Operator Task Analysis of a Shipboard Electronic Warfare System

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(ABSTRACT)

The goal of this work was to evaluate an electronic warfare system from a human factors engineering perspective. The evaluation began by looking at the top level system requirements and included a functional analysis of critical components of the man-machine interface. Once a critical operator task was identified, two separate trade-off studies provided objective data for redesign recommendations.

The first section of this work defines the operational requirements and maintenance concept for an electronic warfare system. This is the first step in defining the human interface requirements for the system.

The second section provides a brief history of the U.S. Navy's AN/SLQ-32(V) Electronic Warfare System. Although recognized as an

integral part of the U.S. Navy's defense against low-flying anti-ship missiles, several incidents indicate a need for system improvement.

The next section of this work defines the AN/SLQ-32(V). The definition starts from a macro-level and, then, discusses the system to the level necessary to understand the system. The goal was to conduct and document a task analysis of the interface between the operator and the AN/SLQ–32(V). This task analysis was used as a tool to compare system redesign options.

The final section of the work involved the acquisition of information from naval operators and the assessment of existing system design features from actual and simulated Display Control Consoles (DCC). The critique of these data considered operator task requirements in actual and simulated electronic warfare scenarios. This included the time required to detect, analyze, and act-upon radar intercepts in anti-ship missile defense. From this evaluation, recommendations were developed and justified for DCC system design changes.

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To my loving wife Sharon, who put up with me on a daily basis and supported me all the way during my graduate school activities.

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GLOSSARY

AECM (Active Electronic Countermeasures) - Electronic countermeasures involves active radio frequency (RF) radiation. This includes the broadcast of electronic signals to confuse or negate the capabilities of hostile forces.

AEGIS - A system of complex radar, computers, missiles, and missile control systems developed to improve ship air defense capabilities.

AEW (Airborne Early Warning) - System with the ability to monitor the airspace and control combat resources.

AN/SLQ-32(V) - A passive system that receives radio-frequency energy and can detect and analyze signals from any bearing surrounding the ship. The system provides identification of energy sources and the bearing to the source from the ship.

AWACS (Airborne Early Warning and Control System) - U.S. Air Force system with the ability monitor potentially hostile airspace and control friendly combat resources. The airframe currently used is the modified Boeing 707-320B.

CIC (Combat Information Center) - Area on-board ship that contains the command and control functions and equipment needed to operate and identify threats to the ship.

DCC (Display Control Console) - Portion of the AN/SLQ-32(V) where the operator interfaces with the machine. The principle operator input/output devices of the DCC consist of a cathode–ray tube (CRT) visual display, light emitting diode (LED) auxiliary indicator display, an alphanumeric keyboard, and assorted fixed–action function keys.

ELINT (Electronics Intelligence) Number - Number assigned to a specific electromagnetic radiation.

ESM (Electronic Support Measures) - A part of electronic warfare involving actions taken to search, intercept, locate, and identify radiated electromagnetic energy for the purpose of immediate threat recognition.

EW (Electronic Warfare) - Military action involving the use of electromagnetic energy to determine, exploit, reduce, or prevent hostile use of the electromagnetic spectrum.

EW Supe (Electronic warfare supervisor) - The EW Supervisor often operates the NTDS console which is located beside the EW operator in the CIC. The EW Supe also monitors all EW activity on-board ship.

LORA (Level of Repair Analysis) - Analysis used to establish a least-cost maintenance policy and to influence design in order to minimize logistic support cost.

LSA (Logistics Support Analysis) - Analytical process used to establish the necessary logistic support for a new system.

NTDS (Naval Tactical Display System) - A computerized system linking consoles, ships, and aircraft for processing and sharing of tactical data.

O-Scope (Oscilloscope) - An electronic instrument that produces an instantaneous visual display on a CRT screen representing time-varying voltage signals.

RF (Radio Frequency) - Coherent electromagnetic radiation energy at frequencies from 100 hertz to 100 gigahertz.

Sea Trials - Period of time when a group of sailors and a ship perform training exercises as a fighting unit.

Soft Kill - The rendering of a weapon harmless to an intended target through the use of non-destructive EW techniques.

Standard Missile - U.S. Navy missile used to defend ships against anti-ship missiles.

Super RBOC (Super Rapid Bloom Off-Board Chaff Launchers) - The chaff cartridge launching system used with the AN/SLQ-32 Countermeasures set.

TAO (Tactical Action Officer) - The senior naval officer in command of tactical operations for a particular ship or battle group.

ULQ-16 - Spectrum analyzer used with the AN/SLQ-32(V) to give an EW operator additional information about the parameters of a given emitter.

I. INTRODUCTION

The goal of this work was to evaluate an Electronic Warfare (EW) system from a human factors engineering perspective. The evaluation examined the top level system requirements and included a functional analysis of critical components of the man-machine interface. Once a critical operator task was identified, two separate trade-off studies provided objective data for redesign recommendations.

II. BACKGROUND

2.1 Development of System Requirements

A major part of this project was to document the activities of an EW operator in the performance of a portion of his task, examine several different methods to accomplish the task, and then to make recommendations for redesign. Figure 1 shows the general methodology used in this project (Blanchard, 1992).

Human factors requirements in design were derived initially from system operational requirements and the system maintenance concept. A description of the operator's mission was an essential first step in the requirements definition process. Based on this information, a functional analysis was accomplished in which operator and maintenance functions were identified. Analysis of system requirements was a prerequisite for determination of system

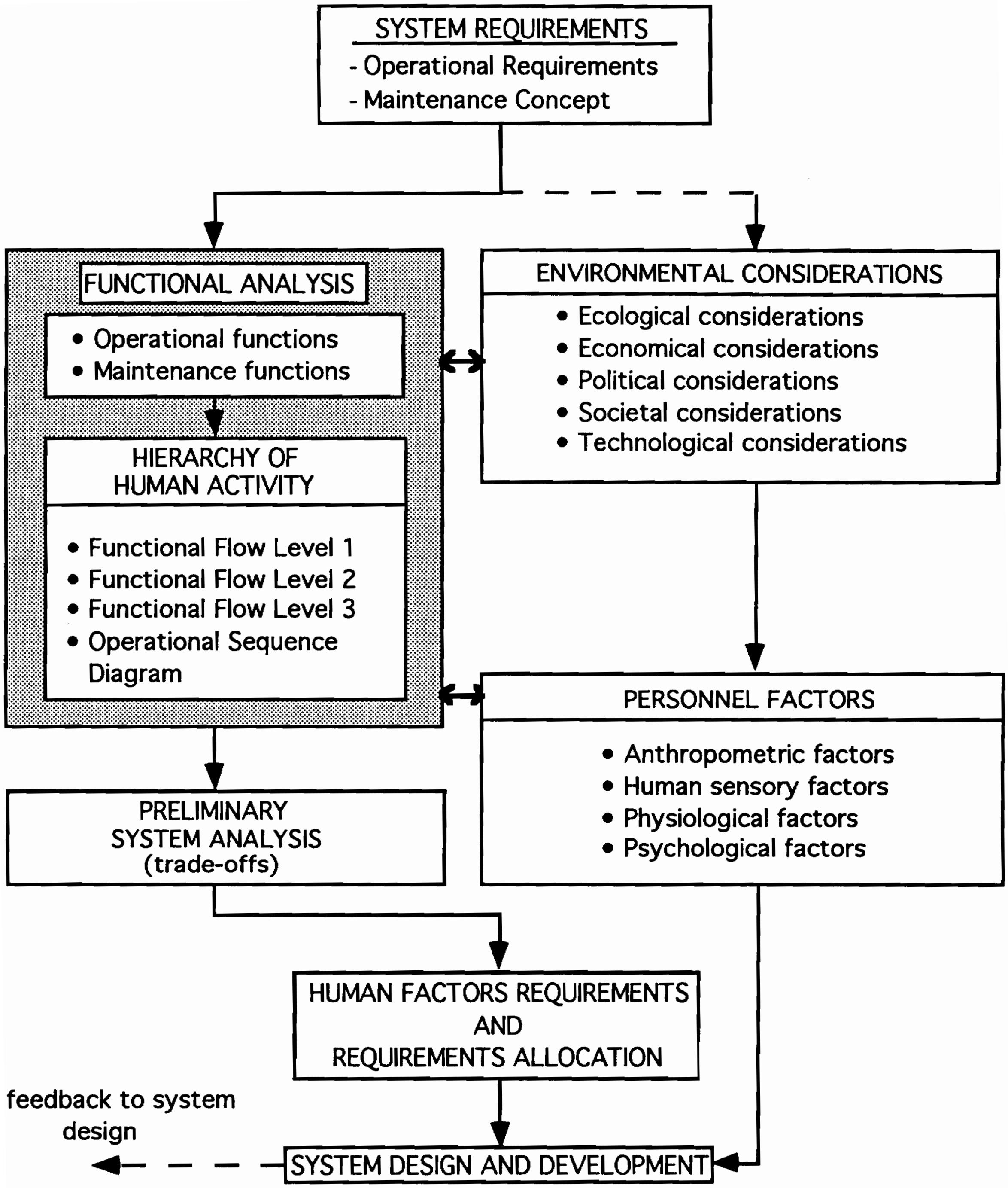


Figure 1. Overview of methodology employed in project.

functions, since these functions are inherent in and derived logically from requirements (Meister, 1985).

Top level function descriptions are general in nature. Although these descriptions give helpful insight into the system, the definition of human factors requirements often dictates a lower level breakdown of functions. This report documents three levels of a functional flow diagram for a specified portion of the operator's task. Once the hierarchy of human activities reaches the third level, the operational sequence diagram was used to show the detail necessary to make the necessary assessments.

2.1.1 Operational Requirements

2.1.1.1 Mission Profile. A mission profile is a graphical or pictorial model of the mission that a system is expected to perform. If a system has several missions, it is necessary to draw individual profiles for each mission. A mission segment is a typical time period in the system profile (Meister, 1985).

Figure 2 shows the mission profile of a nuclear-powered cruiser with regularly scheduled six month deployments.[1] Table 1 shows a breakdown of system mission profile and operating hours. This information is essential to the system designers to determine the logistics requirements for the system.

[1]USS Virginia shipboard visit, 6 Dec 1991.

Table 1. System Mission Profile and Operating Hours

1. Mission Scenario	Percent of Life
Operations	71
Maintenance and Calibrations	23
Training	6

2. Operating hours for one system during an 8.5 month cycle	
Sea Trials	24 hours/day x 15 days
Deployment	24 hours/day x 30 days/month x 6 months
Maintenance	8 hours/day x 5 days/week x 8 weeks

3. Total operating time during an 8.5 month cycle = 5000 hours

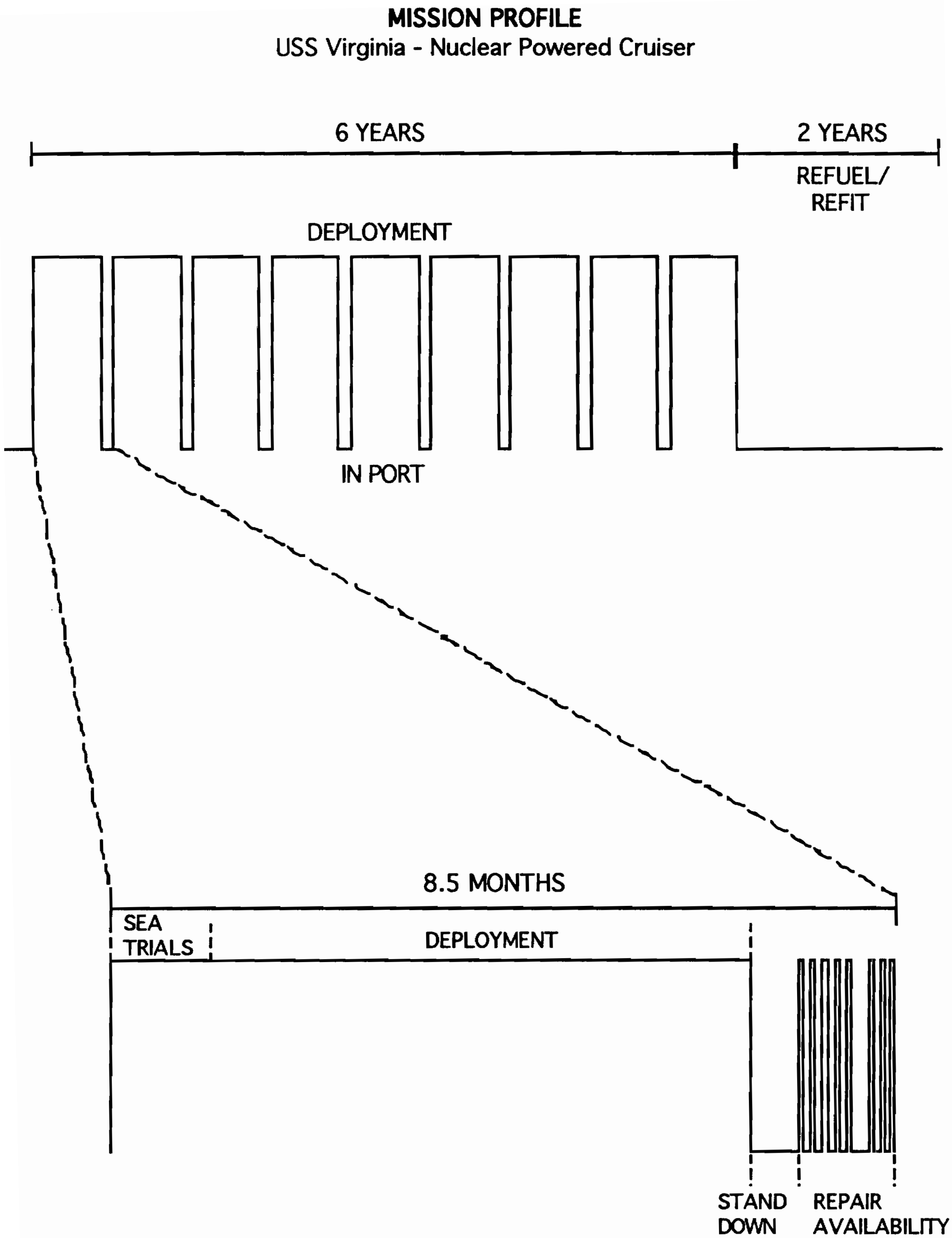


Figure 2. Mission profile of a CGN Guided Missile Cruiser.

