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THESIS

COST-BENEFIT STUDY OF IMPLEMENTING CURRENT AND FUTURE TECHNOLOGY FOR ENHANCED STATION-KEEPING DURING UNDERWAY REPLENISHMENT OPERATIONS

by

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This thesis analyzes the feasibility of using new technology such as laser rangefinders to enhance ship station-keeping during Underway Replenishment (UNREP) Operations. The introduction of new technology is the single best method to reduce manpower requirements on board Navy vessels today. UNREP at sea is the most manning intensive evolution required by the Navy for Commanders and sailors to execute. This research explores new methods to communicate and determine approach and alongside ranges between ships at sea. Research was conducted on five classes of combatants using laser rangefinders. Laser rangefinders were found to be the only mature, suitable technology to replace the Phone and Distance line legacy system. An analysis of alternatives based upon cost estimates and observed benefits revealed that using lasers could provide enhanced situational awareness to ship Commanders, Officers of the Deck and Conning officers. A modest investment in laser rangefinders for each ship in conjunction with billboard range displays on replenishment ships and reconfigured sound powered phone lines would cost effectively simplify Underway Replenishment evolutions by reducing time alongside, increasing safety to personnel and vessels at sea, and sailors Quality of Life.

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ABSTRACT

This thesis analyzes the feasibility of using new technology such as laser rangefinders to enhance ship station-keeping during Underway Replenishment (UNREP) Operations. The introduction of new technology is the single best method to reduce manpower requirements on board Navy vessels today. UNREP at sea is the most manning intensive evolution required by the Navy for Commanders and sailors to execute. This research explores new methods to communicate and determine approach and alongside ranges between ships at sea. Research was conducted on five classes of combatants using laser rangefinders. Laser rangefinders were found to be the only mature, suitable technology to replace the Phone and Distance line legacy system. An analysis of alternatives based upon cost estimates and observed benefits revealed that using lasers could provide enhanced situational awareness to ship Commanders, Officers of the Deck and Conning officers. A modest investment in laser rangefinders for each ship in conjunction with billboard range displays on replenishment ships and reconfigured sound powered phone lines would cost effectively simplify Underway Replenishment evolutions by reducing time alongside, increasing safety to personnel and vessels at sea, and sailors Quality of Life.

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I. INTRODUCTION

A. BACKGROUND

The U.S. Navy has been conducting Underway Replenishment (UNREP) Operations as a method to keep ships fueled and supplied since 1899 when the collier USS Marcellus supplied fuel to the USS Massachusetts. Since World War II, the methods and technology have changed little. Worldwide, ships remain dependant on oil for propulsion, which makes UNREP critical to sustained operations. Very few navies in the world can accomplish this operation, which gives the United States a key advantage in maintaining a Bluewater Navy.

UNREP is formally required by OPNAVINST 3501.311A. Mobility Mission Area (MOB) is a primary mission for all surface combatants. For example Required Operational Capabilities, MOB 10.2 and 10.3, state that a DDG-51 class destroyer must be fully able to refuel and resupply at sea during Condition 3 and 4 steaming using special teams. The "Underway Replenishment Detail" evolutions watchstations are outlined in the UNREP watchbill. [Ref. 1]

During UNREP, two ships must steam within 200 feet of each other at 13 knots or faster on a parallel course (Romeo Corpen). Ship separation is critical, because once inside 140 feet, the hydrodynamic force between ships begins to rapidly pull them toward one another. Therefore, it is critical to be able to determine distance and rate of change between vessels.

The Navy presently uses the Phone and Distance (P/D) line (see figure 1) to determine distance and communicate between ships. The P/D line is a sound powered phone line[1] draped with flags 20 feet apart. The flags labeled with 5-inch tall numbers indicating distance are color-coded to enable the conning officer and bridge personnel to visually determine distance. Color-coded lights are added in addition to the flags during nighttime UNREP. [Ref. 2] All officers on the bridge and rig captains on the

[1] A Sound Powered Phone Line is a tensioned wire cased in a flexible rubber casing, which transmits acoustic vibrations from one phone diaphragm to another.

replenishment stations use distance information to make proactive maneuvering decisions during the UNREP.

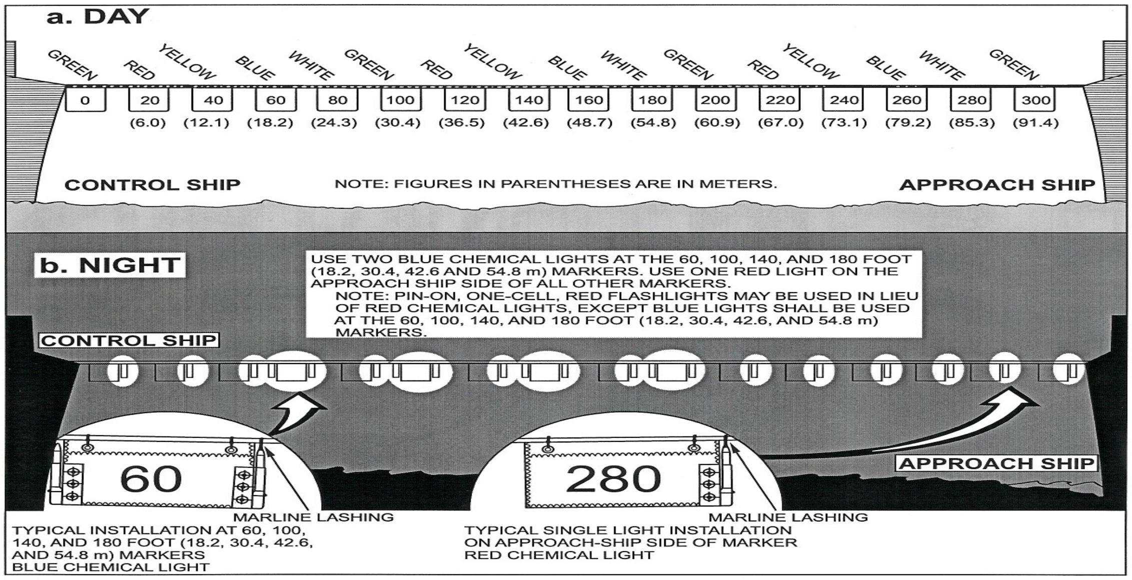

Figure 1. P/D line configuration [From Ref. 2].

Despite being highly reliable and simple to maintain, the P/D line has several limitations. First, there is an excessively long period between the time the ships are alongside before the line is set up and useful. If the shotline breaks or falls short of the other ship, this period can take as long as 20 minutes. During this period, the lack of precise distance between vessels for the conning officer increases risk of collision. The P/D line tending is manpower intensive and puts personnel at risk of injury and exposure to the elements of the sea. Errors result from the difference in the location of the line tenders on each vessel and slack in the line, there by decreasing accuracy which is esoroborated by different size vessels. Rate of change in distance is hard to determine accurately since the flags are twenty feet apart. Additionally, the phone line's exposure to the elements frequently allows water and corrosive salt to penetrate its connections, which causes communications to fail. At night, colored chemical markers indicate the flag locations [Ref 1.]. Color-coding increases the risk of misinterpreting the distance, especially under emergency conditions. An organic, real-time laser rangefinder or other similar system could provide accurate range and rate of closure information immediately day or night.

Replenishment operations are further complicated when the receiving vessel leaves waiting station and approaches the supply vessel from astern. The receiving vessel's Conning Officer must estimate the separation between vessels when alongside in station. To accomplish this, the Radian Rule[2] is used to determine the lateral separation once alongside. To employ the Radian Rule, the distance to the supply vessel must be accurately determined along with the bearing to the closest side of the supply vessel. Currently, the Navy uses a Stadimeter to determine distance once both vessels are inside 1000 yards of one another. This requires precise calibration and accurate input of mast height. Additionally, backup ranges are announced from the radar repeater to reduce the chance of operator error. At best, range accuracy is within 100 yards. A rangefinder providing accurate information to the conning officer and CO would be highly beneficial during the approach and maintaining station alongside during the transfer evolution.

Current technologies such as laser rangefinders or future technologies under development at the Naval Sea Systems Command could provide the accurate and flexible range information needed for a variety of evolutions on board Navy surface vessels. At ranges inside one nautical mile, the typical surface radar does not provide accurate range and bearing information, particularly when tracking small vessels with small reflective signatures. A rangefinder would provide range information for bridge personnel during underway replenishment and a variety of other evolutions, such as: tactical maneuvering, helicopter operations, formation steaming, target sled operations, and pier approaches. The commercial sector and the military use laser rangefinders for many applications. The military currently uses lasers with a high degree of satisfaction in mechanized infantry and forward observation operations. Tanks use laser rangefinders to compute trajectory parameters, and Army and Marine infantry use them to determine distances to targets. In the commercial sector, civil engineers use them for construction projects and golfers use them for improving their game.

In a Capstone Requirements Document for Operational Logistics drafted by N42 (Director, Strategic Mobility & Combat Logistics) and endorsed by N4 (Deputy Chief of

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[2] The Radian Rule is represented by the equation $S=(A/60)*R$ where S is the lateral separation in yards, A is the angle to the closest side of the replenishment ship, and R is the range in yards. Therefore, if you are at 500yds and have 6deg of separation, you will be 50yds or 150ft apart when alongside.

Naval Operations, Fleet Readiness and Logistics) on 03JAN02, a requirement for "Laser Improved Phone/Distance" was stated. Vice Admiral McGinn,, Deputy Chief of Naval Operations (N7 Naval Warfare Requirements & Programs), also highlighted the requirement in his response to N4. Vice Admiral McGinn stated that he believed these changes were of paramount importance and required minimal funding. He also went on to state that they were currently stagnating due to lack of funding priority. [Ref. 3]

B. PURPOSE

This study gathered information about a variety of distance measuring and communicating equipment for use during replenishment operations, found which equipment best suits the needs of the Navy, and determined if a suitable replacement for the P/D line is warranted given the cost. The Surface Warfare community leadership and Naval Sea Systems Command (NAVSEA) can use this information in their search for the best option and funding method.

C. RESEARCH QUESTIONS

There were two primary questions for this research:

- What alternative technologies are available to the P/D line during the Underway Replenishment Evolution?
- What is the cost to the Navy to implement a current technology?

