate Element. (Lundgren, 1994)

4. Exercise Layout

This section is provided to give the reader a better understanding of the distances between operational sites and the physical layout of the of the operations area. There were two landing sites setup during Agile Sword-94. One for PIE and one for COTs. The container lot was set up in an area approximately 1 mile from the beach. The AAOG and the AAOE for the command element were at a distance of about three miles from the beach. (Lundgren, 1994) The remaining AAOEs were three separate sites. The distances to these sites ranged from 3 to 8 miles. (Taylor, Lamont, Smith, Angel, 1995)

B. MITLA/RF SYSTEM BENEFITS

Exercise Agile Sword-94 was the first operational evaluation of MITLA products. By all written evaluations the MITLA product performed exceptionally well. The performance bench marks achieved by MITLA during this exercise are a testimony to the robustness of these assets. During the exercise, interrogators were set up on the beach, the movement control center, the container lot, and all of the AAOEs. (Taylor, Lamont, Smith, Angel, 1995) Agile Sword equipment came ashore the interrogators would "collect" all the tags within its operating range. The information contained in the tags memory was collected and sent via wireless modem approximately 3 miles to the AAOG. Upon arrival at the AAOG the information was received at the computer and updates were automatically made to MDSS II. The total time from when the tags were interrogated to when the MDSS II update was complete was on average one minute (Lundgren, 1994) During the offload, Marines in the AAOG were able to control all of the interrogators on the beach as well as the interrogators in the container lot and the AAOE for the command element. This feature allowed just one Marine to track and obtain up-to-the minute tracking information from all of these locations via the MITLA system. (Taylor, Lamont, Smith, Angel, 1995) After the equipment left the AAOG it proceeded to its respective AAOE location. Each of the AAOEs had MITLA equipment and was able to obtain accurately track all equipment arriving at and leaving each location. Each of the AAOEs controlled their own MITLA data collection devices. During this exercise, updates from the AAOEs to the AAOG was done by courier disk. In future operations this will be done via the RF link.

Agile Sword-94 demonstrated the substantial potential associated with the MITLA asset tracking system. Outlined below are some of key areas in which MITLA assets excelled.

1. Increased Accountability

As items moved from the beach through the various control agencies the equipment location code in MDSS II was automatically updated by the MITLA assets. At any point during the offload process the MITLA operator could quickly ascertain the location the offloaded assets. The location code updating process was continued until the owning unit took receipt of the equipment. (Lundgren, 1994)

2. Tracking Accuracy

One of the objectives of Agile Sword-94 was to evaluate and document the accuracy of the MITLA assets. Exercise evaluators wanted to know how accurately MITLA would track supplies and equipment as they moved from the ship through the staging areas to the owning unit. During the exercise, MITLA was able to accurately track and account for 93% of the PEIs. The 93% figure is a best estimate based on the following data. Since the actual number of PEIs that were outfitted with MITLA tags was not precisely known it had to be estimated. Exercise evaluators estimated the number of PEIs to be 353. During the exercise, MITLA assets collected a total of 329 PEI tags yielding a tracking accuracy of 93%. Container accuracy was much more precise. The actual number of tagged containers was known to be 76. During the exercise, MITLA collected 74 container tags. Hence, MITLA had a accuracy of 97% for tracking the container inventory. (Taylor, Lamont, Smith, Angel, 1995)

3. Manpower Reductions

During the exercise MITLA demonstrated significant manpower efficiencies. Although not a completely autonomous system, the operation of the MITLA assets required far less manpower than did the team of Marines using the LOGMARS equipment. The MITLA interrogators and computer only require one Marine operator at each station. In this scenario with five AAOEs and two beach stations, two stations at the movement control center it is estimated that it would require 9 Marines. The number Marines dedicated to asset tracking could actually go down if all the sites were linked together via the RF link. With the RF link established all operations could be tracked and updated from one central computer. Conversely with LOGMARS it requires 3 Marines per station. In this exercise that amounted to about 30 Marines. In this one ship off load MITLA had a manpower savings of 21 Marines over the use of LOGMARS. This equates to about a 30% reduction in the number of Marines required to perform this function. This potential savings in personnel could foster a realignment of our logistic organizational structure. Through the use of theis technology the support structure could become more responsive and accurate with fewer personnel. If you extrapolate these numbers over a simultaneous offload of a full MPF squadron the numbers grow into significant manpower savings for the Marine Corps. (Taylor, Lamont, Smith, Angel, 1995)

4. Speed of Collection

The speed at which MITLA collects and updates the location of items far surpasses that of LOGMARS. MITLA products can collect all of the tags in a given area in a matter of minutes. With LOGMARS the scanning process takes only seconds but the process must be repeated for every item at the location. The walking or driving to all of these items would increase the total time to collect. (Taylor, Lamont, Smith, Angel, 1995) The differences in collection times and the flexibility of MITLA assets was actually substantiated during Agile Sword-94. During back load of equipment MITLA assets were placed on a vehicle and driven around the vehicles in a staging lot. In 15 minutes, MITLA assets had collected all of the tags in that location. The total collection time for LOGMARS scanners was 5 hours. (Lundgren, 1994)

5. Equipment Preparation

The interface software program used during Agile Sword-94 streamlined the writing to tag process. As stated earlier pre-defined fields in MDSS II were chosen to be written to the tags. The program used in this exercise was a shell that runs on top of MDSS II.