2.1.1.2. Physical Parameters. The AN/SLQ-32(V) Display Control Console (DCC) meets the following dimensions (NOSC, 1 April 1991):

- -Height 60"
- -Width 26"
- -Depth 24"
- -Weight 550 pounds

2.1.1.3 Power Consumption. When the DCC is powered on, it consumes no more than 2000 Watts of electrical power. When the system is switched off, the console consumes no more than 200 Watts of electrical power. The DCC is equipped with anti-condensation heaters that are separately fused and switched. The heaters are switched off automatically when the console is switched on.

2.1.1.4 Operational Life Cycle. Current hardware is expected to remain on ships until the year 2020. New systems will be manufactured until 1993, and they will have an expected operational life cycle of 27 years.

2.1.1.5 Environmental Protection. The DCC is designed to meet the following militarized performance requirements (Gumble, 1988):

a. Shock: Capable of withstanding the following shock for a duration of 11 milliseconds : a) During operation - 20g+. b) In non-operational mode - 30g+

b. Vibration: Capable of withstanding vibrations from 4 Hz to 50 Hz.

c. Temperature: Can meet all performance requirements within temperatures range 0 to +50 degrees centigrade. Also, can withstand temperatures from -62 to +71 degrees centigrade when in a non-operational status, and return to operational mode and meet all performance requirements within 30 minutes.

d. Humidity: Meet all performance requirements after exposure to relative humidity of 95%, for both continuous and intermittent periods. This includes both the operational and non-operational state, including conditions where condensation results from either water or frost.

e. Fungus: Fungus resistant in both operational and non-operational states.

f. Salt Spray: The unit is sealed and is capable of withstanding salt fog and spray conditions.

g. Blowing Dust: Capable of withstanding the effects of blowing dust.

h. Pressure: Meets full performance requirements when operated over the range of pressures from -250 to +250 millibars with respect to ambient pressure.

i. Inclination: Is fully capable of meeting the full range of performance requirements when inclined. The maximum angle tested for the console is 60 degrees from horizontal for both operations and maintenance.

2.1.2 Maintenance Concept

The system uses a maintenance concept consisting of three levels: Organizational (O), Intermediate (I), and Depot (D). Organizational maintenance is performed by trained shipboard personnel, but no detailed electronics work on intricate parts is conducted. There is a small amount of intermediate level maintenance performed on the system. Depot repair is performed at either a Navy depot or at the contractor's facilities. Exact O, I, and D level maintenance tasks and procedures are determined by a Logistics Support Analysis and a Level of Repair Analysis. The relationship between the maintenance levels is shown in Figure 3, Maintenance Concept (Blanchard, 1990).

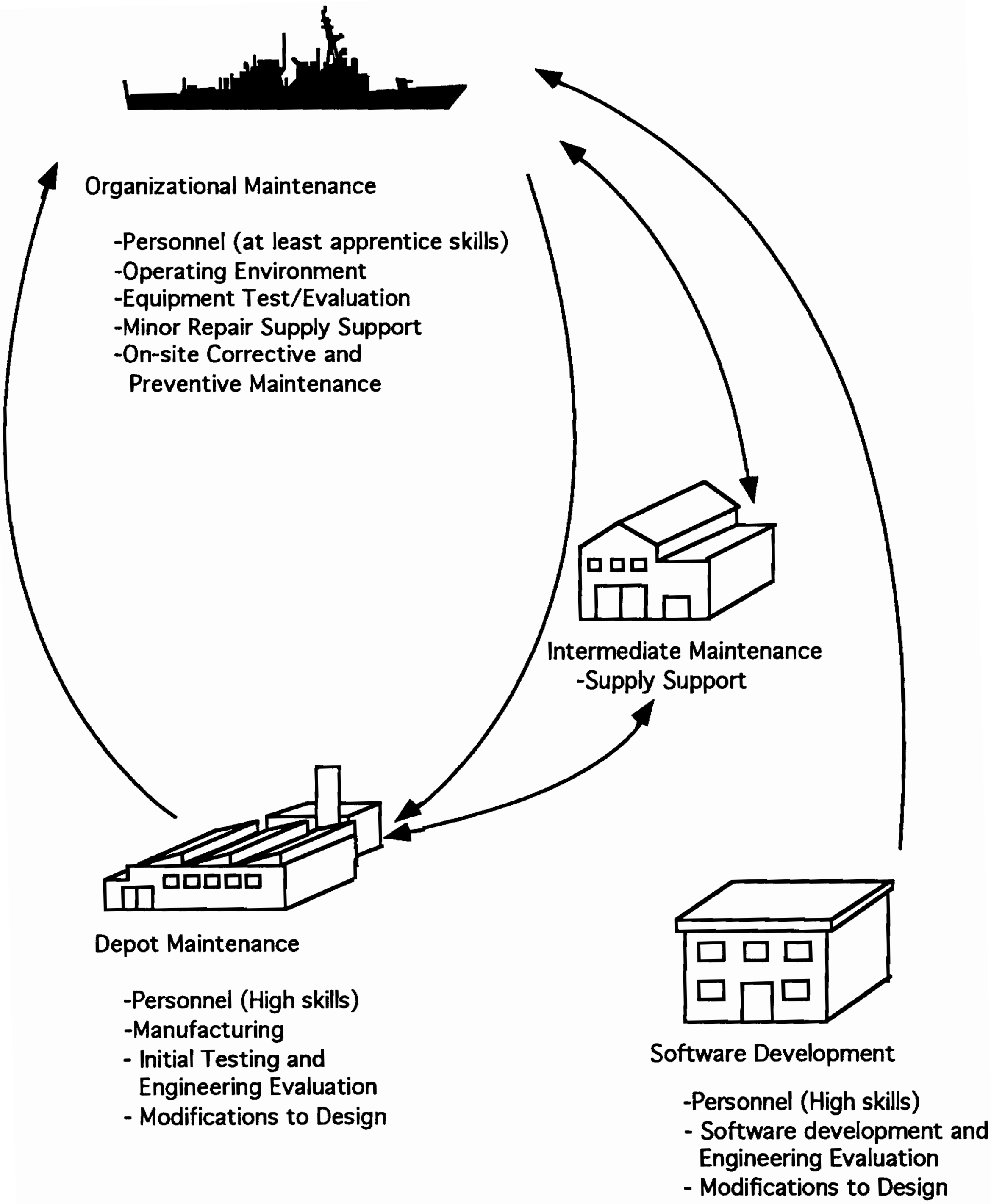


Figure 3. Maintenance concept for AN/SLQ-32(V).

2.1.2.1 Organizational Maintenance. Organizational maintenance includes the following types of maintenance actions that are performed by trained personnel of the Navy rank of Petty Officer third class (Godshall, 1990):

1) Corrective adjustments and alignment of electrical and mechanical components;
2) System testing using Built-In-Test (BIT) fault location capability to monitor performance and detect system faults;
3) Removal and replacement of Lowest Replaceable Units (LRUs);
    a) electronic modules,
    b) circuit card assemblies,
    c) lamps and fuses
    d) chassis mounted piece parts, and,
    e) mechanical parts within the organizational maintenance capability;
4) Discard of selected components as determined by the Level of Repair Analysis.

2.1.2.2 Intermediate Maintenance. Intermediate maintenance includes the supply and administrative support between the organizational maintenance and the depot level maintenance organizations. The intermediate maintenance facility most likely are located in the home port of a vessel. Since there are no corrective actions performed on the components of the system at the intermediate maintenance facility, this activity could be integrated with other supply and support activities.

2.1.2.3 Depot Maintenance. Depot maintenance includes repair and overhaul of all repairable components of the system. Maintenance at the depot level will be performed by trained mechanical and electronic personnel at the Contractor facilities and includes the following types of maintenance actions:

1.) Testing and fault isolation of the returned system components;

2.) Disposition of the Lowest level of Replaceable Units (repair or discard at failure as determined by the Level of Repair Analysis);

3.) Reassembly and testing, as required to meet system operating requirements as detailed in the technical manuals and technical repair standards;

4). Return of the system components to the Navy supply inventory as required.

2.1.2.4 Software Upgrades. Software development is initiated to meet changing operational requirements. Any system changes can have far-reaching consequences for system life-cycle costs. The development of software will create a new system which has its own deployment and training requirements.

2.2 Need for System Redesign

The purpose of a system must be defined so that system components may be developed to provide the desired output for a given set of inputs. Once defined, the system purpose makes it possible to establish a measure of effectiveness indicating how well the system performs (Blanchard, 1990).

The next section of this report provides a brief history of the U.S. Navy AN/SLQ-32(V) Electronic Warfare System. Although recognized as an integral part of the Navy's defense against low-flying anti-ship missiles, several incidents indicate a need for system improvement.

2.2.1 Nature of the Existing Deficiency

2.2.1.1 Falklands Islands War Lessons. The development and deployment of the anti-ship missile created a new era in naval tactics. The new missiles gave any surface navy an offensive capability which increased the vulnerability of naval surface vessels to catastrophic loss. These anti-ship missiles created a need for new defensive mechanisms. One of the resulting defensive mechanisms was the AN/SLQ-32(V) system which is examined in this work.

Although the AN/SLQ-32(V) system was deployed in the mid-1970s, anti-ship missiles did not see significant combat usage until 1982 in the Falklands Islands War. The conflict between Great Britain and Argentina provided a glimpse of the destructive power of this new weapon. Of three ships that were hit, only one missile is believed to have detonated. However, the impact of the three missiles caused fires which led to the loss of the destroyer HMS

SHEFFIELD and the aircraft-carrying ship HMS ATLANTIC CONVEYOR, and damaged the destroyer HMS GLAMORGAN (U.S Senate Committee on Armed Services, 1983).

The Exocet missile is an anti-ship missile that can be fired from naval vessels, aircraft, or shore launching sites. The missile is a sub-sonic, sea-skimming projectile with a 360-pound warhead.

The U.S. Navy studied the lessons of the Falklands War in light of the potential new threat of the anti-ship missile. The Navy made its report to Congress in 1983 and outlined a four point defensive plan to defeat the new threat.

First, each U.S. carrier had four E-2 Hawkeye AEW aircraft. These aircraft provided around-the-clock and around-the-compass early warning of hostile air attacks and controlled defending fighters.

Second, the long range weapons/radar capability of the F-14 Tomcat provided the opportunity for early intercept of attacking planes.

Third, the U.S. Navy's missile cruisers and destroyers were all fitted with 3-D radars and the Standard missile which were designed to give the ship an even greater capability against sea-skimming anti-ship missiles.

Fourth, the Navy provided all battle-force ships with close-in defenses: the Sea Sparrow missiles and the Phalanx Close-In Weapons Systems. For soft kill, all battle-force ships were fitted with the AN/SLQ-32(V) ECM system and chaff/decoy launchers. The AN/SLQ-

32(V) could detect the radar of hostile missiles. Through jamming and deception, the AN/SLQ-32(V) became a vital element in the defense against missile attacks (U.S Senate Committee on Armed Services, 1983).

The anti-ship missile proved to be a highly reliable weapon in the Falklands, capable of destroying or damaging large naval vessels. The U.S. Navy responded to the threat by reviewing and updating its war-fighting doctrine, given the capabilities of its existing defensive mechanisms.

2.2.1.2 U.S.S Stark Attack. In order to protect the world supply of oil flowing from the Persian Gulf, President Reagan ordered the reflagging of eleven Kuwaiti oil super tankers in early 1986. This was done in cooperation with Kuwait and under the auspices of the U.S. Navy. The object of the program was to stop the destruction of merchant shipping by the belligerents in the Iran-Iraq war. The U.S. Navy provided escorts for the tankers through the Straight of Hormuz to the Indian Ocean. On 17 May 1986, the U.S.S Stark, an Oliver Hazard Perry class frigate, was struck by two Exocet anti-ship missiles which resulted in 37 dead and 21 wounded sailors (Morrocco, 1987).

At about 9:05 p.m. on 17 May, the Stark's EW operator monitoring the AN/SLQ-32(V2), detected a Cyrano-4 radar operating in the search mode. The shipboard personnel correlated this signal with the Iraqi aircraft they were observing on their own air search radar. Also, they heard about the Iraqi plane from the AWACS aircraft, which identified the Mirage F-1 as Contact Number 2202. About one minute later, the AWACS radar operator, who employed U.S. Armed Forces operating procedures, asked the Stark to provide any electronic identification it had on track 2202. The Stark passed along its identification of the Mirage Cyrano-4 radar to the AWACS. The EW operator also activated a loudspeaker on the AN/SLQ-32 so that the signal could be heard in the CIC (U.S. House of Representatives, Committee on Armed Services, 1988).