The secondary questions, which support the primary questions, are as follows:

- What are the risks associated with replacing the P/D line?
- How would this technology affect manning during the UNREP evolution?
- Could any Quality of Life benefits be gained by the introduction of new technology?
- What benefits would result from a change?
- What are the costs to implement each alternative?
- How can the Navy fund a replacement program?

D. SCOPE

The scope of this thesis includes: (1) a review of current and future systems available; (2) an in-depth cost and benefit analysis of possible replacements; and (3) a recommendation of one or more optimal solutions. The research includes an analysis of capabilities needed, of all costs and benefits for various alternatives, of acquisition methods, and of any operational impacts. The thesis concludes with a recommendation of solutions and areas for future study.

E. LITERATURE REVIEW AND METHODOLOGY

Currently, McConnell Technology and Training Center (MTTC) located in Louisville Kentucky has a project in progress that addresses hand-held laser rangefinders. NAVSEA, Panama City recently cancelled a fixed, gyro-stabilized laser rangefinder project due to technical difficulties, delays, and rising costs. Naval Surface Warfare Center, Crane Division has funded the procurement of Leica Vector IV laser rangefinders.

The methodology used in this thesis research consisted of the following steps:

- A literature search of Navy Publications, DOD guidance, Internet web sites, magazine articles, and other library information resources.
- Gathering life cycle cost and specification information on various rangefinders and communications sets.
- Collecting safety center data on collisions and associated repair costs.
- Gathering ship manning cost data.
- Conducting tests at sea using the USNS Tippecanoe (T-AO 199) and current combatants as test platforms.
- Calculating a cost estimate for each alternative.
- Studying risks involved and propose methods to reduce risk.
- Proposing an optimal rangefinder and communication set configuration.
- Studying the various acquisition alternatives available and propose an optimal direction for short-term and long-term implementation.

F. ORGANIZATION OF STUDY

Chapter I: Introduction
Chapter II: Requirements and Capabilities Analysis
Chapter III: Underway Testing
Chapter IV: Analysis
Chapter V: Risk Reduction and Recommendations

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II. REQUIREMENTS AND CAPABILITIES ANALYSIS

A. INTRODUCTION

Personnel safety is always the first consideration in evaluating any new alternative. Alternatives that have the potential to reduce manpower and maintenance requirements are counterproductive if they put personnel and ships at risk. Requirements to operate in a wartime environment introduce additional considerations. Controlling electromagnetic energy, light, heat, and sound are important factors in avoiding enemy detection during military operations. This chapter addresses the governing requirements and capabilities for any rangefinding and communication method, and it introduces the available equipment and configurations analyzed in Chapter IV that meet those requirements and capabilities.

B. AVAILABLE TECHNOLOGIES

The equipment must be able to reliably determine distance and maintain communications, day and night, for extended periods in all weather. Currently, there are four technological means to determine distance: visual, physical, electromagnetic energy, and light. The Stadimeter uses the visual means; the P/D line and Sonar use the physical means; radar uses electromagnetic energy; and lasers (Light Amplification by Stimulated Emission of Radiation), the newest (invented 1959) and most promising means, uses light.

For communications, the available technologies are visual, physical, electromagnetic energy, light, and electrical. The Navy continues to frequently use the visual means to communicate via flag hoist or flashing light. Sound powered phones employ the physical means to communicate; radios use electromagnetic means; and telephones use the electrical method. Infrared light communications is the newest of the technologies and is common in electronic remote controls.

When selecting specific technologies, old as well as new technologies are valid candidates. If a technology is old, it can still possibly do the job better for less cost than a new technology. That is why in the analysis in Chapter IV; the P/D line is considered.

Captain Dick Gilbert USN (Ret), an ex-Surface Warfare Officer and Engineering Duty Officer, is MTTC's Technical Director. He served in a variety of roles during his career ranging from the Operations Officer on USS Marvin Shields (FF-1066) to the Phalanx CIWS Program Manager at NAVSEA. At MTTC, Mr. Gilbert is responsible for the technical analysis and appraisal of products and processes that may be suitable for military technology transfer. In August of 2001, NAVSEA (SEA-05N) requested that MTTC investigate the possibility of using Commercial Off-the-shelf (COTS) equipment to replace the P/D line. MTTC agreed to undertake the project. NAVSEA wanted the MTTC project to compliment a stabilized electro-optic, laser rangefinding, ship control system under development at NAVSEA. Since that time, the NAVSEA project has encountered technical difficulties and rising costs, and it was cancelled. The intention of these projects was to eliminate some line-tending watchstations.

MTTC Internet research concluded that rangefinders could be modified for shipboard use. MTTC found two U.S. firms that were responsive to shipboard requirements. MTTC requested Opti-Logic Corp. and Laser Atlanta, Inc. submit proposals for a "Bridge Kit", which included a laser rangefinder, an external display, support equipment, two low power .5W handheld radios, and documentation. MTTC selected Laser Atlanta's Advantage model rangefinder and purchased two "Bridge Kits" for at-sea testing using money provided by NAVSEA.

C. REQUIREMENTS/ CAPABILITIES

Navy regulations and U.S. governmental law establish the governing requirements listed in this section. The necessary capabilities are determined from analysis of the Surface Warfare Community's professional experience, preferences, and judgment.

1. Governing Requirements

Most requirements covering the area of study are general but Navy doctrine has established some specific guidelines. Emissions Control (EMCON) is a set of guidelines for the use of electromagnetic energy onboard ships. Under EMCON, Hazards of Electromagnetic Radiation to Ordnance (HERO), Hazards of Electromagnetic Radiation to Personnel (HERP), Hazards of Electromagnetic Radiation to Fuel (HERF), and Radio

Silence are set limits on output power. Radio Silence limits the output power of radios and other electromagnetic devices to prevent detection by other than friendly forces. The other major requirement is Food and Drug Administration (FDA) rules. For laser rangefinders, FDA eye safety classification limits protect eyesight by establishing intensity limits.

a. Rangefinder

MTTC's project manager, Mr. Gilbert, contacted Third Fleet and NAVSEA (SEA-05L8), Branch Head of Shipboard Auxiliary Equipment, Mr. Don Neuman concerning governing requirements for a rangefinder [Ref. 4]. MTTC engineers used their technical expertise and Mr. Neuman's guidance to develop their requirements for a rangefinder. MTTC added their requirements to a Request for Quotation they distributed to Laser Atlanta, Inc. and Opti-Logic Corp. The requirements were as follows:

- If radio-frequency transmitters are used, they should be of minimum power to accomplish the mission. Encryption is not required. There are two issues involved with r.f. radiation: EMCON (Emission Control-Radio Silence) where r.f. signals that can provide locating data are minimized/eliminated); and HERO (Hazards of Electromagnetic Radiation to Ordnance where r.f. signals can cause explosive devices to detonate). For HERO purposes, 20mW power output at the antenna is desirable, but powers up to 100mW are acceptable (larger separation to ordnance is required).

- If electro-optic sources of are used, they must be Class I eye-safe. [Ref. 4]

This list provides the basic requirements provided by MTTC to the manufacturer, who in turn determined what products would meet those requirements. Two additional requirements are important to ships. A junior sailor with tools available on the ship should be able to accomplish normal maintenance. It is also essential that the Commanding Officer and the Officer Of the Deck be able to read the range data externally.

b. Communications

The governing requirements for the communications equipment are essentially the same as for the rangefinder. The Request for Quotation states:

> If r.f. is utilized, it should be of minimum power, as stated above. It should radiate at frequencies that limit detection ranges. [Ref. 5]

EMCON is once again the most important requirement. Communicating during radio silence was not listed specifically in the request but is necessary.

2. Capabilities

Each alternative technology should meet range, accuracy, and reliability specifications. To generate the desired capabilities or specifications MTTC and NAVSEA consulted senior Surface Warfare Leadership.

a. Rangefinder

The following are the capabilities MTTC felt were important after consulting Surface Warfare Officers and NAVSEA:

- Each ship shall have the capability to determine inter-ship distance independently.

- Each ranging device should be handheld, lightweight and powered by a disposable/ rechargeable battery. A supplementary external power source is feasible.

- Ranges must be accurate to +/- 3 feet. Only the line-of-sight distance readout is desired. Range rates and other geometric values would confuse the display and are not desired.

- An external readout display must be provided so that personnel, other than the operator may continuously view the latest distance value. The display should be visible to a distance of 6 feet and off the perpendicular axis by +/- 45 degrees. It shall be readable in bright daylight and at night with no external lighting. The display can be driven by battery or 110V AC. While typical inter-ship distances are in the 80-150 ft range, longer ranges are desirable since the rangers could potentially be used in other shipboard applications such as approaches and navigation.

- The capability to export data from the ranger via RS-232 cable is desirable but not required. With such a port, range information can be supplied to laptop computers, billboard displays and other peripherals.

- The ranger should be robust and capable of withstanding the normal shipboard environment. A pair of binoculars could be used as a comparison standard. [Ref. 5]

NAVSEA stated in its response to MTTC that in the future ships would be operating at greater ranges. Therefore, a rangefinder should be able to range from 20 – 400 ft. A range of 300ft would be the smallest maximum range allowable with the maximum range dictated by price and safety. The range finder frequently will be operated in inclement weather and therefore must be able to work at sufficient ranges even when exposed to salt spray, rain, and snow.

b. Communications

Bridge to bridge communications must be a reliable emergency communication channel to allow the ships to make split second maneuvering decisions. MTTC listed the following communications specifications:

- Each ship will be supplied with matching transceivers. Ultimately, if the system is used fleet-wide, all transceivers would have to be compatible. Each transceiver should be handheld, light weight and powered by a disposable/ rechargeable battery. A supplementary external power source is feasible.

- If electro-optic systems are utilized, the receiver should be as omni-directional as possible. Since bridge to bridge communications are used irregularly, it is not desirable to constantly direct the receiver to the opposite transmitter. If a narrow field–of–view receiver is used, a paging function, using r.f. or other technology should be used to alert the receiver that s/he should orient the receiver towards the transmitter, in order to conduct a conversation. If paging is accomplished using r.f., output powers should be of minimum power, as stated above.

- An audio speaker/ microphone or combined headset is acceptable.

- The transceiver should be robust and capable of withstanding the normal shipboard environment. A pair of binoculars could be used as a comparison standard. [Ref. 5]

D. AVAILABLE EQUIPMENT

In this section, manufacturers of available technologies for rangefinding and communication are listed and equipment that meets the requirements and capabilities are presented.