It read the selected data fields and associated them to the appreciate tags. According to the Marines from Headquarters Marine Corps transferring the information to the tags from MDSS II was a effortless process that required about an hour.

In summary, Agile Sword-94 expounded many advantages to developing and implementing MITLA products. The potential savings in manpower and the increased asset tracking provided by this technology necessities continued operational evaluations and product development.

VI. CONCLUSIONS, RECOMMENDATIONS AND FINAL REMARKS

A. CONCLUSIONS

After thoroughly analyzing all aspects of MITLA/RF technology and attending a product capabilities demonstration, we can conclude that Marine Corps is clearly taking this technology in the right direction. The increased asset visibility and accountability provided by this technology will enhance and complement our logistic effort. The use of wireless networks takes asset tracking technology out of the warehouse and into the operational logistic environment. Initial operational tests have shown MITLA products to be superior to barcodes in the area of speed and accuracy. MITLA products have been able to achieve these impressive results with 30% fewer Marines. The incorporation of an electronic mail server to the SAVI wireless network is an enhancement that will improve and enhance an already responsive and flexible logistic system.

As a logistician this author will continue to follow the developments and improvements to the MITLA/RF initiative. It is an exciting and interesting tool that will enhance our logistic responsiveness. Responsive and timely logistics is what the war-fighter needs. MITLA/RF will allow the logistician to meet those needs well into the next century.

B. RECOMMENDATIONS

This section contains recommended product enhancements that the author believes will further enhance and improve the functionality of the SAVI RF link.

1. RF Link Power and Frequency Spectrum

These two improvements are mutually inclusive. Under current system design the output power and the frequency is governed by Part 15 of the FCC Code of Federal Regulations. As explained earlier this was done to avoid having to go through the FCC licensing procedure. However, for military operations we are not concerned with licensed operations. We could achieve greater transmission ranges by utilizing a portion of the military frequency spectrum for the establishment of the RF link. By utilizing the military frequency spectrum we could incorporate a more powerful spread spectrum radio transceiver. Then by increasing the output power we simultaneously increase the transmission range. With greater RF link range we would not have to establish as many units in the area of operations. Currently, the effective range of the RF link unit is a quarter to a half a mile depending on line of sight characteristics of the region you are operating in. This limited range is a detriment to a limited manpower. To span greater distances requires the establishment repeater sites. To ensure the security of the repeater sites you need to guard them. This causes an unnecessary drain on the available personnel. By increasing the output power we could easily achieve transmission ranges that are in miles not quarter or half miles.

2. Component Design

In most operational cases the RF link unit is deployed with a SAVI Interrogator. Currently, the only time this does not happen is when the RF link is used in the repeater mode of operations. As described in Chapter III the interrogator communicates with all the tags in its range and the RF link communicates with other RF link units to establish the network. To keep the system simple and compact for the user the author recommends that both the SAVI interrogator and the RF link unit be incorporated into one housing. This design change will pay great dividends when the system is put into operational use. It will reduce not only setup time but system complexity. The fewer system components that need to be transported and assembled, the more efficient, functional and reliable the system will be.

3. Directional Antenna for the RF Link

Another way to increase transmission ranges and reduce the electromagnetic signature of the system is through the implementation of directional antennas. If SAVI could incorporate a directional antenna option into the design of the RF link it would aid in reducing the risk of data interception while increasing the range of the transceiver. This would be very useful when the RF link is operating in the repeater mode.

During the offload operations, an interrogator with a directional antenna would help to track assets as they are being unloaded from the ship. On shore a directional antenna could be skewed towards the water to scan incoming shipments. By employing a directional antenna you could decrease the data collection times by only collecting new assets as they arrive on the beach. The use of a directional antenna may not be desirable in all operational situations, but there are clearly situations where it would prove beneficial to the end-users of the system.

C. FINAL REMARKS

The reader of this thesis must remember that the topics discussed in the preceding chapters relate to emerging RF technologies. These technologies are being developed to meet the new operational challenges associated with over-the-horizon amphibious operations and maneuver warfare. The solutions offered today are stepping stones that will enable us to obtain the ultimate goals of "in the box and in-transit visibility" on a global scale. The final MITLA/RF product may be significantly different than the technology shown in this thesis. However, the underlying principles of the technology and the lessons learned in system development and testing will only serve to enhance the final product.

As stated in Chapter II, the current asset tracking devices employed by the Marine Corps cannot meet today's logistic needs. The increased operational pace and flexibility associated with maneuver warfare and over-the-horizon operations only make today's asset tracking technology more inadequate. In order to meet the logistic challenges associated with the new operational concepts we need to continue to refine and develop MITLA/RF technology to its full potential. Every effort should be made to incorporate not only RF technology but all automated logistic technologies into one common operating environment. Systems interoperability across the spectrum of Marine automated information systems is the goal we should continue to pursue. To meet the logistic challenges brought about by the new operational requirements and reduced force structure we need to develop technological solutions that will enhance our responsiveness and then incorporate them into our operating procedures. MITLA/RF is one technology that will increase our logistic responsiveness and allow us to better serve the logistic needs of the combat element.

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