Shortly thereafter, the EW operator detected a shift in the mode of the Cyrano-4 radar from the "search" mode to the fire control or "lock-on" mode. This change also was perceptible on the loudspeaker in the darkened CIC. The operator announced to the Tactical Operations Officer (TAO), "We've been locked-on." The operator asked the TAO for permission to arm the chaff launchers, located on the deck above the CIC. The TAO granted permission, and the operator sent his assistant up to prepare the chaff launchers, which took about 30 seconds.

After notifying the EW control ship, U.S.S Coontz, of the lock-on and after the passage of about 5 to 7 seconds, the operator detected a shift of the Cyrano-4 radar back to the search mode. Some 7 to 10 seconds later, the aircraft radar locked-on the ship again and, about 5 seconds later, returned to the search mode. It was about 10 seconds after this second radar lock-on that the first of two missiles impacted the ship. See Figure 4 for timeline of the missile's flight. Figure 4 shows the small amount of time that the

Stark's crew had to react to the incoming missiles. The first missile to impact took approximately three minutes to reach the Stark. The second missile took approximately half that time (1.5 minutes) due to the distance that the aircraft had closed with the ship.

The Exocet missile is fed tracking data by the Cyrano-4 radar just prior to launch. That data carries the missile to a point near the target. At that point, a tracking radar aboard the Exocet begins emitting and guides the missile over the final distance to the target. The pilot can select one of three points - approximately 2, 4, or 6 miles from the target - at which the tracking radar will begin emitting. At best, there would be less than a minute in which to detect the missile tracking radar.

The EW operator on Stark claims that he never detected the signal from either Exocet. The operator said the AN/SLQ-32(V) did contain the Exocet signal parameters in its memory and, therefore, should have been able to make the identification. If the AN/SLQ-32(V) had made the proper identification, it would have provided both an audible signal and a video symbol on the operator's screen. The operator indicated he had turned off the audible alarm feature because too many signals were being received that were setting off the alarm, requiring actions that distracted him from performing other signal analysis tasks. Moreover, the operator claims he never saw the video signal for the Exocet missile. The AN/SLQ-32(V) operator at the time of the incident was one of the most experienced operators on the ship.

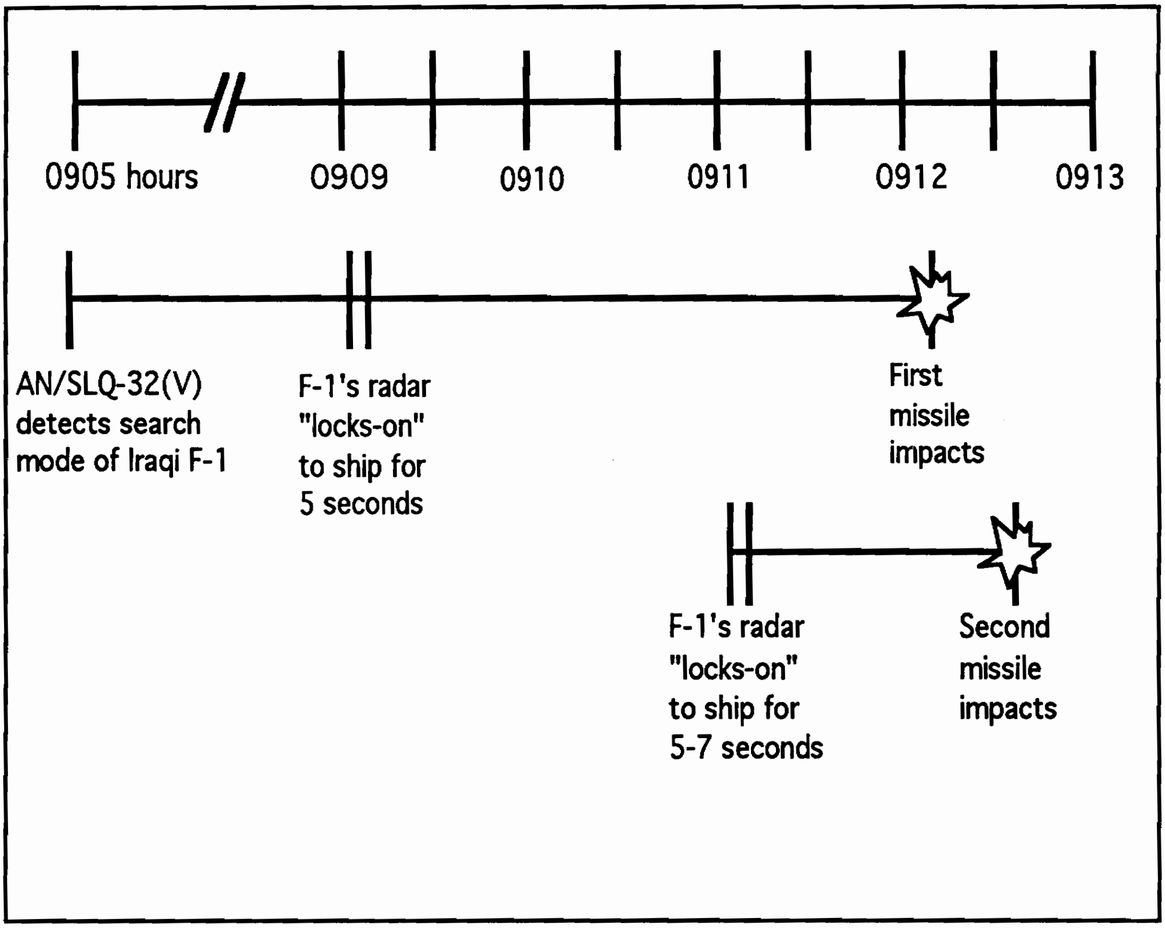


Figure 4. Timeline of the U.S.S. Stark Attack.

Based on the evidence, the Navy concluded that the AN/SLQ-32(V) performed as it should have, but that the operator failed to detect the signal because the audible alarm was turned off and because he was distracted and missed the visual signal. There was a great deal of activity in the CIC at that time. The AN/SLQ-32(V) operator not only had to watch his scope, but also had to communicate with the TAO and with another EW operator on-board a near-by ship.

A congressional subcommittee heard testimony concerning the Stark attack from October 1987 to March 1988. One part of the discussion centered on the allocation of functions in the anti-ship missile defense system. Representative Foglietta asked Admiral Rowden: "Have we reached the point where the systems are so sophisticated that it is no longer prudent or appropriate to have the 'man in the loop'?" Admiral Rowden replies, "I think that certainly automation is necessary to be able to provide a reduction in reaction time for those things that can be properly programmed in a computer, but there is no substitute for the judgment of a man..." (U.S. House of Representatives, Subcommittee on Seapower and Strategic and Critical Materials, 1989, page 42).

This was a critical life-cycle juncture for the AN/SLQ-32(V) system. The Navy realized that the system was not fast enough to process and respond to the potential threats. The solution was to decide which functions to program into the computer to reduce reaction time without removing the operator from the decision cycle. There was a recognized need for an assessment of function allocations in the system, particularly the man/machine interface.

2.2.1.3 U.S.S. Vincennes Incident. The AN/SLQ-32(V) was noted in a separate incident in the Persian Gulf in July 1987 when the U.S.S Vincennes shot down a civilian Iranian Airbus. Some experts maintained that the AN/SLQ-32(V) anti-ship missile defense system should have been able to identify the approaching plane as a commercial airliner.

> *The system uses multiple beam antennas for reception in all bands and has a lens-fed multiple beam array capable of rapidly detecting hostile signals and concentrating intense amounts of jamming power against them. Identification probably could have been accomplished if the Airbus had its weather or main radars turned on and they were working properly. Although that cannot be determined, it later was revealed that commercial (as well as military) aircraft flying over the Gulf often had routinely turned off their system radars in order to reduce the noise levels of chaff said to be common in the area* (Jaszka, 1988, page 60).

It is difficult to assume that the AN/SLQ-32(V) or its operator were in any way responsible for the downing of the civilian airliner since the Iranian government never turned over the airliner cockpit voice recorders for examination. However, investigations into the incident revealed that an unknown member of the Vincennes CIC incorrectly identified the contact as an Iranian F-14 (U.S. Senate, Committee on Armed Services, 1988). This started a chain of events that led to the downing of the airliner. The identification of emitter radar is one of the primary functions of the AN/SLQ-32(V). Also, an F-14 radar would transmit an IFF signal (Identification Friend or Foe). The EW operator would be able to positively identify this unique signal as an F-14 Tomcat. Since the airliner did not present the IFF signal, this indicates that the EW operator did not rely on the information from the system that was available for him to analyze.

2.2.1.4 Next Generation Anti-Ship Missiles.

> *The advent of the anti-ship missile increased the vulnerability of the warship as no other naval weapon had previously done. Such missiles can be launched from over-the-horizon distances at sea-skimming altitudes (at super-sonic speeds in the new generation)* (Baranauskas, 1988, p. 20).

The Falklands and Iran-Iraq conflicts highlighted the vulnerability of both war and merchant ships to anti-ship missiles.

A major technical revolution in anti-ship missiles will have a profound impact upon seafaring nations, according to a report released by Forecasts Associates, a market intelligence firm. The study entitled, *The Market for Anti-ship Missiles and Defensive Systems Through the Year 2000* predicts that a new generation of supersonic, sea-skimming, anti-ship missiles soon will replace the already deadly subsonic missiles of today. Present generation missiles, such as the Harpoon and Exocet, will remain a serious threat, but will become technologically obsolete.

The Falklands and Persian Gulf conflicts demonstrated the successful use of anti-ship missiles and the difficulty of defending against them. These difficulties will be compounded not only by the vastly increased speed of the new missiles, but also by electronic countermeasures built into them.

Forecasts Associates analysts believe the introduction of advanced technology supersonic anti-ship missiles will dictate another major revision in naval tactics (Baranauskas, 1988, p. 20). Defensive system reaction times already are down to about 60 seconds (as noted in the Stark attack timeline in Figure 4). This time may need to be reduced further with the deployment of supersonic missiles. The study concludes that supersonic sea-skimming missiles can shift the naval balance so that small, agile craft armed with them will have the capability of sinking large naval vessels.

2.2.2 Total Quality Management

Total Quality Management (TQM) can be described as a total integrated management approach that addresses system/product quality during all phases of the life cycle and at each level in the overall system hierarchy (Blanchard, 1990). TQM provides a before-the-fact orientation to quality and focuses on system design and development activities, production, manufacturing, assembly, logistics support, and related functions.

TQM is a scientific approach described as making decisions based on data, looking for the root causes of problems, and seeking permanent solutions rather than quick fixes.

The U.S. Navy uses this life cycle approach to system design, but adopted the program as Total Quality Leadership (TQL). Some specific characteristics of TQL are:

1) Total customer satisfaction is the primary objective, as compared to the practice of accomplishing as little as possible in conforming to the minimum requirements. This includes surveying "fleet" users of any given system and providing those end-users with a means to influence design recommendations. These comments often provide the insight needed to identify the root causes of the problem. It is necessary to identify the root causes of the problem to develop permanent solutions.

2) Emphasis is placed on the iterative practice of continuous improvement, as applied to engineering, production, and support processes. The goal of continuous improvement is to look-ahead and anticipate the resources and training necessary for a successful system.

3) An individual understanding of the processes, the effects of variation, and the application of process control methods is required. If individuals are to be contributors relative to continuous

improvement, they must be knowledgeable of various processes and their inherent characteristics.

4) TQL emphasizes a total organizational approach, involving every group in the organization, not just the quality control group. To accomplish this objective, the U.S. Navy formed a team of experts to examine and make recommendations for design changes to the AN/SLQ-32(V).

5) Under the TQL process, the U.S. Navy requires design changes to be backed up by the collection of meaningful data. In other words, the U.S. Navy is much more willing to make system design changes when there is empirical data to support the change. Peter R. Scholtes in *The Team Handbook*, points out;

> *Often people think they know the cause of a problem before they even start the project, and probably are convinced they have a perfect solution. And maybe they do. But if all team members are committed to the scientific approach, hunches must be supported by data. If the hunches turn out to be right, you can still benefit from this exercise by learning a lot about how to make the change. More often, though, the solution turns out to be something entirely different from what you expected* (Scholtes, 1990, p. 5).

The TQL process provides the framework for system improvement. The evaluation of the AN/SLQ-32(V) by the Displays and Controls Laboratory at Virginia Polytechnic Institute and State University helped to provide the data for system design recommendations. Although more time is spent in the beginning stages of the process, the end product/system is defined better. The investment in time gives the user a better product and can reduce the costs of updates during the system life-cycle.

2.3 System Definition

This section of the report describes the AN/SLQ-32(V). The discussion starts from a macro-level and, then, discusses the system to the level necessary to understand the system.

The goal of this work was to conduct and document a task analysis of the AN/SLQ–32(V) DCC for a specific task. Since the focus of the work is on the man-machine interface, the chosen task encompasses a broad range of the operator's duties at the DCC. The task analysis will be used as a tool to compare system redesign options.

The work effort involved the acquisition of information from naval operators and the assessment of existing system design features from actual and simulated DCC units. The critique of these data considers operator task requirements in actual EW scenarios, such as the time required to detect, analyze, and act-upon radar intercepts in anti-ship missile defense. From this evaluation, recommendations are developed and justified for DCC design changes.