1. Rangefinders

During an exhaustive search of both the Internet and hundreds of publications on Lexis Nexis, no new emerging technologies for determining range were discovered. Most searches returned laser rangefinders. Less frequently, radar and physical measures such as yardsticks were the results. MTTC discovered that sonic devices were another option, but the maximum range for these devices were too short for this application [Ref. 6].

Radar would seem to be the most logical choice for a new way to determine distance to a ship alongside. However, EMCON and radio silent considerations eliminate small, low power radars from consideration as a method.

Using a physical means such as an automatically tensioned P/D line could be a way to save manning with the existing system. However, this option presents pinch-point safety hazards and increases installation costs and maintenance of the P/D line.

The Navy conducts extensive research in sonar systems. A sonar rangefinder did not yield any worthwhile search results, but could be a method worth further study. It seems logical that a simple active transponder on the side of ships could provide accurate ranges and even a means of communication. Commercial fish finders operate on this type of technology. NAVSEA may simply be able to reprogram an existing fish finder to provide range information to a nearby vessel. The only possible drawback would be EMCON restrictions and vulnerability to submarine detection. However, researchers may find the presence of two noisy ships steaming alongside each other as more detectable or distinguishable by an opposing force.

Many laser rangefinders are available commercially. Defense contractors also manufacture laser rangefinders already in use by the Army and Marines for mechanized infantry and forward observation operations. The three major categories of laser rangefinder are sportsman/surveying, industrial, and military. The inexpensive sportsman/ surveying type of laser rangefinder typically costs less than a few thousand dollars and is handheld for use in golfing or contracting/surveying. Machinery positioning controls for factories employ industrial laser rangefinders. The military versions are expensive at over $5,000, and they include many features, such as night vision, compasses, inclinometers, and GPS targeting input/outputs.

There are many manufacturers of laser rangefinders ranging from small foreign companies to large domestic defense contractors like Litton. Table 1 in appendix A lists the manufacturers, models, features, and prices of various types of laser rangefinders.

NAVSEA, Panama City was engaged in a cooperative project with a private firm to design and test a stabilized laser rangefinder system that would provide information to a future ship control system that would steer the ship automatically. This system was to include a built-in IR communications system. The project was recently cancelled due to technical difficulties and rising system costs. Just before the project was cancelled, the cost was estimated to be over $100, 000 per unit [Ref. 31].

Eliminating various models of laser rangefinder from the list of available models is easy, when one considers the requirements and capabilities. Rangefinders that are not Class I eyesafe or capable of 300ft ranges do not meet specifications and can be dropped from consideration. All rangefinders marked with a "yes" (* means fixed system) in column "Meets Req./Cap." (see Table 7, Appendix A)are eligible for further consideration. Fixed laser rangefinders are included to allow for flexibility in configuration setup, but they do not meet the handheld requirement given to MTTC.

MTTC held an informal bidding process for a "Bridge Kit" that would include a rangefinder and a means of communication. Two companies responded, Opti-Logic, Corp. and Laser Atlanta Optics, Inc., and submitted responses. Laser Atlanta won the bid and MTTC procured two "Bridge Kits" for testing (see figure 2) that included an

Advantage Laser Rangefinder and two commercial Motorola Talkabout radios as well as a spare battery, cable, and external range display.

Figure 2. Laser Atlanta "Bridge Kit" [From Ref. 6]

Figure 3. Leica Vector IV [From Ref. 8]

The Naval Surface Warfare Center, Crane Division has a project funded to study procurement of laser rangefinders for the entire Navy to be used in various ship missions and amphibious operations. The project initially received $300,000 of research funding to procure as many Leica Vector IV laser rangefinders (see appendix A) for operational testing as possible. Figure 3 show a picture of the Vector IV. NSWC is seeking additional procurement funding to buy rangefinders for the entire Navy and various shore commands. [Ref. 7]

2. Communications

The fleet currently uses the sound powered phone line to communicate bridge to bridge. Both ships maintain cover on VHF bridge-to-bridge channel 16 and a safety/emergency channel pre-designated on the Replenishment At-Sea Request (RASREQ) message reply. Frequently, COs use VHF before the P/D line is rigged to brief breakaway procedures. The ships use flashing light, flag hoist, and semaphore to communicate intentions both before and during the UNREP. Signalmen generally train using flashing light and semaphore.

The only promising new technology found during the Internet search was infrared communications. This technology is still in its infancy but with further development, could be suitable for shipboard use. This technology presents no threat to ordnance or personnel, and it cannot be detected beyond line of sight. Infrared is directional and must be directed specifically at a receiver. The disadvantage of this technology is that the ocean absorbs this light spectrum, weakening the signal strength. The Navy used to have IR beacons on its ship's yardarms. The signal "Nancy Hanks" alerted the receiving ship of an incoming signal. It was not determined why they are no longer used.

In response to MTTC's Request for Quotation, Opti-Logic, Corp., which produces a handheld laser rangefinder, suggested using an infrared communicator. The major drawback is the users must point the receiver and transmitter at each other in order to transmit. The only solution is to have a paging device such as a bright flashing light or a radio beacon. The latter defeats the purpose of having a radio silent mode of communication. An optimal solution would be a mast mounted omni-directional transmitter and receiver. Multiplexing and encrypting could provide multi-channel secure communications for various other operations.

The Navy uses a wide variety of VHF and UHF hand-held radios. The newest addition to the fleet is HYDRA radios. HYDRA performed well during Smartship testing on USS Yorktown. It is expensive but interfaces well with existing systems on the ship. The Motorola XTS-3000 is already in wide use throughout the fleet and is compatible with a variety of radios such as: DC WIFCOM, SIWICS, AN/SRC-59, PVPCS, MOMCOM, and WICS [Ref. 9]. The radios can be tuned down to 20mW and up to 2W, therefore meeting HERO requirements. Another alternative, low power hand-held radios with a maximum output of .5 watts and a range of up to 2miles are available commercially from many retailers. Unfortunately, they do not meet HERO requirements.

Modifying the existing sound powered phone line configuration is another option that is highly attractive. During an underway replenishment, up to four phone lines (depending on how many stations are used) are brought across to the receiving ship. All the associated line handlers could be eliminated if all the phone lines were rigged to the fuel hoses and integrated into a single quick disconnect plug. Alternatively, a more simple option would be to double up the sound powered phone line forward and run a line up the bridge for bridge-to-bridge communications.

E. CHAPTER SUMMARY

This chapter summarized the requirements and capabilities needed to select a new method for rangefinding during an UNREP. New technologies and existing technologies provide ways to eliminate the P/D line requirement during UNREPs.

Of these technologies, laser rangefinders provide the most logical choice for a short-term replacement of the P/D line. Sonar and Infrared fixed ship systems could provide long-term future solutions for rangefinding and communications.

A list of the many models and manufacturers of laser rangefinders was provided. The models incompatible with established requirements and capabilities were eliminated. Varieties of new communication methods provide viable alternatives to the P/D line.

In Chapter III, underway testing results are presented. The testing provides valuable insight into the optimal configurations for the rangefinder, configurations that are evaluated in Chapter IV.

III. UNDERWAY TESTING

A. INTRODUCTION

To validate the use of a laser rangefinder during UNREP, an underway test was conducted to provide qualitative information about the rangefinder's capabilities, limitations, user acceptance, required procedures and maintenance, and utility is essential. McConnell Technology and Training Center received permission from NAVSEA and COMTHIRDFLT to conduct a test of a Laser Atlanta Advantage rangefinder in April 2002. Because Third Fleet has a role as the Navy's Sea-based Battle Lab, it coordinated scheduling the underway test. The author of this thesis assisted MTTC (Mr. Gilbert) during the underway test and data collection. On April 5, 2002, COMTHIRDFLT notified MTTC that the USNS Tippecanoe (T-AO-199) was assigned as the at-sea test platform for the rangefinder.

Underway testing was conducted from 22-25 April 2002, which was insightful into the limitations and optimal configurations for the laser rangefinder. The Tippecanoe's Master, Captain Bruce Butterfield, Chief Mate, and crew were instrumental in conducting valuable testing and data collection. They also provided personnel cost data and a MSC perspective on the project.

During the underway period, seven tests were conducted on the following classes of ships: LHD, FFG, DD, DDG, CG. The operational tests were conducted from a variety of locations on board Tippecanoe.

B. OBSERVATIONS

USNS Tippecanoe had two distinct advantages for use as a test platform. First, it provided a large number of UNREP observations and secondly a variety of platform sizes and shapes. The disadvantage of using a TAO is that it maintains course and does not maneuver during the UNREP. Additionally, no U.S. Naval Officers would provide feedback about the rangefinder during an approach or an alongside. To avoid test bias, the team attempted to transfer to USS John Paul Jones (DDG-53), but the ship's schedule did not support a transfer. However, the team did discover that many ships were already using inexpensive laser rangefinders.

Test data of the .5 Watt radios in the "Bridge Kit" did not occur because the team could not be transferred to the receiving ships before each UNREP. The radios have a two mile range, which is ample for separations common for UNREP.

Throughout the test, weather and sea state were typical for Southern California, with temperature highs around 65 degrees Fahrenheit and no precipitation. Sea state was approximately zero with waves less than 2 feet and minimum swells. This weather did not permit testing the limits of the rangefinder in inclement weather.

1. Day One

The team embarked the USNS Tippecanoe Monday 22 April 2002 around 1200. The author then traveled to Naval Station San Diego and talked to personnel from several ships about laser rangefinders. He discovered USS John Young (DD-973) and USS Lassen (DDG-82) use inexpensive binocular laser rangefinders for UNREP operations. The Navigator on the Lassen said, "I would say it is the norm now for ships on the waterfront to use a laser rangefinder." The Navigator went on to say her relief as Navigator told her the amphibious ship she transferred from used a laser rangefinder too. After these interviews, the author returned to Tippecanoe, which departed the fuel pier in the evening. The oiler immediately transited to the Tuesday rendezvous point west of San Clemente Island.

During the transit out of San Diego Harbor, the test team ranged a few buoys and an SH-60 helicopter. The maximum range achieved on the buoys was 2400 feet. The helicopter maximum range was 1200 feet. This demonstrated the usefulness of the rangefinders for navigation and contact ranging. A rangefinder with a night vision capability would provide even more utility for this use.

Once clear of buoy 1SD, the Tippecanoe transited to the western reaches of the Southern California Operation Areas (SOCAL OPAREA) for rendezvous.

2. Day Two

The Tippecanoe provided fuel to five ships on Tuesday 23 April, four in the morning, and one in the evening. At 0800, the Tippecanoe rendezvoused with four ships, to do two simultaneous alongside UNREPs in succession. Transfer of the test team to the receiving ships was not feasible because of the number of ships involved. The safety problems involved with personnel transfer at night eliminated the possibility of transfer for the night UNREP.

The first two ships to come alongside were USS Mobile Bay (CG-53) and USS Reuben James (FFG-57). The Master of Tippecanoe notified the ships a test team was onboard using an eyesafe laser for experiments. Mobile Bay made an approach to starboard, and the Reuben James approached to port shortly afterward. Using the rangefinder mounted on a tripod, the team ranged the cruiser at 850 yards. Using the rangefinder in non-continuous passive[3] mode, the team then removed the rangefinder from the tripod and alternated between bridgewings to range both ships as they made their approach and adjusted alongside separation. The cruiser's range was initially 300 feet and it slowly closed to 150 feet to pass lines. The frigate initially came alongside at 220 feet then closing to 150 feet when passing lines. Both ships were alongside for 6 to 10 minutes before the P/D lines were operable.

The USS Paul Hamilton (DDG-60) and the USS Fletcher (DD-992) came alongside next. At 0935, the Paul Hamilton made an approach to port and the Fletcher came alongside to starboard. Both ships were ranged reliably at about 800 yards. The UNREP was very similar to the first with 6-10 minutes elapsing before the P/D lines were operable.

The Laser Atlanta rangefinder has an accuracy of .5 feet [Ref 7]. It was hard to tell what the range was on the P/D line from the oiler, but using a binocular, the team could compare the P/D line to the rangefinder. A discrepancy of about 10-20 feet was apparent from the bridge. Since the P/D line accuracy is approximately plus or minus 10 feet, the difference was hard to determine. The difference was small if the line tenders were diligent and pulled hard to keep slack out of the line. Upon discussion, the team determined the error was the result of the inclination angle of the rangefinder when ranging the hull of the receiving ship. Using simple trigonometry, the team figured the error to be 27 feet at 200feet with a down angle of 30 degrees. Ship's roll did not affect the testing since the sea state was minimal.

[3] Passive is using the laser without a reflector.

The Paul Hamilton had seven people on the forecastle tending the P/D line. The Tippecanoe uses two Able Bodied Seamen, but they do not tend the line. They are present to release the P/D line if an Emergency Breakaway occurs.

The evening UNREP was with the USS Bunker Hill (CG-52). To maintain proficiency, a ship periodically accomplishes a night UNREP. In order to try a ranging position lower on the ship, the rangefinder was moved forward on the O1 level, just aft of the raised forecastle. This Bunker Hill was ranged when it closed to 1067 yards. The cruiser was continuously ranged until alongside. When the bow crossed the laser beam, the cruiser was at 165 feet separation. The rangefinder was aimed at 90 degrees relative to the oiler. The first line was over at 2008, but the distance line was not useable until 2021. Shortly after being set up, the 40 yard chemical light fell off the P/D line. The rangefinder was left in continuous mode and monitored hands-off for the duration of the 2 hour long UNREP.

The Bunker Hill maintained distance at 160 feet plus or minus 5 feet during the extended period without separation information. The test team wondered if the ship was able to do this with excellent conning, or if it used a laser rangefinder. Captain Butterfield asked the CO of the cruiser if they used a rangefinder; he emphatically denied using one.

3. Day Three

The ship anchored off Coronado for the duration of the day. The Tippecanoe was the designated training deck for H-60 helicopters from North Island NAS on Wednesday. The test team used the day to discuss the experiment with the MSC crew and discuss the data collected to date.

4. Day Four

The USS Boxer (LHD-4) was the first UNREP of the fourth day. Four hours was the scheduled length of the UNREP. The rangefinder was mounted on a tripod beside the aftermost stanchion of the lifeline on the raised forecastle. The longest range achieved was 1300 yards. Reliable range hits were received at 750 yards.

The Boxer initially came alongside to port at 260 feet but quickly moved out to over 300 feet. After two shotlines missed, and armed with the knowledge that the Boxer was over 300 feet, Captain Butterfield talked the Boxer in to a reasonable separation. The Boxer initially believed they were within 200 feet. The Master requested ranges via phone line from Mr. Gilbert every 30 seconds and transmitted the range via VHF bridge-to-bridge radio channel 9 to the Boxer. Finally, the Boxer got close enough to send shotlines. The P/D line was established 21 minutes after coming alongside. The UNREP lasted for about 3 hours and the rangefinder operated continuously without changing batteries.

Once lines were established, the Boxer expressed concern about the laser and its safety. The Master reassured the Boxer that it was eyesafe and aimed at the hull. This concern on the part of the Boxer demonstrates the necessity of safety guidance to the fleet if a laser is eventually adopted.

The Boxer utilized 10 linehandlers to tend the P/D line. This could have been for training or a reflection of the increased stationing distance and UNREP duration for large ships. The Tippecanoe still used two Able Bodied Seamen.

The last UNREP of the day at 1330 was with the USS John Paul Jones (DDG-53). The test team had hoped to transfer to the John Paul Jones for the UNREP to give the junior officers there a chance to try out the rangefinder and express their opinions. The ship was not heading into port Friday, so the team could not embark.

The rangefinder was placed in the same location as the Boxer UNREP. Ranging off the SPY-1 array, the laser achieved a maximum range of 1200 yards and consistent ranges at 700 yards. The destroyer made the approach to port and took station at 155 feet. She then opened to 170 feet for the rest of the UNREP. The P/D line was established in six minutes. The destroyer utilized seven P/D linehandlers. The UNREP was uneventful and lasted two hours.

This UNREP approach was the best observed, so the test team wondered if a laser rangefinder was used. During discussion with the ship's CO, he said they routinely use a small hand-held commercial laser rangefinder for UNREP operations.

5. Day Five

The ship entered the harbor in heavy rain and moored at Naval Submarine Base Point Loma at 0830. The test team debarked the Tippecanoe after thanking the Master and Chief Mate for the ship's hospitality and the valuable insight they provided. [Ref. 6]

C. CONCLUSIONS

Tables 1 and 2 list the team's significant findings. During the week of testing, the test team encountered no major problems with the laser or radios such as not being able to use the radios, not being able to take readings of a vessel, or accuracy being worse than the P/D line accuracy. The team came to several conclusions regarding the use of laser rangefinders. Most importantly, all the ships are vulnerable to collision during the 6-10 minutes they are alongside the oiler without a P/D line set up.

Error increased as the team used the rangefinder higher on the oiler. The same error would occur if used on the receiving ships. To fix this problem, an inclinometer and software modification installed on the rangefinder would correct for the inclination error [Ref. 10]. Another way to eliminate the error would be to remotely mount the laser low on the oiler, such as on the tank deck/main deck, and aim it directly across at the receiving ship's hull (zero inclination).

The Advantage rangefinder at 4.8 lbs is too heavy for handheld use by the Conning Officer during an UNREP [Ref. 11]. A couple of options could remedy this problem; use a smaller lighter rangefinder or have a waiting officer monitor the rangefinder on a tripod. Typically, three or more officers conn during an UNREP. They wait their turn to drive the ship for Officer of the Deck (OOD) qualification signatures. The officer waiting to drive the ship could monitor the rangefinder to ensure it is aimed properly without creating another evolution watchstation.

The test team consistently achieved ranges of 700 yards. This makes the rangefinder an acceptable replacement for the Stadimeter during approaches, saving the Navy the Stadimeter's maintenance and procurement costs. Additionally, the Stadimeter can typically have up to 200 yards of error or more. The laser's range capability, coupled with night vision, could provide an opportunity for other uses, such as ranging small boat contacts or docks.

U.S. Navy ships use four or more men to tend the P/D line for UNREP operations, depending on sea state [Ref. 2]. All the ships encountered for the tests used significantly more men (6-10) to tend the line. This increases the benefit of using a laser rangefinder for the cost calculation in Chapter IV. The Master of the Tippecanoe expressed his strong desire to eliminate the two men stationed on the forecastle for the P/D line. Tippecanoe is operated with 65 personnel, diverting those personnel to stand on the forecastle puts a burden on the crew especially during a double UNREP.

The remote display provided with the "Bridge Kit" worked and was visible from a distance. It is mountable on a swivel bracket that could be clamped to a variety of spots on the bridgewing. However, after discussion, the team decided the use of a billboard display on the side of the oiler would eliminate the need for the receiving ship to use a rangefinder during an UNREP. This would allow the majority of ships to use an inexpensive lightweight laser rangefinder for the approach or as a backup for the billboard display.

Phone lines were established at every station and via the P/D line. These lines were always the last things brought back to the Tippecanoe. They could not be dropped in the water like the span wire upon breakaway because the saltwater would corrode the terminals. Up to five minutes would pass by during the retrieval of these lines. The team discussed mounting the phone lines parallel to the hoses or wire rope as part of the replenishment rig. The Master told the test team the Navy was going to switch to a "Bluechip Rig" in the near future. When the Navy modifies the UNREP rigs, it could integrate two or three sound powered phone lines to each rig. One line would be for the bridge and the others for station phone talkers. A quick disconnect would allow emergency breakaways and simplify connection. The only drawback is phones will take longer to establish because the ships would have to wait for the probe to seat.

More testing must occur to determine if a fixed laser has significant error in heavy seas and ship roll. If so, a stabilized platform could be used to mount the laser. Inputs from the ship's gyro will provide input just as weapons mounts receive input. The mount for the Stabilized Glide Scope Indicator uses this type of system.

During every UNREP, the only information passed besides laser ranges was the brief of the emergency breakaway procedure. This raises a question; does the Navy need the bridge-to-bridge phone line at all? Every ship knows the sequence of events for an emergency breakaway. If an emergency should happen during EMCON in war, will the use of low power commercial encrypted radios be worth the risk? If the enemy has RF monitoring capability, they will have to ask themselves whether the received signal is a U.S. warship or a commercial vessel using commercial radios. Commercial ships frequently use these radios to communicate between watchstations.

The Advantage rangefinder's passive ranges were close to specification and the battery lasted long enough for a carrier to conduct an UNREP (greater than 4hrs). Battery swaps took about 5 seconds including a remote display cable swap. The backlight for the display allowed easy use at night. The rangefinder could not make a reading at any distance when the lenses were fogged with breath. This indicates the lenses will have to be cleaned frequently in rain and high winds, where sea spray is common.