2.3.1 System Deployment

The AN/SLQ-32(V) is an electronic countermeasures system, informally referred to as the "Slick-32". The basic system is a passive receiver of radio-frequency energy that can detect and analyze signals from any bearing surrounding the ship. The unit provides an identification of the energy source and the bearing to the source from the ship. Rapid identification of signals is made by matching the characteristics of the received emitters with a pre-programmed library (U.S. Senate, Committee on Armed Services, 1988).

Five configurations of the AN/SLQ–32(V) system, all manufactured by Raytheon Electromagnetic Systems Division (mid–1970s to present), as designated below (JANE's Radar and EW Systems, 1991-1992):

- (V)1 – provides basic Electronic Support Measures (ESM) for warning, identification, and bearing of radar–guided missiles. The AN/SLQ–32(V)1 suite was designed for Knox–class frigates and smaller support ships.

- (V)2 – provides expanded ESM capabilities for early warning, identification, and bearing of navigational and targeting radars associated with missile launch platforms. The AN/SLQ–32(V)2 suite was designed for DDGs, FFGs, and Spruance–class destroyers.

- (V)3 – provides expanded ESM as well as additional Active Electronic Counter Measures (AECM) for jamming targeting radars and deflection of launched missiles. The AN/SLQ–32(V)3 suite was designed for cruisers and other larger ships.

• (V)4 - provides the same capabilities as the (V)3 suite to the carrier class ships. The hardware includes an additional processor to compensate for the separation of the antennae.

• (V)5 Sidekick - Add-on module to supplement the Oliver Hazard Perry class frigates (V)2 capabilities.

Although hardware subsystems differ across AN/SLQ–32(V) suites, the operator DCCs are designed identically. The principle operator input/output devices of the DCC consist of a Cathode–Ray Tube (CRT) visual display, Light Emitting Diode (LED) auxiliary indicator display, an alphanumeric keyboard, and assorted fixed–action function keys. The AN/SLQ–32(V) DCC is designed as an interactive workstation affording control of various ESM and AECM functions, as well as the MK36 Super Rapid Bloom Off–Board Chaff (Super RBOC) launchers.

The AN/SLQ-32(V) plays a critical part in the modern U.S. Navy. During the late 1980's and early 1990's, the AN/SLQ-32(V) has been a major budget item for the Navy.

The initial Request For Proposal (RFP) for the system was released in 1973, as an outgrowth of the Navy's design-to-price electronic warfare suite (DTPEWS) program. After 1974, only Hughes and Raytheon remained in the competition for the DTPEWS contract. In 1977, the Raytheon AN/SLQ-32(V) was selected over the Hughes AN/SLQ-31 (Rawles, 1987).

The AN/SLQ-32(V) program currently is 19 years old, and production is expected to continue through 1993. Analysts predict that purchases of the system could continue through 1997.

The system has been deployed on about 400 U.S. naval vessels, as well as a number of allied ships. Figure 5 shows where the five variants of the AN/SLQ-32(V) 1-5 are located among the different classes of ships in the U.S. Navy (JANE'S Fighting Ships, 1991-1992). The silhouettes shown in the figure represent one of the classes of ships which carry that version of the AN/SLQ-32(V).

2.3.2 Core Subsystems on the AEGIS Class Ship

The core subsystems on the AEGIS class ship are shown in Figure 6 (Stroud, 1991). The subsystems provide information to the TAO on-board ship to aid the tactical decision-making process. Each subsystem has a particular mission to perform and is designed to provide feedback in a rapidly changing threat environment. The interactions among these systems is crucial to the effective performance of the ship and its battle-group. Some of the subsystems are designed to electronically network with one another, while other subsystems rely on voice communications to the TAO. The internal communications subsystem, whether by voice or electronic means, is essential to the operators knowledge-collection effort.

AN/SLQ-32(V)1

U.S.S. Raleigh

Type of Ship

AE-21,AE-34,AE-36
AMMUNITION
AFS-1 COMBAT STORES
AGF-3,AGF-11 COMMAND
LKA-113 AMPHIB CARGO
LPD-1 AMPHIB TRANSPORT DOCK
LSD-36,LSD-41 DOCK LANDING
LST-1179 TANK LANDING

AN/SLQ-32(V)2

U.S.S. Arleigh Burke

Type of Ship

DD-963 DESTROYER
DDG-2 GUIDED MISSILE DESTROYER
DDG-51 GUIDED MISSILE DESTROYER
FF-1052 FRIGATE
FFG-1,FFG-36 GUIDED MISSILE FRIGATE
WMEC-901 MEDIUM ENDURANCE CUTTER
WHEC-715 HIGH ENDURANCE CUTTER

AN/SLQ-32(V)3

U.S.S. Virginia

Type of Ship

AOE-1,AOE-6 FAST COMBAT SUPPORT
AOR-1 REPLENISHMENT OILER
BB BATTLESHIP
CGN GUIDED MISSILE CRUISER
CG-16,CG-26,CG-47 CGN GUIDED MISSILE CRUISER
DD-993 DESTROYER
DDG-37 GUIDED MISSILE DESTROYER
LCC-19 AMPHIB COMMAND
LHA-1 AMPHIB ASSAULT
LHD-1 AMPHIB ASSAULT
LPH-2 AMPHIB ASSAULT

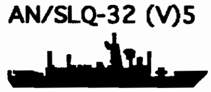
AN/SLQ-32(V)4

U.S.S. Kennedy

Type of Ship

CV AIRCRAFT CARRIER
CVN AIRCRAFT CARRIER

AN/SLQ-32 (V)5



U.S.S Oliver Hazard Perry

Type of ship

FFG 7 GUIDED MISSILE FRIGATE

Figure 5. Deployment of the AN/SLQ-32(V).

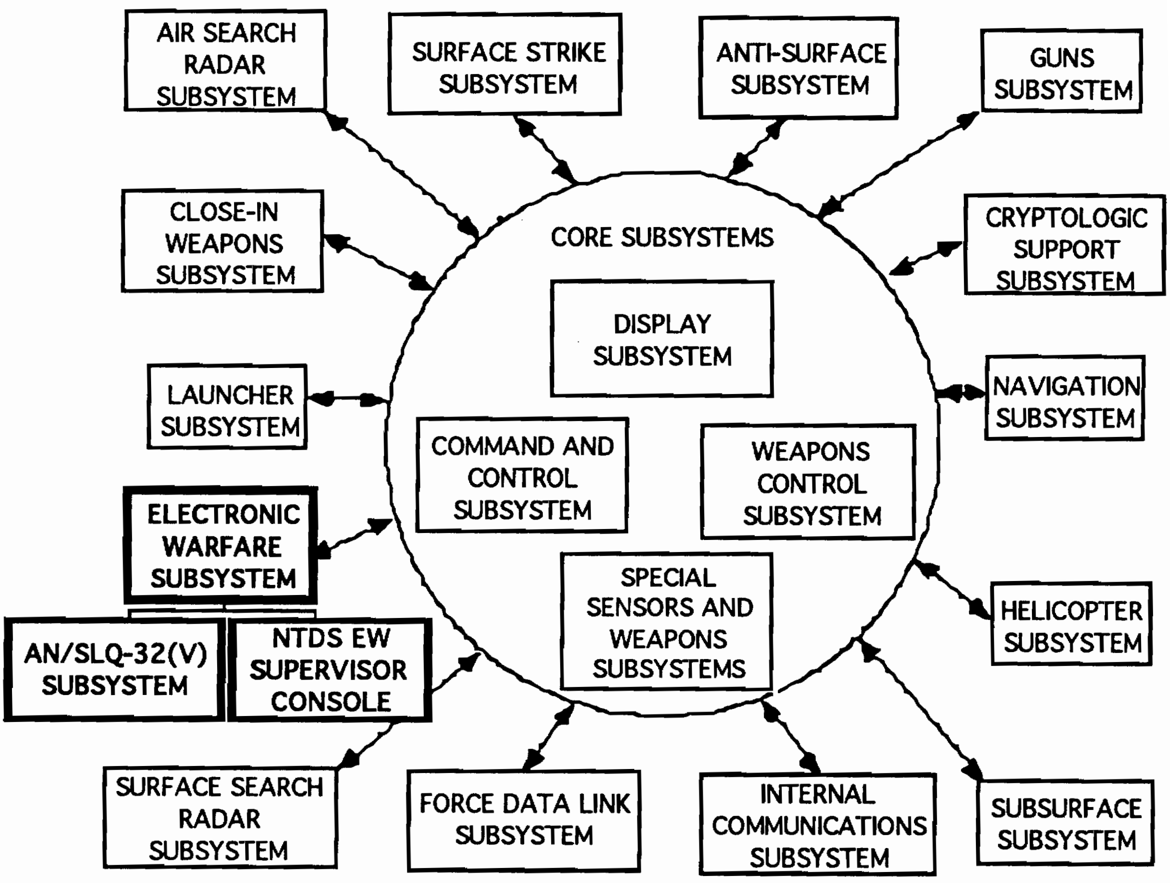


Figure 6. Diagram of the AEGIS class combat system.

In this report, the EW subsystem is of particular interest. The goal is to document a portion of the EW operator's task, conduct trade-off experiments, and recommend design changes based on objective data. It should be pointed out that any design changes for the AN/SLQ-32(V) should be viewed within the context of all subsystems in Figure 6. This is an area for possible future research and is beyond the scope of this work.

2.3.3 The AN/SLQ-32(V) Electronic Warfare System

Figure 7 is a simplified schematic of the AN/SLQ-32(V) subsystem. Radar signals are detected by the AN/SLQ-32(V) antennas located on the superstructure of the ship. The signals are passed through a receiver to determine if a pulse chain of similar signals are present. A pulse chain from the same bearing (location)is an indication that there is an emitter present. When the processor is able to identify a pulse chain, that information is compared to the emitter parameters in the AN/SLQ-32(V) on-line library. The classified emitter then appears on the operator's DCC as a specific symbol. If the emitter cannot be identified from the on-line library, the operator is presented a symbol for an unknown emitter.

The operator spends most of his time identifying emitters that appear on his display. However, the more advanced versions of the AN/SLQ-32(V) provide the operator with the capability to launch chaff and electronically jam hostile emitters.

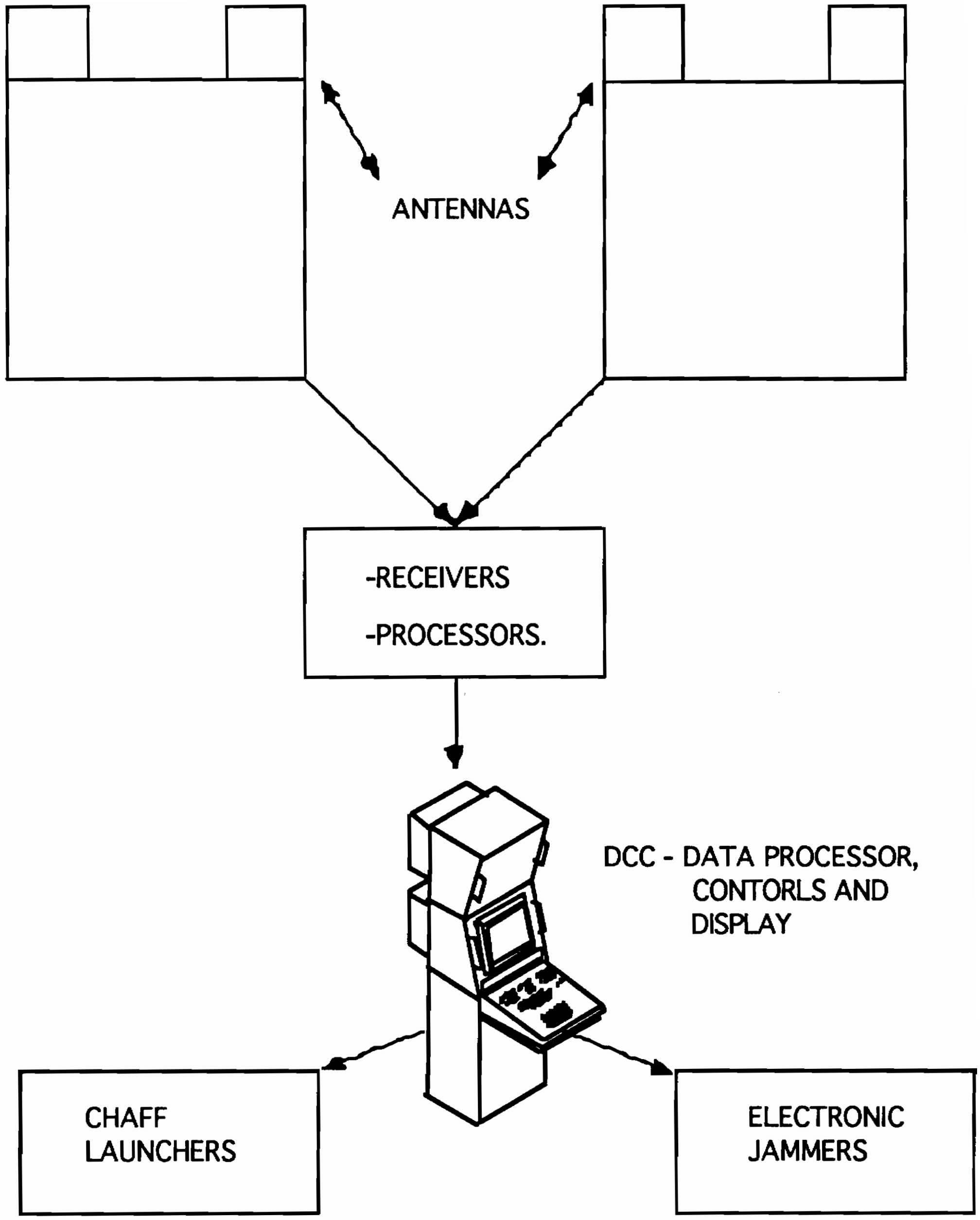


Figure 7. The AN/SLQ-32(V) electronic warfare system deployed in the U.S. Navy.