		Distance			
		75 feet	**150 feet**	**225 feet**	**300 feet**
Method	**P/D Line**	+/- 5 feet	+/- 10 feet	+/- 12 feet	+/- 15 feet
	Laser Rangefinder	+/- .5 feet	+/- .5 feet	+/- .5 feet	+/- .5 feet
	Delta Error	**4.5 feet**	**9.5 feet**	**11.5 feet**	**14.5 feet**

Table 1. Estimated Error By Method and Distance

Ship	Maximum Laser Range	Time to Establish P/D Line and Communications	Initial Laser Range Alongside	Problems Maintaining Proper Distance Without P/D Line?	P/D Line Tenders Receiving/ Delivering Ships	Length of UNREP
CG-53	850 yards	6 minutes	300 feet	yes	6/2	1.5 hours
FFG-57	*	10 minutes	220 feet	no	6/2	1.5 hours
DDG-60	800 yards	10 minutes	170 feet	no	7/2	2 hours
DD-992	800 yards	10 minutes	190 feet	no	5/2	2 hours
CG-52	1067 yards	13 minutes	165 feet	no	5/2	2 hours
LHD-4	754 yards	21 minutes	310 feet	yes	10/2	3 hours
DDG-53	700 yards	6 minutes	155 feet	no	9/2	2 hours

Table 2. Summary of Testing Findings.

* Not Recorded

D. CHAPTER SUMMARY

This chapter summarized the observations made during the underway test period and the conclusions reached by the test team. The team encountered no major problems with the laser or radios. The laser rangefinder operated as envisioned during UNREP operations.

A minor problem occurred with placement of the rangefinder due to ship-to-ship angularity (slant range); however, it was immediately corrected by placement of the laser on a lower deck, thus eliminating the angularity.

Chapter IV will show whether implementation of laser rangefinders is a valuable investment for the Navy based on manpower considerations and material costs. It will discuss the effects replacement of the P/D line will have on MPN and OMN costs and attempt to quantify any benefits to the Navy. The cost to the Navy of various configurations will be analyzed, thus providing information for decision-making.

IV. ANALYSIS

A. INTRODUCTION

This chapter is an informational analysis of alternatives for replacing the P/D line. It will provide the benefits and costs for each alternative. An underway test provided insight into the operational benefits of using a laser rangefinder to replace the P/D line. Pricing data collected from manufacturers allowed a cost estimate to be calculated based on the number of ships involved. If a program were to be initiated, it would begin at Acquisition Milestone C, since laser rangefinders have been in production for some time.

Corporate financial managers base capital budgeting decisions for projects or investments on such things as operational research, management's judgment, awareness of the business environment, and financial tools. Some tools available to the financial manager are Internal Rate of Return (IRR), Payback Period, and Modified Internal Rate of Return (MIRR), Net Present Value (NPV), and Post Audit. [Ref. 12]

OMB Circular A-94, which applies to all agencies of the Executive Branch of the Federal Government, states that government programs should use net present value analysis to justify implementation of programs. In this method, the expected future net benefits (benefits minus costs) are discounted to the current year. This allows transactions that occur in the future to be transformed to a common unit of measurement. However, if no benefits can be monetized this method will provide no insight into the gain of social resources to society or the Navy. If NPV is not computable, other summary measures of effectiveness such as collisions prevented per dollar of cost, man-hours saved per dollar of cost, and IRR can provide insight and may be used. [Ref. 13]

B. BENEFIT ANALYSIS

The cost-benefit analysis compares alternatives having differing benefits. A cost-benefit analysis is appropriate in this thesis because each alternative has differing benefits. [Ref. 13] The benefits of using the P/D line are preventing collisions between ships during UNREP, which likely would occur if no method to determine distance were used. Purchasing laser rangefinders provides the added benefits of reducing personnel requirements and increasing available distance information and safety for watchstanders during UNREP and other evolutions.

1. Collision Considerations

The Naval Safety Center provided collision and injury information from its database that spans from 1969 to present [Ref. 14]. Collisions and personnel injuries that may have occurred from the use of the P/D line during UNREP operations were analyzed for the root cause of the accident. The data revealed that only two collisions appeared to have occurred because of insufficient distance or separation information. Based on incident reports, the CO, OOD, and Conning Officer may have misinterpreted distances or had insufficient rate of change information to make timely maneuvering decisions. The collisions that occurred cost the Navy funding for repairs to each ship. Additionally there were personnel injuries. The ensuing changes in ship schedules to accommodate the shipyard work periods created hidden costs in increased attrition, fuel, training, transportation, and readiness. These costs are as important as the material cost to repair the ships.

The first collision occurred in 1974 and cost the Navy $270,744. Adjusted for inflation to CY01 dollars this equates to $1,037,936. The collision occurred because the approach ship took station alongside too close, and it was sucked into the low-pressure area between the ships. The second collision occurred in 1994 and cost the Navy $51,600 ($60,735 CY01). This collision was caused by the inability of the conning officer to use the radian rule effectively due to incorrect or insufficient range information. Many other collisions occurred during UNREP operations but were the result of mechanical failures. The real causes are hard to determine from the information provided in the report.

2. Personnel Reduction

By far, the most important benefit to the Navy in using laser rangefinders would be a reduction of personnel required during the UNREP evolution. The Navy is trying to transform itself to a less manpower intensive service, but it historically resists implementing new technology that will reduce requirements/ manning on ships. In the life cycle of a ship, manpower is the most significant cost for the Navy. For example, on average each enlisted sailor costs the Navy $41,996 in FY02 Military Personnel Navy (MPN) dollars. Military personnel costs account for 29% of the Navy's Total Obligation Authority (TOA) and is growing. Additionally, many current labor practices that reduce quality of life (QOL), increase costs due to increased attrition and associated training of replacement personnel.

By using new technology in a variety of applications, the Navy can reduce its heavy reliance on human capital to accomplish its mission. New ships on the drawing boards are being designed to operate with requirements/ manning levels of fewer than 100 people. This cannot be accomplished if UNREP continues to require the volume of personnel it does today. Each replenishment station requires up to twenty personnel tending lines with up to another 3-5 running the station. The P/D line has up to 10 people involved. Finally, on the bridge at least ten people are on watch. Thus manning for a destroyer with three stations connected can run as high as 95 people. This would require the entire crew of one of these new ships to man just the UNREP evolution watchstations, leaving no personnel to man other ship control stations.

By instituting the use of laser rangefinders, the positions associated with manning the P/D line on the UNREP watchbill could be eliminated for both ships. Based on the number of personnel observed manning the P/D line during the week of testing, up to 12 people could be freed to accomplish other tasks during the UNREP (see figure 8 and 9 in Appendix B). This has differing implications for the supplying ship and the receiving ship. It may be tempting to count this reduction as monetary savings to the Navy from reducing shipboard personnel, but the real benefit is in increased Quality Of Life (QOL) to the sailor.

UNREP is a special team evolution as outlined in OPNAVINST 3501.311A MOB 10.2 and 10.3. This means the ship must be fully capable of conducting this evolution, but it is a special occurrence in addition to regular duties. Sailors no longer required for UNREP could accomplish maintenance they otherwise would have had to accomplish after hours. Meaning this additional available time would not constitute a reduction in manpower requirements since UNREP is an evolution. A reduction in shipboard requirements could only happen if the normal workday maintenance and watch requirements were reduced.

For Military Sealift Command (MSC), which operates most replenishment ships, manning the P/D line has a direct cost in overtime pay. The civilians who work on these ships receive hourly wages and overtime wages for hours worked over an established baseline in a pay period. Any reduction in watchstations during UNREP will reduce overtime costs since most Able Bodied Seamen and Ordinary Seamen typically work 40 to 100 hours of overtime per month.

From the USNS Tippecanoe's UNREP logbook, the ship conducted about 200 UNREPs in the last year. A conservative estimate for the average time if an UNREP is two hours each. Usually two men man the P/D line and that means that 200 UNREPS x 2 hours x 2 Seamen = 800 hours are spent manning that line each year. Since these men could be doing daily routine work if they were not involved in the UNREP, all the Unlicensed Seamen onboard would work less overtime. The MSC overtime rate for Unlicensed Seamen is $27.50 per hour. As a rough estimate, the overtime cost saved would be $27.50 x 800 hours = $22,000 for each MSC ship per year. There are 27 MSC replenishment ships, so the total saving would be $594,000 per year.

3. Safety Increases

The personnel required to man the P/D line are exposed to the elements more than any other personnel during an UNREP. On most classes of ships, the P/D line is tended on the bow of the ship. This area is exposed to more wind, sun, precipitation, and wave/ swell effects. There is a risk of frostbite and hypothermia in cold environments and being washed over the side in heavy seas. Entanglement in lines is a significant risk, if rapid maneuvering occurs during an emergency breakaway. Reduced exposure to the elements and physical injury risk means less costs to the Navy and increased QOL for the sailor.

4. Decreased UNREP Duration

By instituting laser rangefinders, the approach ship will be able to maneuver to the required distance quickly once alongside. As evidenced in Chapter III, ships without range information tend to have greater separation from the replenishment ship. The increased distance slows transfer of shotlines and messengers. During the week of testing, up to 21 minutes of alongside time was spent adjusting range so lines could be passed. With ships steaming at full power and 80 plus personnel engaged each minute is expensive.

Long after the stations were disconnected, the stations were still passing the P/D line and station-to-station phone lines back to the sending ship at the end of the UNREP. During the week of testing, up to five minutes was required to return the phone lines. If the phone lines could be eliminated, the Navy could save up to five minutes in each UNREP.

5. Increased Situational Awareness

Bridge watchstanders would benefit from increased situational awareness of distance between ships and rates of change of distance. With laser rangefinders, this would reduce risk of misinterpretation of the Radian Rule and ship separation; consequently reducing the risk of collision.

6. Maintenance Reduction

A reduction in the amount of maintenance is hard to determine. An Internal Communications Petty Officer should check the sound powered phone cable and jack for continuity problems before each UNREP. The P/D line requires setup each time it is used for UNREP and must be faked out on the forecastle with any damaged/ missing flags replaced. [Ref. 2]

The Stadimeter requires a routine preventative maintenance check that cleans, inspects, and aligns the instrument before each UNREP and extended deployment. This check requires .5 hours of work from a Quartermaster Third Class Petty Officer.