2.3.4 A Partial EW Module

The AN/SLQ-32(V) was designed originally as a stand-alone system for the EW environment. Since then, the NTDS system was added to the command and control structure of Navy ships. Currently, the AN/SLQ-32(V) and the EW supe console make up the EW Subsystem or Module. Data obtained during operator interviews and shipboard visits indicate that additional equipments have been added to the EW module to aid the operator in the performance of his task (Shipboard visit, 6 December 1991). Figure 8 represents a partial EW module in the U.S. Navy.

The AN/SLQ-32(V) DCC and the EW Supe's console comprise the base EW system. In addition, there is an internal intercom system, a radio/telephone, a radar device, an oscilloscope, a publications holder, and a frequency analyzer with supporting monitor. These additional pieces of equipment require attention resources of the operator, and they were added over the years to help the operator perform his job more efficiently.

2.4 Functional Analysis

Functional analysis is a logical, deductive, and systematic approach to system design and development. It constitutes the process of translating operational and support requirements into specific qualitative and quantitative design requirements. The process breaks down top-level requirements into finer detail by

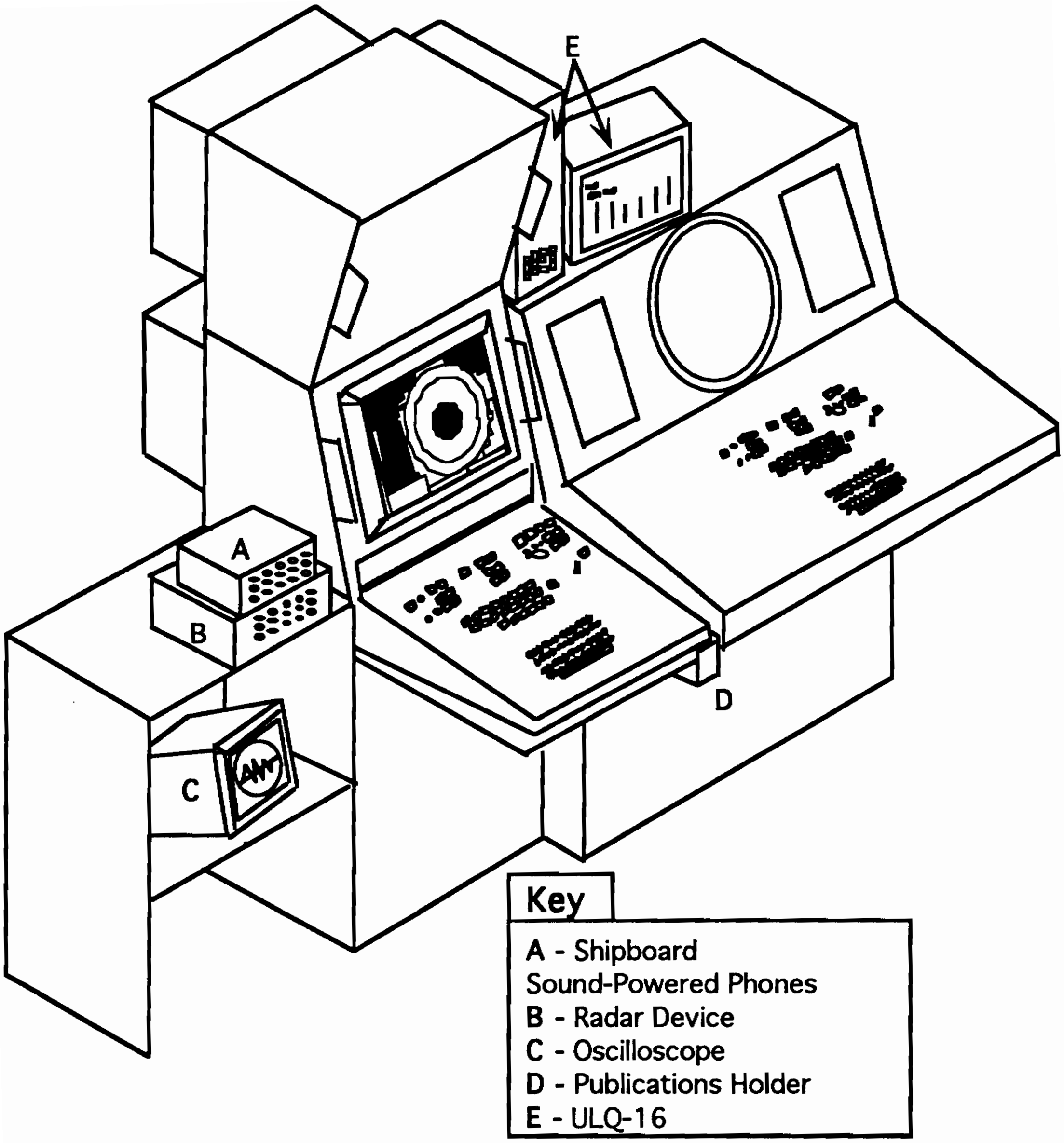


Figure 8. Partial electronic warfare module deployed in the U.S. Navy.

determining the inputs and outputs needed to meet each level of the requirements. This detailed analysis describes the functions to be performed by the system. These functions have behavioral implications in terms of the demands that they impose on both the machine and the operator (Meister, 1985). The functional analysis process is iterative, and is accomplished through the development of functional flow diagrams, which provide a graphical representation of the system.

2.4.1 Functional Flow Diagram

Functional flow diagrams were developed for the purposes of structuring system requirements into functional terms, to indicate basic system organization, and to identify functional interfaces. The decision concerning the allocation of functions should not be made until the complete scope of functional requirements has been clearly defined. Figure 9 shows the system top-level functions. In order to limit this project to a reasonable scope, the author chose to evaluate Function 9.0, "Operate System", in the top-level structure (see Figure 9).

Most of the system problems were identified during the operation of the system. Also, both the operator's expertise and shipboard interviews were used in the evaluation of the system. Any possible system changes also should consider the effect on the system maintainers, which is not within the scope of this project.

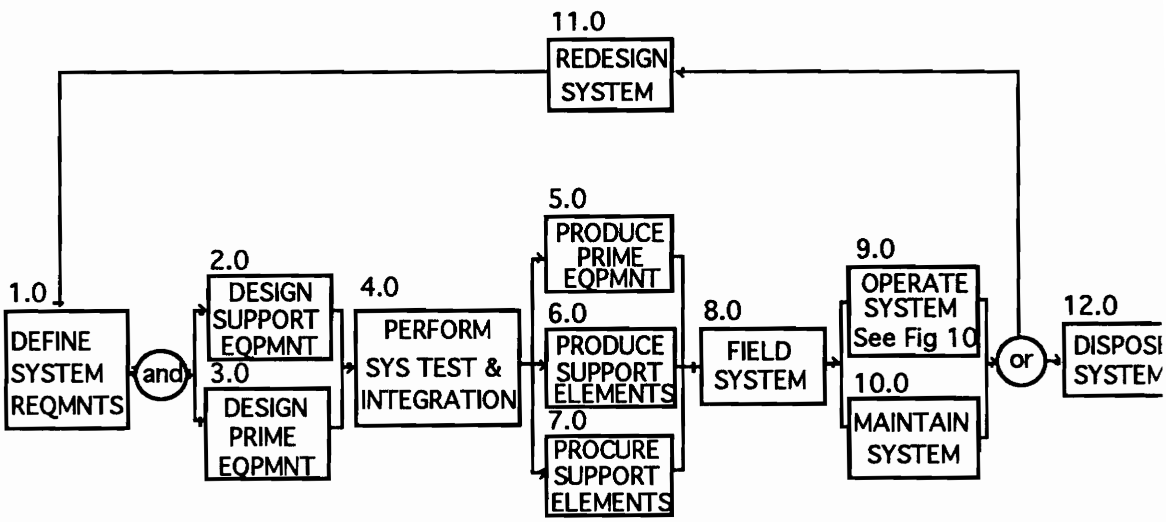


Figure 9. System level functional flow diagram.

In 1987 as a result of changing naval tactics, a decision was made to review the man/machine interface between the AN/SLQ-32(V) DCC and the operator. This created a feedback loop in the functional flow diagram. Instead of disposing of the system, the system would undergo a review of the system requirements.

Figure 10 shows the next lower level in the functional flow diagram for the operation of the system. This series of items represent the entire watch of the EW. He receives a watch briefing when he comes on duty, and he briefs his relief personnel as he goes off duty. This functional flow diagram was verified with actual operators during a 6 December 1991 shipboard visit to the USS Virginia in Norfolk, Va.

The AN/SLQ-32(V) is an essential part of the ship's Combat Information Center (CIC). During combat or peacetime operations, the EW operator provides information to the TAO concerning friendly and potentially hostile radar emitters. Most of the operator's time is spent processing new emitters. Figure 11 shows a functional flow diagram of this critical task.

2.4.1.1 Function Allocation. The development of a functional analysis does not determine how the functions should be carried out. The functions could be carried out by a machine, human operator, or a combination of both.

Once the functions are determined, there may be an option whether the function should be performed by a human operator or by a machine (Sanders and McCormick, 1987).

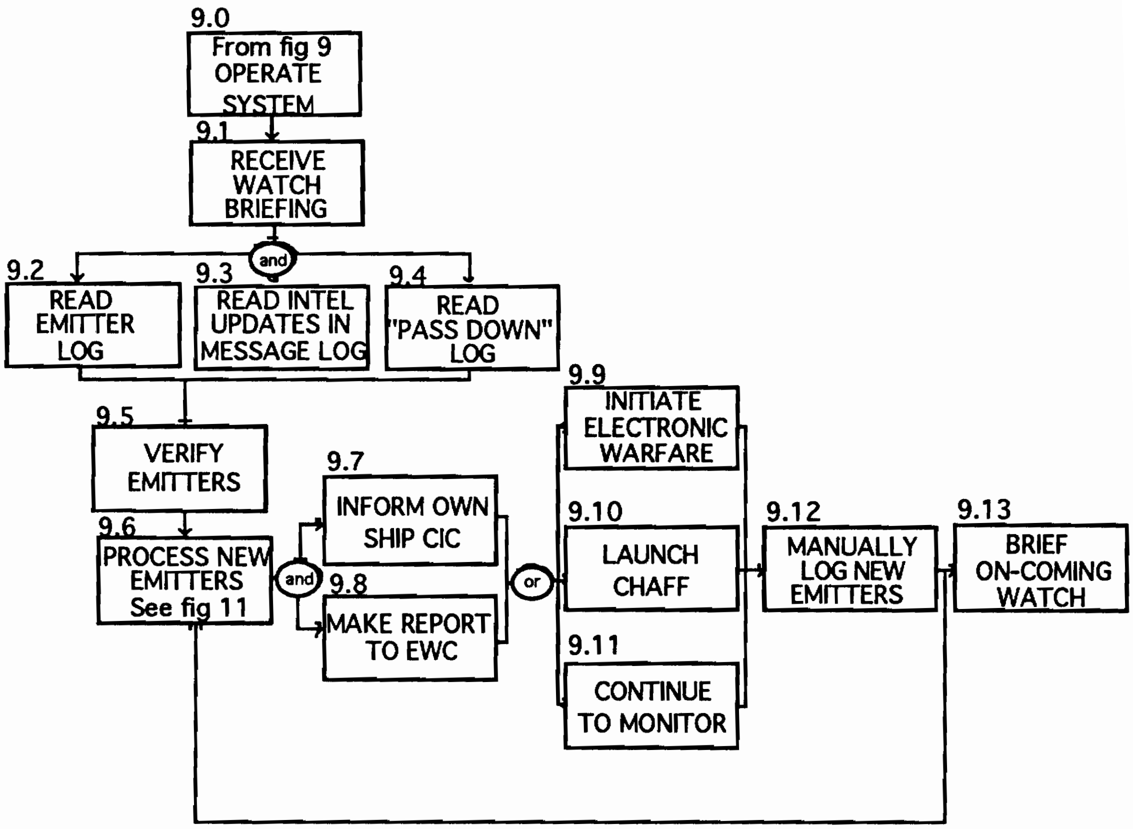


Figure 10. Functional flow diagram for system operation.