C. COST ANALYSIS

As mentioned earlier, the P/D line should not be discarded prematurely. Keeping the existing equipment may be the best value for the Navy if the marginal benefit of replacing it is not worth the cost. With the benefits of eliminating the P/D line in mind, the costs to implement a change in procedure are now estimated. Underway testing provided insight into which laser rangefinder configurations would provide the most convenient and reliable information.

1. Cost Estimates

Three alternatives to the P/D line are to 1) install a fixed laser and a billboard display on the side of the replenishment ship and give all ships a cheaper laser rangefinder; 2) give all ships a good laser rangefinder with excellent range capability that could be used for a variety of activities; 3) or develop a installed laser rangefinding system that is gyro-stabilized, like the system NAVSEA cancelled.

A gyro-stabilized system would provide visual information to the Conning Officers or to an automatic ship control system that would steer the ship to maintain a set distance. This system's cost is beyond the scope of this thesis and would require formal program development and parametric cost estimates.

Some simplifying assumptions were made regarding certain procurement and maintenance costs. For all laser rangefinders, regular lens cleaning and battery charging are the only periodic maintenance required. They need no calibration. Most commercial lens cleaning kits and rechargeable batteries cost less than ten dollars and last for hundreds of uses. Consequently, these two items were ignored because of their small relative cost to hardware procurement costs. Training for personnel using the equipment was also ignored because it will require less training than the existing systems. Life span of the rangefinder or Mean Time Between Failures (MTBF) is usually around 10 years, 100,000 uses, or 13,000 hours depending on the manufacturer (see Appendix A). For example if one figures the a oiler conducts 200 UNREP per year averaging 2 hours each, this gives a life of 13,000 hours/ 400 hours/yr = 32.5 years of life. To be conservative a life of 10 years is assumed.

It is not possible or realistic to give a precise estimate of costs for each system but that is the goal. Since the manufacturers will only provide retail prices and rough estimates of discounts, some error will be present. This will tend to make the estimates high. Many manufacturers said they would give quantity discounts of 10 to 15%. For the purposes of this research, a more conservative assumption of 10% is used. The pricing information and cost estimates in this chapter will still provide a valuable decision making tool.

a. Fixed Laser Rangefinder with Billboard Display

For this configuration alternative, a couple of options are available. First, a fixed industrial laser like the MDL ILM300 could be permanently mounted amidships with a cable either permanently routed or temporarily routed to a liferail-mounted billboard somewhere amidships. The billboard would provide range information to the alongside ship. The second option, the option favored by MTTC, would be to temporarily mount a handheld rangefinder like the Laser Atlanta Optics, Inc. Advantage model with a built in inclinometer on the bridgewing using a tripod or railing mount. Then a cable routed to a nearby liferail mounted billboard would provide the range to the alongside ship. If a ship alteration (SHIPALT) were required, the costs will increase significantly because of the labor and documentation involved. Table 4 breaks down the costs.

All equipment prices are estimates derived from retail websites or conversations with manufacturer sales representatives and are not price quotes or contract figures. Appendix A lists all model information, references, contacts, and if prices are eligible for quantity discounts.

Generally, quantity discounts of at least 10 to 15 percent are available if the Navy were to contract for the equipment. Learning curve theory states that as the manufacturer or producer doubles units produced, the productivity gains from worker learning cause costs to decrease by a certain percentage. For electronics manufacturers, the learning curve is typically 90 to 95 percent.

To arrive at the number of rangefinders needed for the Navy, the Naval Surface Warfare Center, Crane Division provided a chart (see Appendix C) that breaks down the number of laser rangefinders required per Navy ship. The total number required for all Navy ships is 616. The number required for replenishment ships is two per ship for a total of 54 based on the number of ships listed in the Naval Vessel Register [Ref. 15].

The billboard price estimates from Laser Atlanta Optic, Inc provided [Ref. 16] a developmental price for a non-military specification (MILSPEC) unit. MILSPEC is not automatically required for acquisition. Actual production prices will likely be less. Larger billboard range numbering will be preferred in the fleet because it is easier to see; therefore, the price used in the estimate is for the larger 24 inch numbering and a weatherproof unit. The captain of the replenishment ship will need to know what the billboard is displaying to the receiving ship, so a bridgewing display will also need to be installed. An estimate based on the display price for the Laser Atlanta Optics, Inc. "Bridge Kit" display was about $1000, not including installation [Ref. 9].

Installation costs for the SHIPALT are based on wages of $16.37 per hour for a welder and $21.32 per hour for an electrician [Ref. 17]. Job labor was estimated to be 2 hours of welder/ metalworker labor to mount the laser and 4 hours to mount the billboard. Four electricians over two workdays could accomplish the cabling and electrical installation. Based on the above, the installation costs would be ($16.37x6)+($21.32x64) =$1462.70. The other cost that is hidden, is the documentation and planning cost for the SHIPALT. This can be expensive. Table 3 below outlines the cost estimate for a fixed laser system.

Item	Unit price	Qty	Total
MDL ILM 300 Laser Rangefinder	$3500	2	$7000
RS 232 Data Cable	$120	2	$240
Extra Cable Length	$1/ft	1000	$1000
Billboard (24 inch numbering)	$10000	2	$20000
Bridgewing Display	$1000	2	$2000
SHIPALT Installation	$2463	1	$2463
Total Replenishment Ship Cost:			$32703
Multiplied by the number of ships:			X27
Total MSC Fleet Cost:			$882981
LTI Impulse XL200 Laser Rangefinder	$1995	616	+ $1228920
Total Estimated Cost:			**$2,111,901**

Table 3. Billboard Display Option One Cost Estimate

With a 10% discount on the rangefinders and displays, the cost to implement configuration one decreases to $1,910,709. This option will require operational testing to ensure that in heavy seas and high winds, the billboard display and the laser will be reliable and accurate.

For option two, Table 4 summarizes the major implementation costs.

Item	Unit price	Qty	Total
Laser Atlanta Advantage Rangefinder	$4295	2	$8590
RS 232 Data Cable	$55	2	$110
Billboard (24 inch numbering)	$10000	2	$20000
Total Replenishment Ship Cost:			$28700
Multiplied by the number of ships:			X27
Total MSC Fleet Cost:			$774900
LTI Impulse XL200 Laser Rangefinder	$1995	616	+ $1228920
Total Estimated Cost:			**$2,003,820**

Table 4. Billboard Display Option Two Cost Estimate

Configuration two's cost estimate, with a 10% discount on equipment, will decrease to $1,803,735. Additionally, this option could be implemented much sooner than configuration one that requires a SHIPALT to be implemented.

b. Robust Laser Rangefinders for All Ships

Based on the current operational environment and terrorism threat, the ability to use a laser rangefinder for a variety of missions like Maritime Interception Operations, navigation, small craft ranging, and many others necessitates the acquisition of a more robust longer range unit that has night vision capability. NSWC, Crane Division has a project underway that will utilize the Leica Vector IV laser rangefinder for use on all U.S. Navy ships. Mr. Brad Pridemore, the NSWC laser rangefinder project head, provided the prices from the contract and related project information. [Ref. 7] The cost estimate below is based on that information. The NSWC program cost estimates differ from Table 6 because of the differences in rangefinders required. The NSWC project has other missions besides UNREP to focus on, so the numbers of rangefinders required are different because shore detachments and commands are included.

For the purpose of UNREP, the replenishment ships will also need a rangefinder for each bridgewing, so the number of rangefinders listed in Appendix C increases by 54. Additionally, the CO of each ship will want to be able to read the range as it is shot from an external display, so the cost estimate table below lists the display cost as well as the rangefinder costs. Table 5 outlines the cost for allocating each ship with a robust rangefinder.

Item	Unit price	Qty	Total
Leica Vector IV	11000	670	$7,370,000
External Display	1000	670	$670,000
Total Estimated Cost:			**$8,040,000**

Table 5. Robust Laser Rangefinder Cost Estimate

2. Analysis of Alternatives

After estimating the benefits and costs, a NPV analysis of alternatives would typically be conducted to determine the best alternative in accordance with OMB Circular A-94, but since benefits cannot be monetized, a NPV analysis is not possible. The NPV of benefits minus costs would be negative with every alternative for this thesis. The best option for analysis is to calculate a cost estimate for each alternative and divide man-hours saved by the cost to get a summary measure of each alternative. Then a subjective decision must be made by the naval leadership as to whether the increase in cost is justified by the benefits gained.

Based on the above cost estimates for each alternative, the most man-hours saved per dollar would be more for the fixed system or temporary billboard system than buying robust laser rangefinders for each ship. The difference is based primarily on the cost of the Leica Vector IV laser rangefinder.

D. COMMUNICATION ALTERNATIVES ANALYSIS

In order to implement laser rangefinders throughout the fleet, an alternative to the bridge-to-bridge communications function of the P/D line must be addressed. From Chapter II, the options available are IR communication, low power radios, or modified sound powered phone line setups.

If Emissions Control and Hazardous Electromagnetic Radiation to Ordinance restrictions are not loosened, the only options the Navy has to allow implementation of the laser rangefinders is to either eliminate the requirement for bridge to bridge communications during radio silence, modify the phone lines configuration, or to start a more costly IR system program.

1. Alternatives

Based on requirements and capabilities discussed in Chapter II, the only alternatives for communications are to 1) modify the station to station sound powered phones configuration, 2) eliminate radio silence restrictions during UNREP to allow low power handheld radios to be used, 3) install a fixed IR communications system, 4) or eliminate the bridge to bridge communications requirement during radio silence.

2. Benefits

Enabling the elimination of the P/D line generates all the benefits discussed earlier, but there are benefits to each communication option.

a. Modify Station to Station Phones Configuration

There are two options for changing sound powered phone line configurations. Option one involves consolidating the P/D phone line and station to station lines into one line by binding the lines into one larger line by wrapping them in tape or insulation and running connecting lines to the bridge and other stations. This option would allow the communications between ships to be radio silent while eliminating six to ten line tenders. This option may require some internal communication system modifications.

The second option is to modify the replenishment rigs to attach four sound powered phone lines to the rigs. A quick disconnect connection by the probe or traveler would allow for fast connections and emergency disconnect. The four lines would provide connectivity between each station and the bridges. The benefits are eliminating the P/D line and station-to-station phone line tenders. Further research into the hardware modification would be needed before this option could be pursued.

b. Use of Low Powered Handheld Radios

The only way to use low power commercial handheld radios is to loosen or eliminate the radio silence restriction for UNREP operations during EMCON. During the time the ships are alongside without phone lines, they usually communicate with VHF handheld radios. Radios like the Motorola XTS3000 are capable of transmit powers as low as 20 milliwatts.

By using radios, the bridge personnel have continuous communications, even before lines are over. During EMCON, use of radios could be restricted to emergency use only. This would allow elimination of the P/D line without significantly affecting the tactical advantage provided by EMCON.

c. Infrared Communications System

If IR communications became a reality, the benefits would allow P/D line elimination as well as allow all stations and ships to communicate during EMCON radio silence. Flag, flashing light, and semaphore signaling could be replaced with secure voice over a variety of frequencies. IR voice communicators already exist in commercial form.

d. Eliminate Communications Requirement

During the week of underway testing, the only information requested by the receiving ship besides the emergency breakaway procedure briefing was the laser ranges. During an emergency, the communication of maneuvering intentions and communication of problems would be important, but the most important signal is the emergency breakaway signal. If the requirement for communicating between bridges were eliminated, the P/D line could be eliminated.

3. Cost Estimates

With the exception of researching and developing an IR communications system, all the options are very inexpensive compared to the laser rangefinder implementations costs.

a. Modify Station to Station Phones Configuration

The cost to accomplish these two options is difficult to determine without further study. If the lines are banded or wrapped together in the first option, Internal Communications Petty Officers could accomplish the work in a few hours. Some phone line might need to be purchased.

For option two, MSC or contractors would need to accomplish the work and it would be more expensive. Manufacturing the quick connections could be expensive if they had to be designed and fabricated. However, this option is still much less costly than researching and developing a completely new system.

b. Use of Low Powered Handheld Radios

Appendix A lists the models and purchase prices of radios that could be used for this alternative. The Motorola XTS3000 is used by the military and is compatible with many radios already in use in the fleet today. It meets the new DOD-

LMR Policy that urges compliance with APCO Project 25 land mobile radio standard [Ref. 18]. The radios are very flexible, waterproof, and sturdy. Table 6 lists the implementation costs in this alternative for the XTS3000 and a cheaper Family Radio Service (FRS) radio. The quantity involved assumes that two radios will be needed per Navy ship and three per MSC ship. Each ship will have a backup radio (3 and 4 radios respectively).

Radio Model	Price	Quantity	Total Cost
Motorola XTS3000	$2826	692	$1,955,592
Motorola T6310	$130	692	$89,960

Table 6. Low Power Radio Cost Estimate

c. Infrared Communications System

The cost estimate for this alternative cannot be calculated since this alternative requires a formal program, research, and development. It is beyond the scope of this research. The administration, research, development, testing, and evaluation make this option much more expensive than the other options considered here and the time required to field an acquisition program could take over ten years.

d. Eliminate Communications Requirement

This alternative has little or no cost since it only requires a change in procedures and policies. There may be some documentation and administrative costs involved, however, they would be part of Navy overhead costs.

4. Analysis of Alternatives

The easiest and cheapest method of replacing the communications function of the P/D line is to drop the requirement, but that option is not safe, modifying the station-to-station phones configuration is the next best option. If testing proves that modification is not safe or physically possible, the use of low power radio is the next best option. For less than $2 million all of the radios required could be purchased for the fleet.

E. CHAPTER SUMMARY

This chapter presented the relevant benefits and calculable costs for the various alternatives to the P/D line. Costs and benefits were derived from information presented in Chapters II / III and from and various price and cost sources. A Net Present Value analysis could not be calculated, but insight into this investment's cost effectiveness was gained from the cost estimates and non-monetary benefit measures.

For a modest investment, the Navy could reap some major benefits in increased situational awareness, safety, and reduced manning. In Chapter V, the findings presented in this chapter and from earlier chapters will form the basis of some recommendations about how to implement laser rangefinders and reduce the risk of implementing the new investment.

V. RISK REDUCTION AND RECOMMENDATIONS

A. INTRODUCTION

The Chief of Naval Operations in his guidance letter to the fleet says, ”We will achieve future warfighting effectiveness through transformational technologies, innovative operational concepts, and robust procurement.” Using transformational technologies like laser rangefinders is a step in the right direction towards that goal.

Chapters III and IV showed that laser rangefinders can be a cost effective investment for the Navy. This chapter will discuss the best ways to implement and reduce the risk associated with the new investment. Funding alternatives are discussed along with research areas that need further investigation. With a little extra research, Underway Replenishment could be simplified, requiring less human capital and risk.

B. RISK REDUCTION

1. Program Risk

Whenever any organization such as a corporation or the Navy pursues a new investment, the managers involved must seek to mitigate risk and uncertainty. This research is one step in the process of reducing risk. Implementing the use of laser rangefinders is no different than other investment decisions.

This project is based on mature technology, therefore should start at acquisition milestone C to be completed within a couple of years. Prolonging the project risks cancellation and spiraling costs. Currently ships are funding their own purchases of inexpensive sportsman laser rangefinders that have not been formally tested. A decision on implementing lasers cannot wait any longer. More ships are going to realize that others are using lasers and will seek to by them. The procurement burden for new equipment should not be borne by the ships.

Because UNREP procedures have not changed in many years, there will be resistance to change in the chain of command and on the deckplate level. Employees in every organization resist change and if a project is going to succeed, it must have a management champion.

2. Implementation Risk

To reduce risk to ships, all recommendations in this research must be thoroughly tested at sea in all types of sea state and weather conditions. The underway testing was in ideal conditions and further research into the effects of sea spray, sea state, precipitation, laser location, and user knowledge level must be conducted. Ship's roll and laser placement will be significant factors in the success of fixed laser applications. If the laser is not pointing at the hull across from the replenishment ship, the range will be incorrect. Based on the operational testing, a fixed laser mounted amidships on the replenishment ship should provide the best ranges for all lengths of vessels. Lens cleanliness will have to studied to determine the effects of sea spray and condensation. A simple laser hood that protects the lens may be the answer.

Future tests conducted with junior officers at sea will be critical in addressing any user interface issues. This study was unable to determine junior officer comments on the ease of use and their opinions about using laser rangefinders. Billboard readability and external display readability will be important to the Commanding Officers in the fleet.

Concern with laser safety is another issue that must be addressed through education of the fleet and support from a project champion. The Food and Drug Administration regulates the classification of lasers. Many older military lasers were Class II or III lasers which are harmful to eyes because of the power requirements needed to give them longer range. With the new laser technology, long ranges are achieved with Class I eyesafe lasers. The fleet has to be made aware of the differences in lasers. The Boxer's concern during the UNREP about a laser's safety will be commonplace if lasers are introduced to the fleet.

New communication methods should be tested to ensure ease of use and safety. Testing will also mitigate deckplate resistance to changing the rigging or sound powered phone setups. Afloat Training Groups will have to be involved to ensure proper training is occurring once new equipment and procedures are in place.

C. RECOMMENDATIONS

The recommendations herein are based solely on a single underway testing period and the cost analysis in Chapter IV. Further testing of lasers and communications are required during research and development to assess operational feasibility during a variety of conditions.

1. Laser Rangefinders

Based on observations and a discussion with NSWC Crane Division, each ship should receive a long range, lightweight laser rangefinder with night vision capability that can be used for UNREP as well as a variety of mission areas including, Visit Board Search and Seizure (VBSS), ship self defense, force protection/ anti-terrorism, navigation, small boat operations, and docking. A modest investment will provide enhanced station-keeping and ship safety.

Each replenishment ship in the MSC inventory and Navy inventory should receive a fixed or handheld laser rangefinding system connected to a large billboard range display for receiving ships. This will eliminate the need for Conning Officers or other personnel on the receiving ship's bridge to monitor or hold a rangefinder during a UNREP. All personnel will be aware of the range, including UNREP station personnel. The billboard ranges would be available as soon as the hull of the receiving ship crosses the beam of the fixed laser. Testing will indicate if a gyro-stabilized base is required for fixed systems during heavy seas. Care should be taken to assure readability of the billboard by receiving ships. Placement of the billboard would probably need to be amidships.

2. Communications

To replace the communications capability of the P/D line, the feasibility of combining or wrapping sound powered phone lines together should be investigated immediately. This will allow an interim solution while a longer-term solution is decided. When the Navy starts implementing new rigs as part of its effort to improve load capacities and allow containers, it should integrate electric or sound-powered phones into the rig. Based on operational and EMCON considerations, using commercial radios should not be pursued at this time. Initiation of an IR communications system program should be studied.

3. Funding alternatives

Funding for laser rangefinders and a new method for bridge-to-bridge communications should not wait any longer than necessary. Whichever program office receives tasking for research and development, it should accelerate implementation of this project. Funding should be inserted in the Fiscal Years Defense Plan and Planning Programming and Budgeting System immediately for FY03, or should an insert fail, FY04.

D. AREAS FOR FURTHER RESEARCH

During the week of operational testing it was observed that most tended lines were manned by 20 personnel on the receiving ship of which at least five persons did not appear to be effective or required. The USNS Tippecanoe's Master explained that many foreign vessels use electric capstans to haul in the messengers. He also said those ships were able to seat the probe easily compared with U.S. Navy ships. Installation of electric capstans would eliminate the majority of the personnel involved in UNREP operations.

The Master also mentioned a new rig called the "Blue Chip" rig. He explained that this rig is essentially the same as the one the Navy already uses, but instead of sending the end of a messenger line, the replenishment ship sends a bite of line (the middle of the line). This allows the replenishment ship to take the line to power and haul the probe over to the receiving ship with its own winches. No personnel are required to tend lines except to haul the bite of messenger over and insert it into the snatch block. A snatch block is a large pulley that has a side that opens to allow inserting line.

IR communications and sonar rangefinders definitely require further study to determine technical feasibility. If these systems are developed, ships can communicate via many channels without fear of detection from sensors beyond the line of sight and determine range. These systems have application potential in littoral warfare and special operations.

E. CHAPTER SUMMARY

Based on the research in this study, recommendations for implementing laser rangefinders were presented. With further testing and research, the Navy can implement a near-term solution, which requires a small investment. This investment would allow a reduction in manning during UNREP evolutions and supports transformational change in the Navy. Further areas of study were presented that involve improving UNREP and logistical readiness for future naval forces.