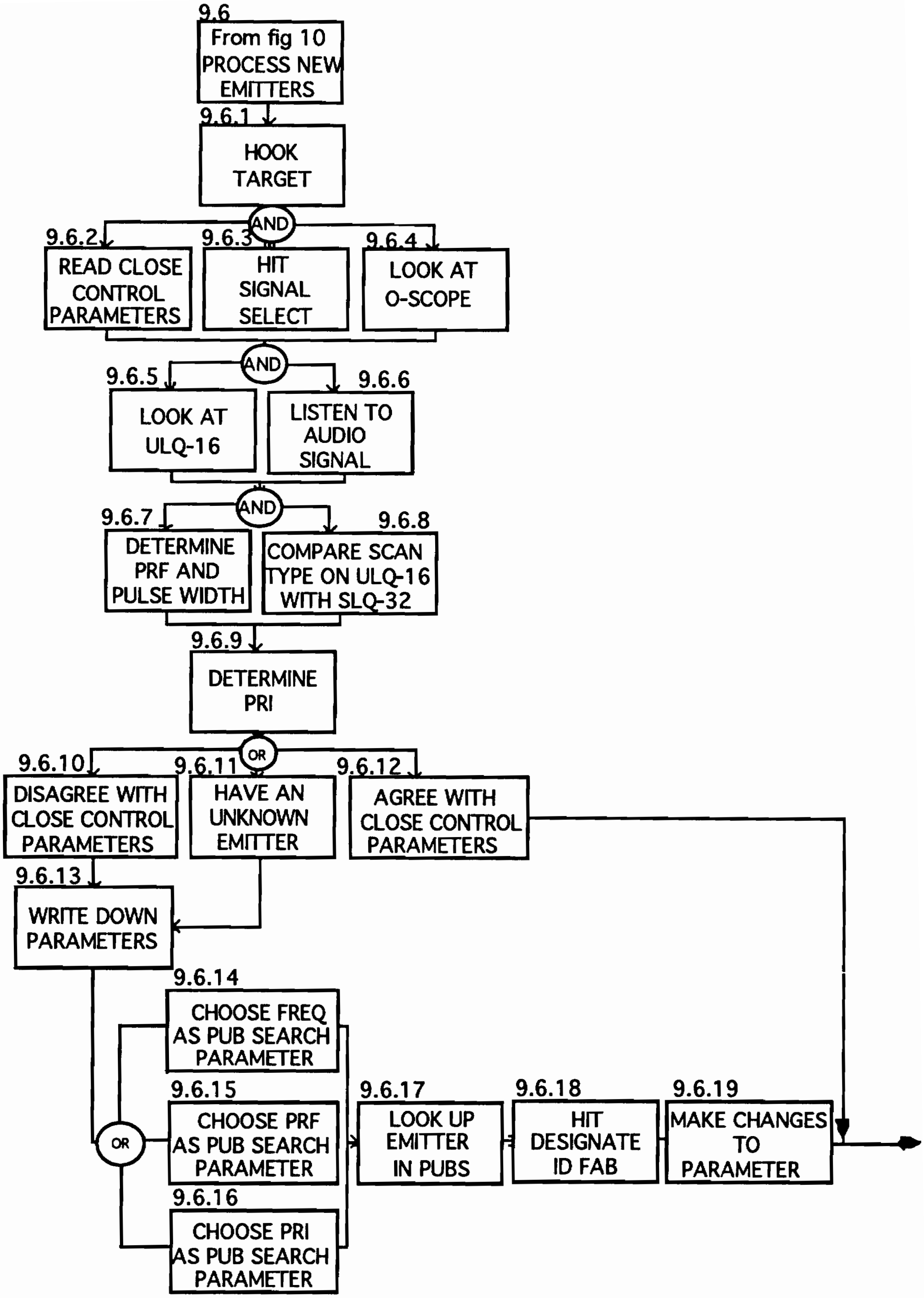


Figure 11. Functional flow diagram for EW watch.

Based on human and machine capabilities, the allocation strategy consists of four principles, as listed below :

1) Mandatory allocations to either the human or machine based on system requirements should be made first. The U.S. Navy wants the operator to remain "in the loop". This rules out a entirely automatic system, but does not dictate the level of operator intervention in the system.

2) For functions that are not identifiable readily as mandatory allocations, human and machine performance must be judged according to task or mission context. This involves the following sequence of steps: Estimate the relative capabilities of the human and the machine. If the task is unacceptable for both humans and machines, then redefine the function or change the requirements of the system. If the task is unacceptable for machines, treat it as a mandatory allocation for humans. Conversely, if the task is unacceptable for humans, then it should be treated as a mandatory machine allocation. If the function is better performed by the human or machine then it may be allocated respectively after consideration of the next two rules.

3) Consider the relative costs of each.

4) Recognize the unique needs of the human, such as the need for information to make decisions, memory limitations, and processing capabilities.

The current system affords few automatic functions to the operator. However, most operators commented that they rarely rely upon automatic system capabilities; for example, chaff launching or emitter identification. Operators commonly expressed a concern that the automatic system capabilities are performed erroneously. This is especially true in the area of automatic emitter identification. In general, most operators prefer to perform the AN/SLQ-32(V) functions manually.

The allocation of functions in the system is critical to an improved system redesign given the decreased time that the operator has to identify and classify emitters. Based on Congressional testimony, the U.S. Navy still wants the operator in the decision loop (U.S. House of Representatives, Subcommittee on Seapower and Strategic and Critical Materials, 1989). This is based in part on the criticality of the system to ship defense.

2.4.2 Operational Sequence Diagram

A major objective in the task analysis was the evaluation of the sequential flow of information from the point in time when the operator first becomes involved with the system to completion of the mission. Information flow in this instance applies to operator decisions, AN/SLQ-32(V) operator control activities, and the transmission of data. The Operational Sequence Diagram (OSD) is one method to portray graphically the sequential flow of information.

The flow of information is portrayed symbolically to represent the reception of information, decision making, and control responses. See Figure 12 for an explanation of the symbology used in the operational sequence diagram (Meister, 1985). It is particularly useful in the integration of task analysis information because it emphasizes interfaces, interactions, and interrelationships. The flow of events is always from the top of the sheet to the bottom. The AN/SLQ-32(V) operator and each piece of equipment that he controls is entered into a separate column. Specifically, these diagrams project different sequences of operation, showing:

1. Manual and automatic operations
2. Operator decision points and control movements
3. Transmitted and received information
4. Time estimates of each of the above

2.4.3 OSD Time Estimates

There were three methods used to estimate task completion times in the OSD. The first is called MODAPTS (Shinnick, 1987). The MODAPTS time estimates are shown in the OSD with a superscript

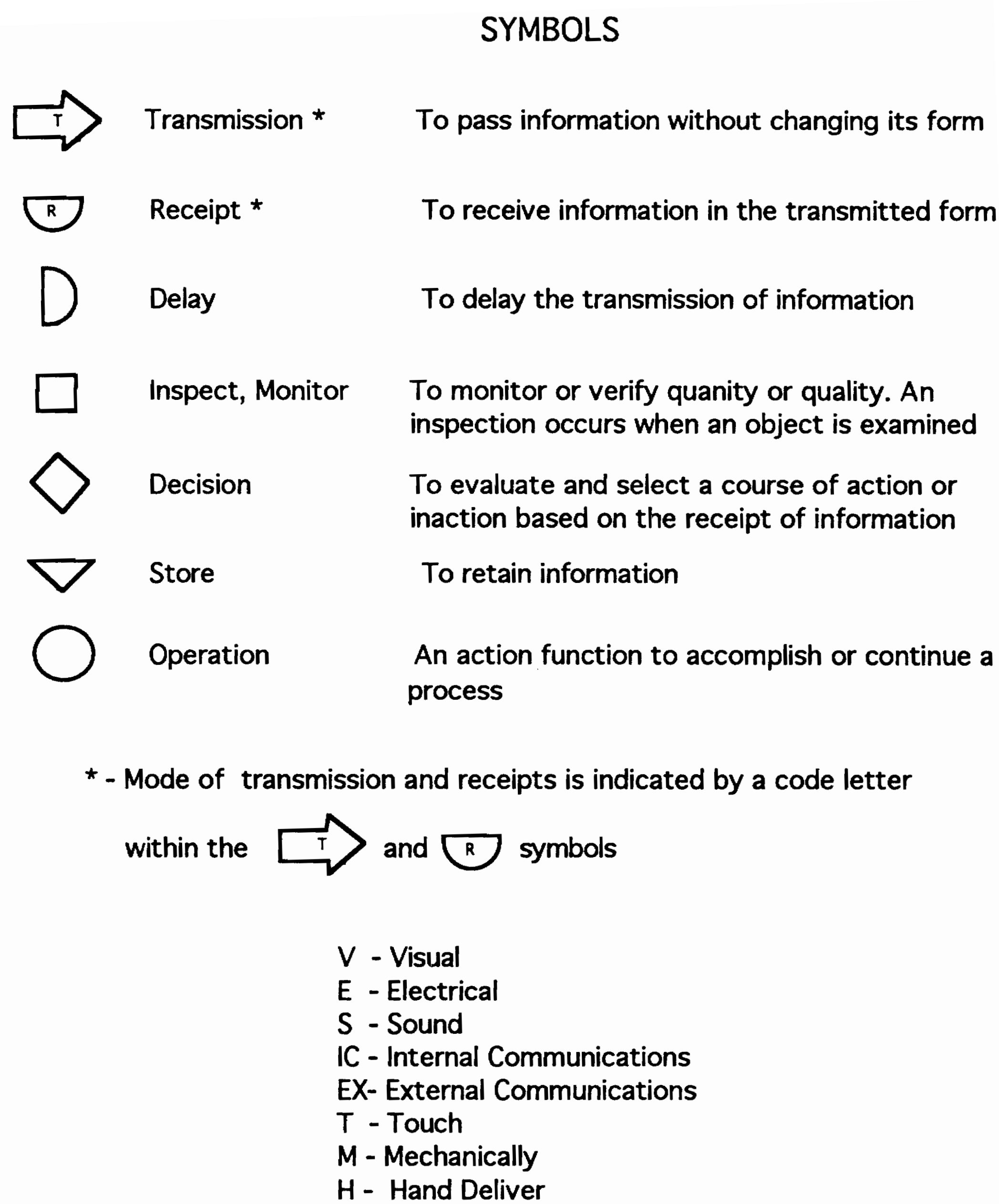


Figure 12. Symbology used in the operational sequence diagram.

"1". The second was video tape analysis of EW operators performing a specified task in a simulated environment. The video tape time estimates are shown in the OSD with a superscript "2". The third time estimate came from an input device study conducted at Virginia Polytechnic Institute and State University in July 1991. The time estimates from the input device study are shown in the OSD with a superscript "3".

2.4.3.1 MODAPTS definition. MODAPTS is an acronym for Modular Arrangement of Predetermined Time Standards. MODAPTS provides a fast, consistent method of determining a "fair day's" work in manufacturing plants, offices, distribution centers, and rehabilitation centers. There are 44 different predetermined time standards covering a variety of tasks. This work is primarily concerned with the MODAPTS measure "MOVE".

Time values are expressed in units called MODS. A MOD equals 129 milliseconds or 0.00215 minutes. Each movement type in MODAPTS has an alpha-numeric code. The numeric character is the time value required to complete the activity. This numeric character is the MOD multiplier.

The MOD value of 0.00215 minutes represents "normal" time, the time required to complete the activity by a qualified, thoroughly experienced person. It does not represent someone working at a fast pace or a slow pace, but at a pace that is comfortable and can be maintained all day without undue stress.

2.4.3.2 Definition of MODAPTS "Move" Element . The element Move is an action of the finger, hand, or arm. This action usually is to or from specific articles or locations. Since the operator deals primarily with button presses, the MODAPTS value will be derived from movements in conjunction with movements of small/light objects i.e. (a button press).

a) M1 - Finger Move; performed with any fingers usual distance of 1"

b) M2 - Hand Move; performed with either hand, usual distance of 2". To award M2, the palm must move.

c) M3 - Arm Move; performed with the forearm, a usual distance of 6". To award M3, the wrist must move.

d) M4 - Whole arm Move; performed with the full arm forward, a usual distance of 12". To award M4, the elbow must move.

e) M5 - Extended arm move; performed with the full arm outward, a usual distance of 18". To award M5, the shoulder must move.

f) M7 - Trunk Move; performed with the arms and body trunk, a usual distance of 30". This move is similar to M5, except the distance requires the trunk body to be moved.

The MOD values are based on the body part which is moved in the performance of a task as well as the type of task performed. For example, a trunk move is M7. The MODAPTS time is the MOD multiplied by 7, (i.e. 0.00215 minutes x 7 = 0.01505 minutes). These values can be used with the OSD to show time estimates for complete tasks.

2.4.3.3 Video tape analysis. Time estimates for designated portions of the OSD will be estimated by video tape analysis. The video tape was made while four different operators performed a selected portion of their task.

The OSD is a further analysis/breakdown of the third-level functional flow diagram (Figure 13 shows the Operational Sequence Diagram.). Once the functional flow reached this level, the OSD shows the interaction between the different pieces of equipment and the operator. The diagram also shows the time required to perform each part of the task. The OSD begins when a new emitter is presented to the operator on the screen of the AN/SLQ-32(V). The operator must perform the actions necessary to identify and evaluate the new emitter. The OSD ends when the operator has enough information to classify the emitter.

The superscript number by each time estimate in the OSD shows the source of the information:

1 - MODAPTS

2 - Video Tape Analysis

3 - Input Device Study

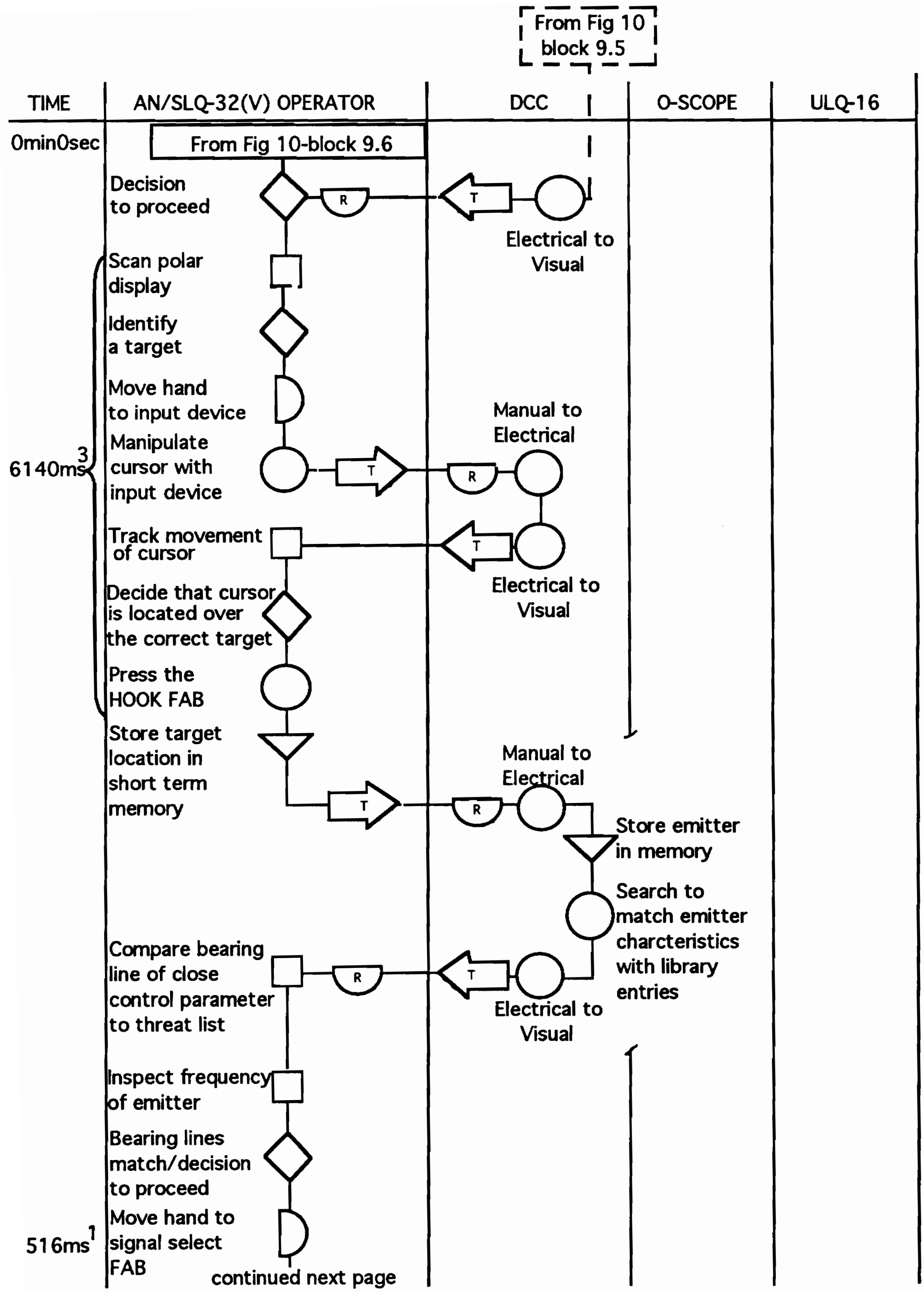


Figure 13 - Operational Sequence Diagram, page 1

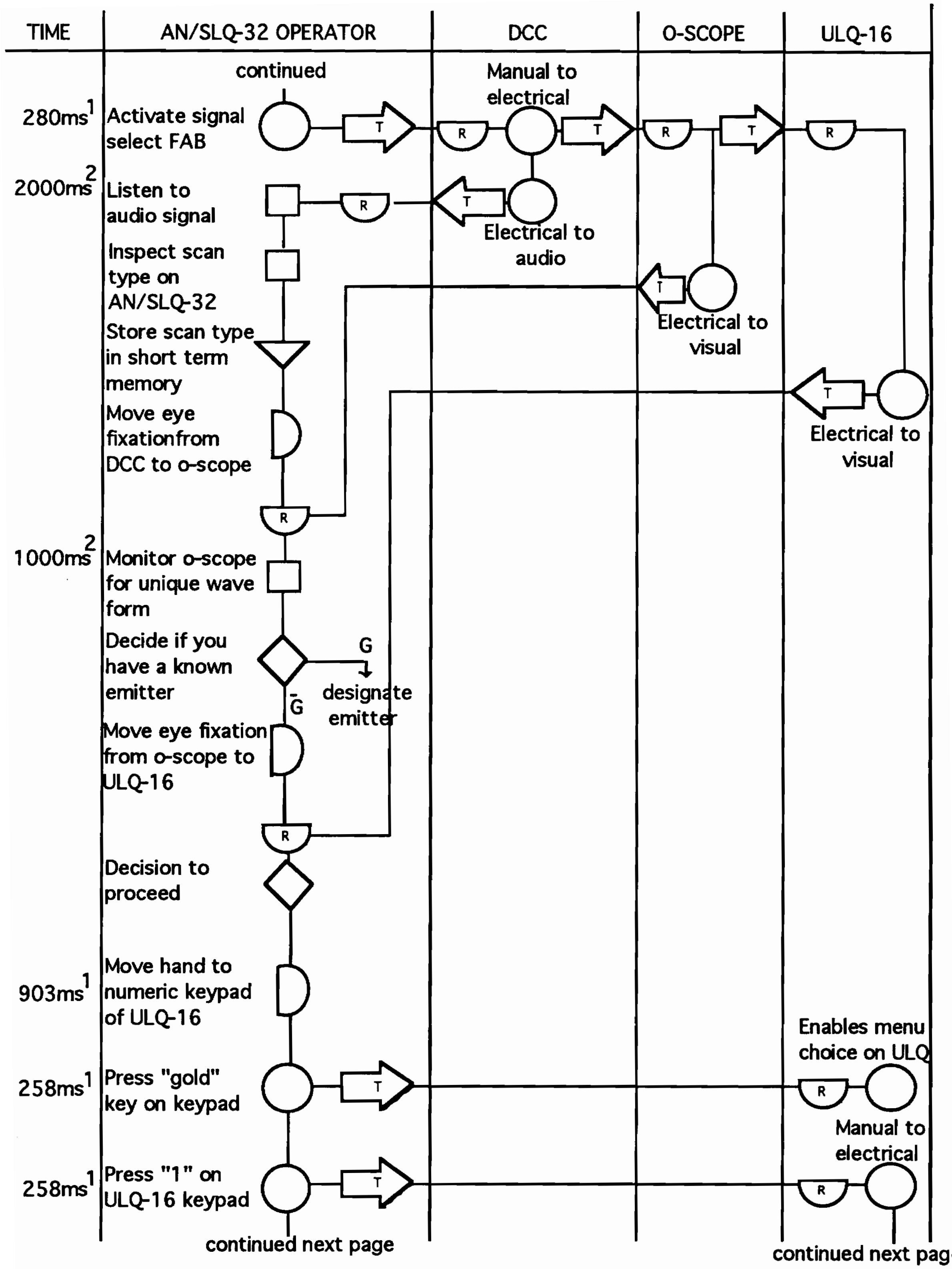


Figure 13 - Operational Sequence Diagram, page 2

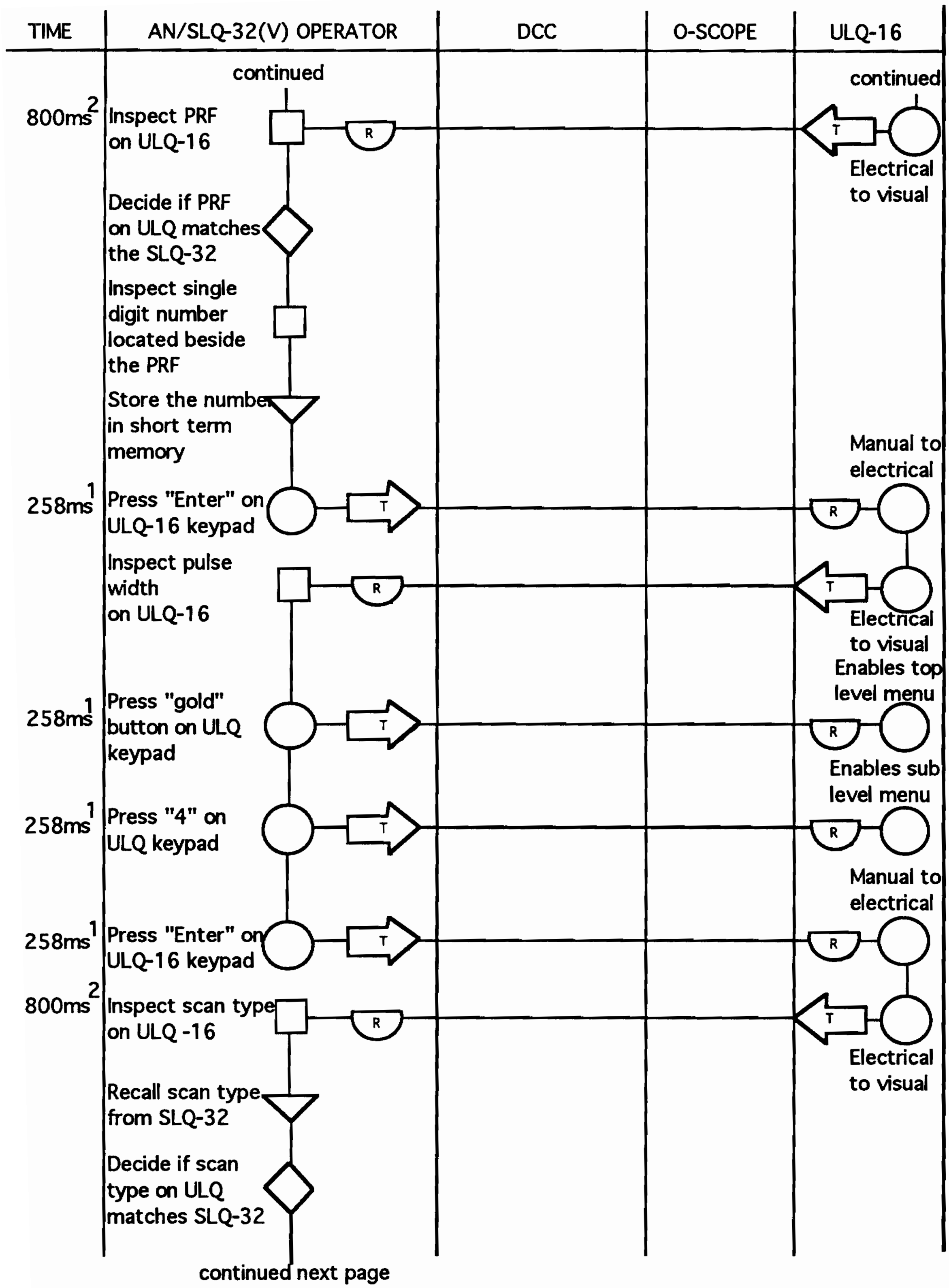