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APPENDIX A: LASER RANGEFINDER MODEL INFORMATION

Model Information													Procurement Information				Maintenance Information		
Manufacturer	Model	Weather-proof	Data Cable	Inclinometer	Optics	Eyesafe	Range	Weight	MTBF	Battery Life	Meets Req./Cap.	Email/ Phone #	Unit Price	Qty Discount	Batteries	Cables/ Bridge Display	Cleaning	Calibration	Reference
Bushnell	Yardage Pro 1000	Resistant	No	No	6x	Class I	1000 yds	383 g	UNK	UNK	No	Retailer	$320	Yes	9 V	NA	$10	No	[Ref. 19]
Nikon	Buckmaster Laser 800	Resistant	No	No	8x	Class I	800 yds	270 g	UNK	UNK	No	Retailer	$300	Yes	4x AAA	NA	$10	No	[Ref. 19]
LTI	Mariner	Yes	Yes	No	1x	Class I	300 m	4.5 lbs	UNK	UNK	Yes	800-790-7364	Did Not Respond				$10	UNK	[Ref. 20]
LTI	Impulse 200 XL	Yes	Yes	Yes	3-9x	Class I	2200 m	2.2 LBS	UNK	20 hrs	Yes	Marcus 800-432-6248	$1,995	Yes	2x AA	UNK	$10	No	[Ref. 21]
Opti-Logic	600XL	Yes	Yes	Yes	UNK	Class I	600 yds	12 oz	UNK	UNK	Yes	931-454-0897	$400	Yes	9V	With RS232, IR communicators, and display: <$2500	$10	No	[Ref. 22 and 23]
Laser Atlanta	Advantage	Yes	Yes	Yes	1x	Class I	2000 ft	4.8 lbs	UNK	2-3 hrs	Yes	770-446-3866	$4,295	Yes	6 V	With display and commercial radios<$4500	$10	No	[Ref. 9 and 24]
Litton	Mk VII	Yes	Yes	Yes	7.3x	Class I	20 km	4.2 lbs			Yes	Bob Raulerson 407-297-4552	Did Not Respond				$10	UNK	[Ref. 25]
Litton	ESL 200	Yes	Yes	Yes	7x	Class I	9995 m	4.08 lbs			Yes	above	same				$10	UNK	[Ref. 25]
Litton	AN/PVS-6 (MELIOS)	Yes	Yes	Yes	7x	Class I	9995 m	4.08 lbs			Yes	above	same				$10	UNK	[Ref. 25]
Hilti	PD25/20	No	Yes	No	None	Class II	300 ft	UNK	UNK	4000 measure-ments	No	Retailer	UNK	UNK	2 AA	UNK	$10	UNK	[Ref. 26]
Leica	Viper/ Vector IV	Yes	Yes	Yes	7x	Class I	4000 m	1.71 kg	13,000 hrs	6000 measure-ments	Yes	Morris 703-404-0335 (AIGINT@aol.com)	$11,000	Yes	$9	UNK	$10	No	[Ref. 7]
Leica	Disto Pro	No	Yes	No	NA	Class II	330 ft	.44 kg	UNK	3000 measure-ments	No	Keith 720-235-4301 (keith.lantz@leica-lsg.com)	$675	10%	4 AAA	UNK	$10	No	[Ref. 27]
MDL	LaserAce 1000	Yes	Yes	Yes	6x	Class I	1000 m	1.45 kg	10 yrs	4-6 hrs continuous use	Yes	Meredith 281-646-0050 (mrhodes@cyberhouse.com)	$9,900	Yes	6 AA	$120+ $3 per meter extra	$10	No	[Ref. 28]
MDL	LaserAce 300	Yes	Yes	Yes	UNK	Class I	300 m	.6 kg	7 yrs	4-6 hrs continuous use	Yes	above	$2,730	Yes	2 AA	$120+ $3 per meter extra	$10	No	[Ref. 28]
MDL	ILM 300	Yes	Yes	No	NA	Class I	300 m	NA	10 yrs	Hard Wired	Yes*	above	$3,500	Yes	NA	$120+ $3 per meter extra	$10	No	[Ref. 28]
Eloptro	LH-40	Yes	Yes	No	6x	Class IIIA	20000 m	<1.6 kg	100k uses	400 measure-ments	Yes	27 11 921 4117	$13,000	UNK	8 AA	UNK	$10	No	[Ref. 29]
Eloptro	LP-16	Yes	Yes	NA	NA	Class IIIA	20000 m	<1 kg	100k uses	NA	Yes*	above	$12,000	UNK	NA	UNK	$10	No	[Ref. 29]

Billboard

Manufacturer	Model	Weather-proof	Min. Power	Power	Range	Meets Req./Cap	Email/ Phone #	Unit Price	Qty Discount	Reference
Unkown	8 IN Digits	Yes	NA	120V	300 ft	?	770-446-3866	$5,000	Yes	[Ref. 16]
Unkown	24IN Digits	Yes	NA	120V	1000 ft	Yes	Above	$10,000	Yes	[Ref. 16]

Radios

Motorola	XTS3000	Yes	20mW	NA	6 mi	Yes	NA	$2,826	Yes	[Ref. 9]
Motorola	Talkabout T6310	Yes	.5W	NA	2 mi	No	NA	$130	Yes	[Ref. 9]
ICOM	IC-GM1500	Yes	.8W	NA	2 mi	No	NA	$850	Yes	[Ref. 30]
ICOM	IC-4008A	Yes	.5W	NA	2 mi	No	NA	$85	Yes	[Ref. 30]

Table 7. Manufacturer, Model, and Pricing Information

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APPENDIX B: FIGURES

This appendix presents pictures taken during the underway testing by McConnell Technology and Training Center's representative Mr. Gilbert and the author.

Figure 4. Rangefinder setup on forecastle with LHD-4 alongside from [Ref. 6].

Figure 5. Twenty minutes after LHD-4 crossed the T-AO 199 stern with rangefinder providing continuous data [From Ref. 6].

Figure 6. DDG-53 Alongside with P/D line and rangefinder in foreground.

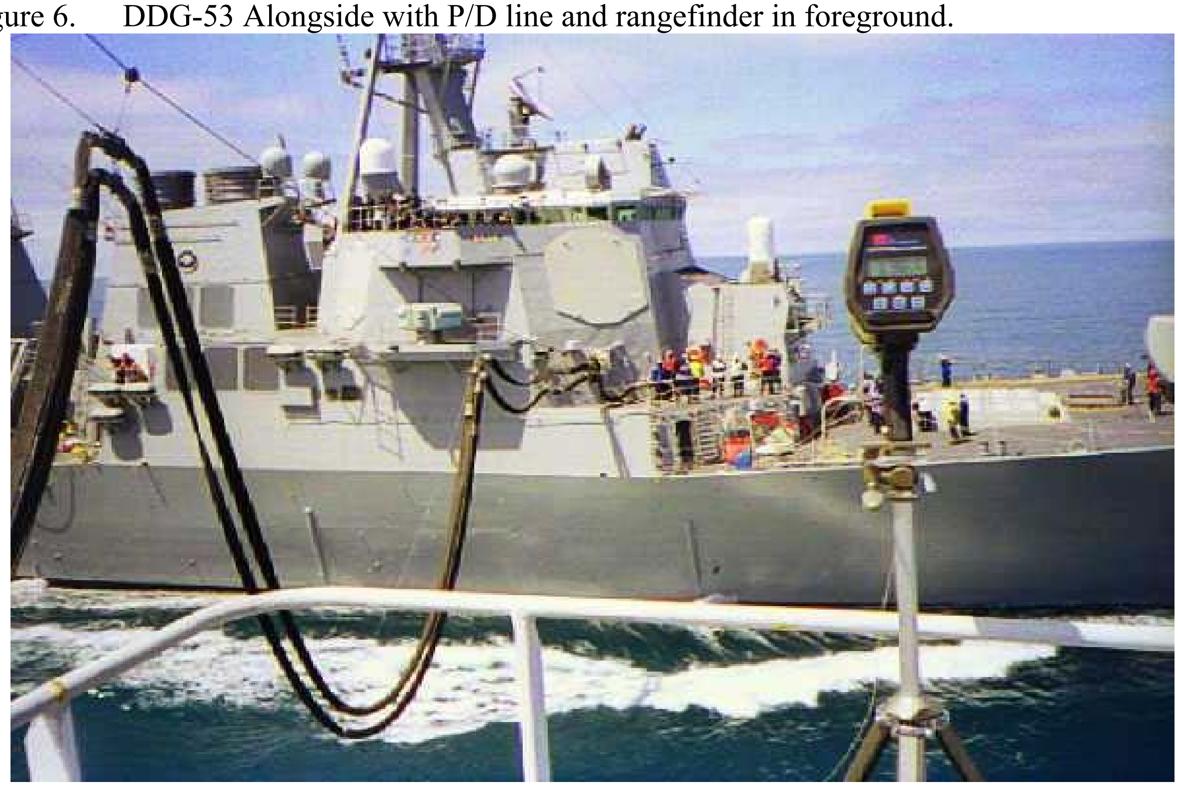

Figure 7. DDG-53 alongside with rangefinder in foreground [From Ref. 6].

Figure 8. DDG-53 P/D line tenders at work.

Figure 9. T-AO 199 P/D line tenders at work.

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APPENDIX C: NAVAL SURFACE WARFARE CENTER PROJECT SLIDE [FROM REF. 13]

NAVSEA
NAVAL SEA SYSTEMS COMMAND

SWNVEO Program Brief

Allowances Per Ship Class (As Validated)

- N42 CDR J. Brooks
- N75 LCDR R. James
- N76 CDR S. Swicegood
- N77 CDR B. Inaba
- N78 CDR B. Cullen

NVEO Equipment	Name	AOE	LHA	LPD	LSD	LHD	LST	MCM	MHC	MCS
Laser Rangefinder	Laser Rangefinder	2	4	4	4	6	4	2	2	2
	Number of ships in class	8	6	11	15	6	2	14	12	1
	Total Required per class	16	24	44	60	36	8	28	24	2

NVEO Equipment	Name	LCC	CG	DD	DDG	FFG	AGF	ARS	SSBN	SSN	AS	CV/CVN
Laser Rangefinder	Laser Rangefinder	4	2	2	2	2	1	1	1	1	1	4
	Number of ships in class	2	27	24	27	37	2	3	18	63	2	12
	Total Required per class	8	54	48	54	74	2	3	18	63	2	48

Total Requirement: 616
Total Funding Required: $6.8M

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