Figure 13 - Operational Sequence Diagram, page 3

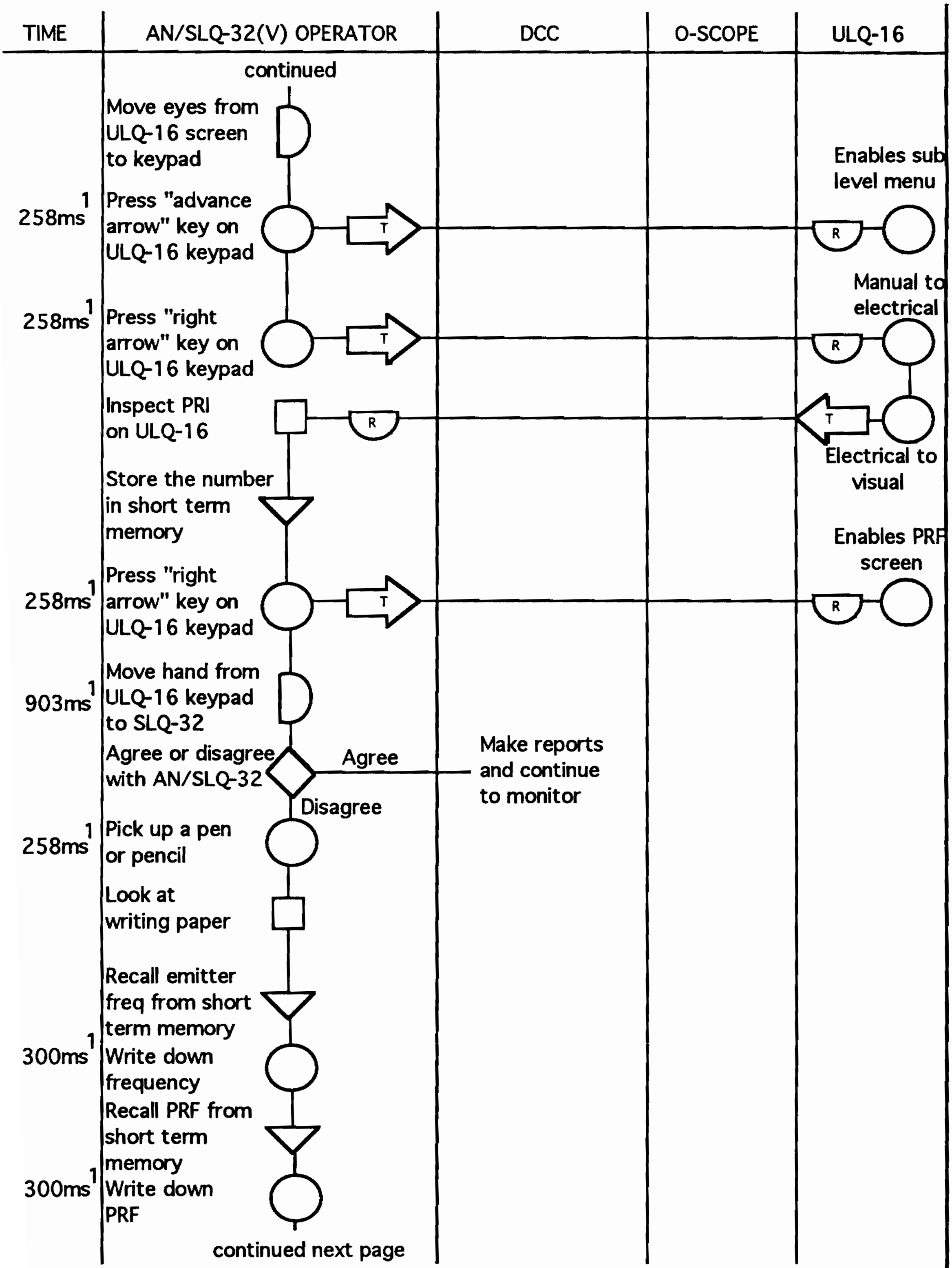


Figure 13 - Operational Sequence Diagram, page 4

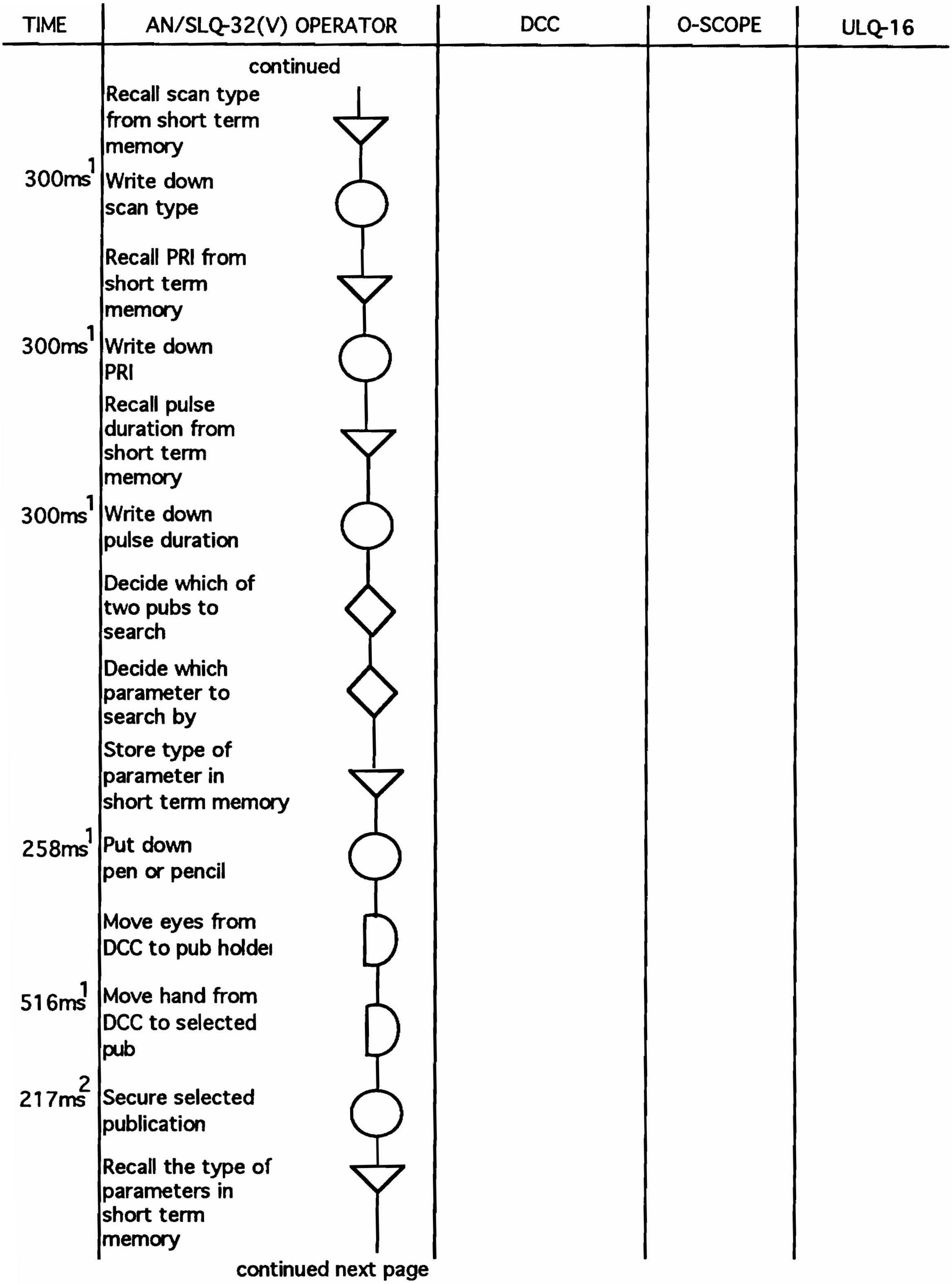


Figure 13 - Operational Sequence Diagram, page 5

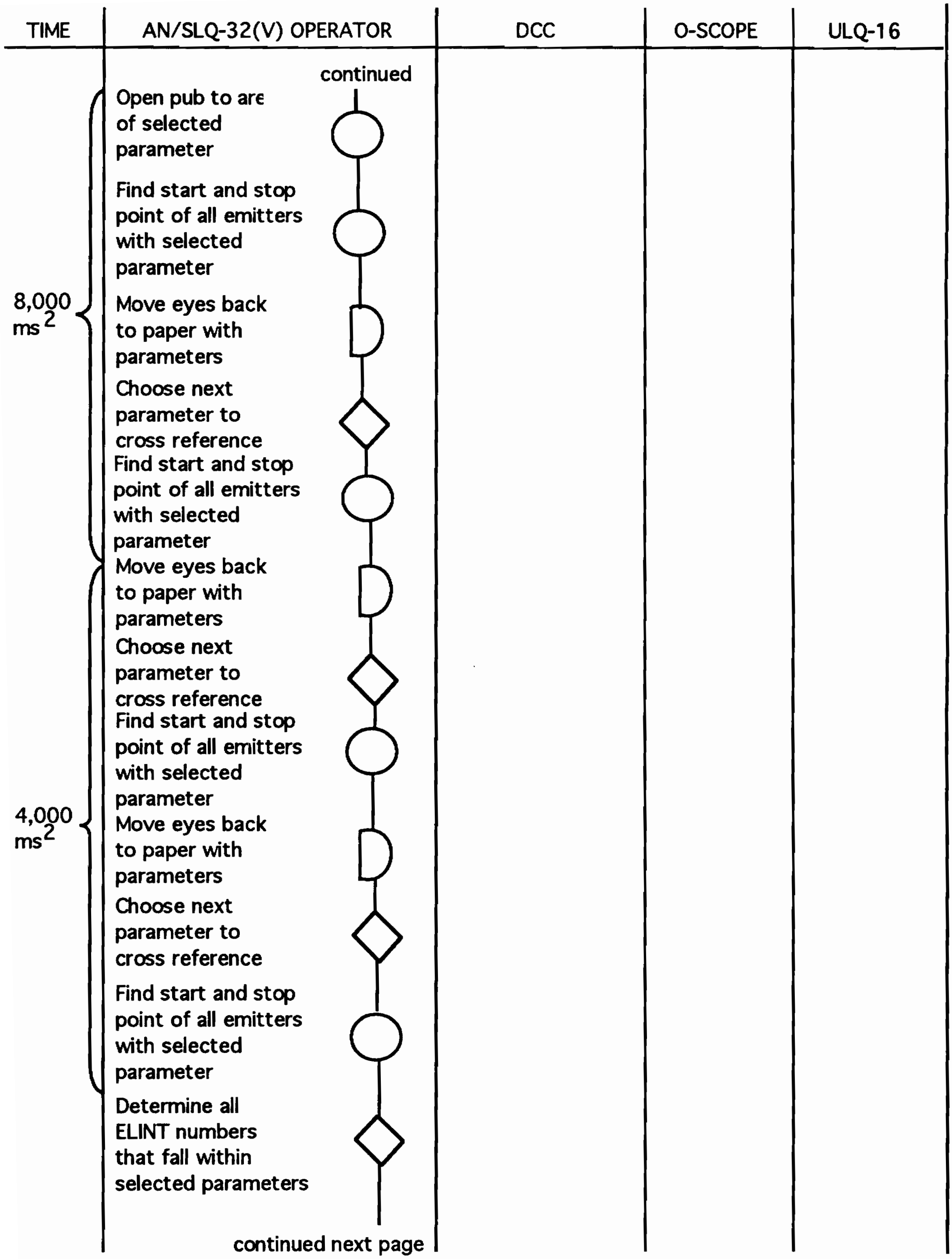


Figure 13 - Operational Sequence Diagram, page 6

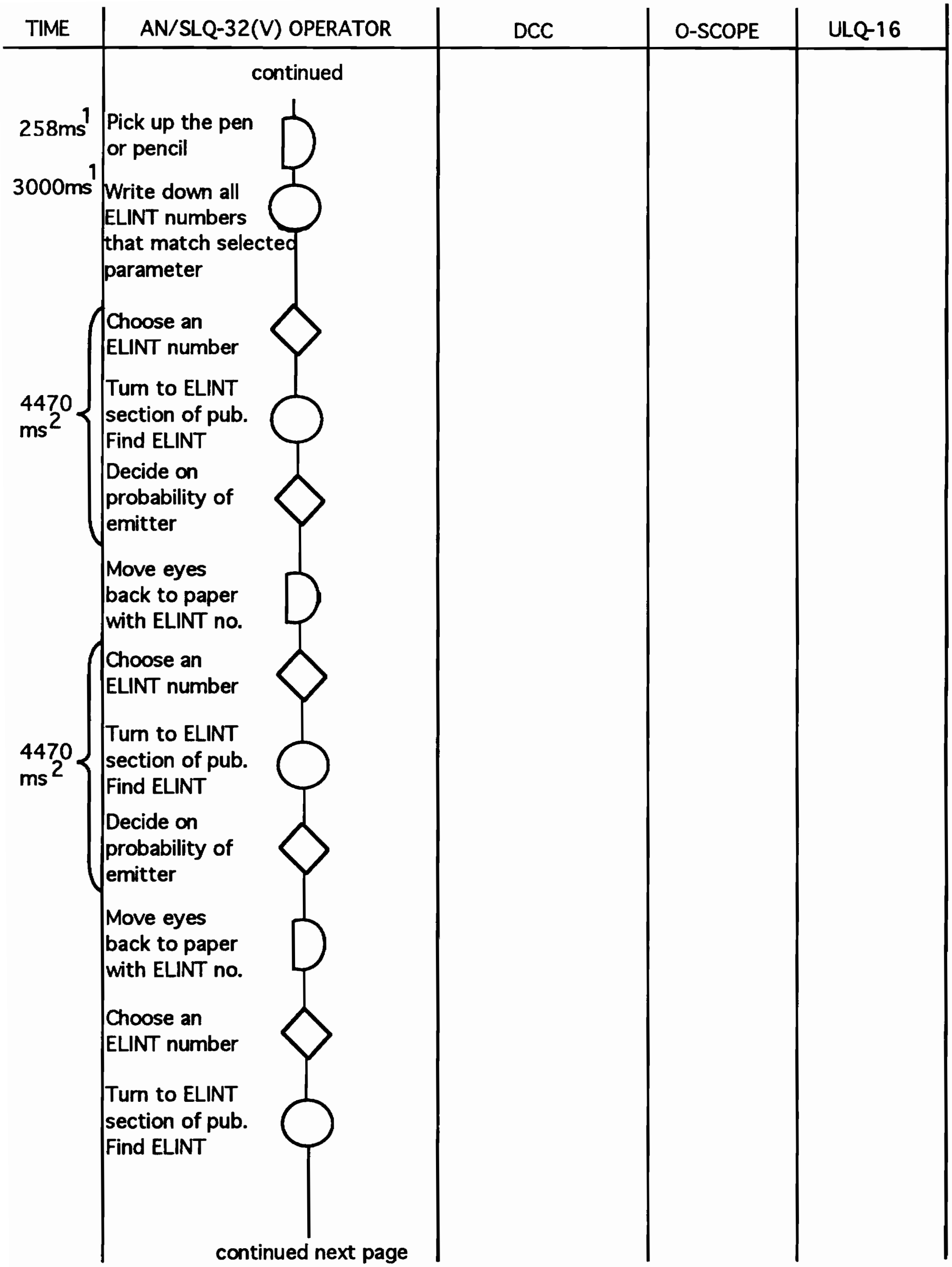


Figure 13 - Operational Sequence Diagram, page 7

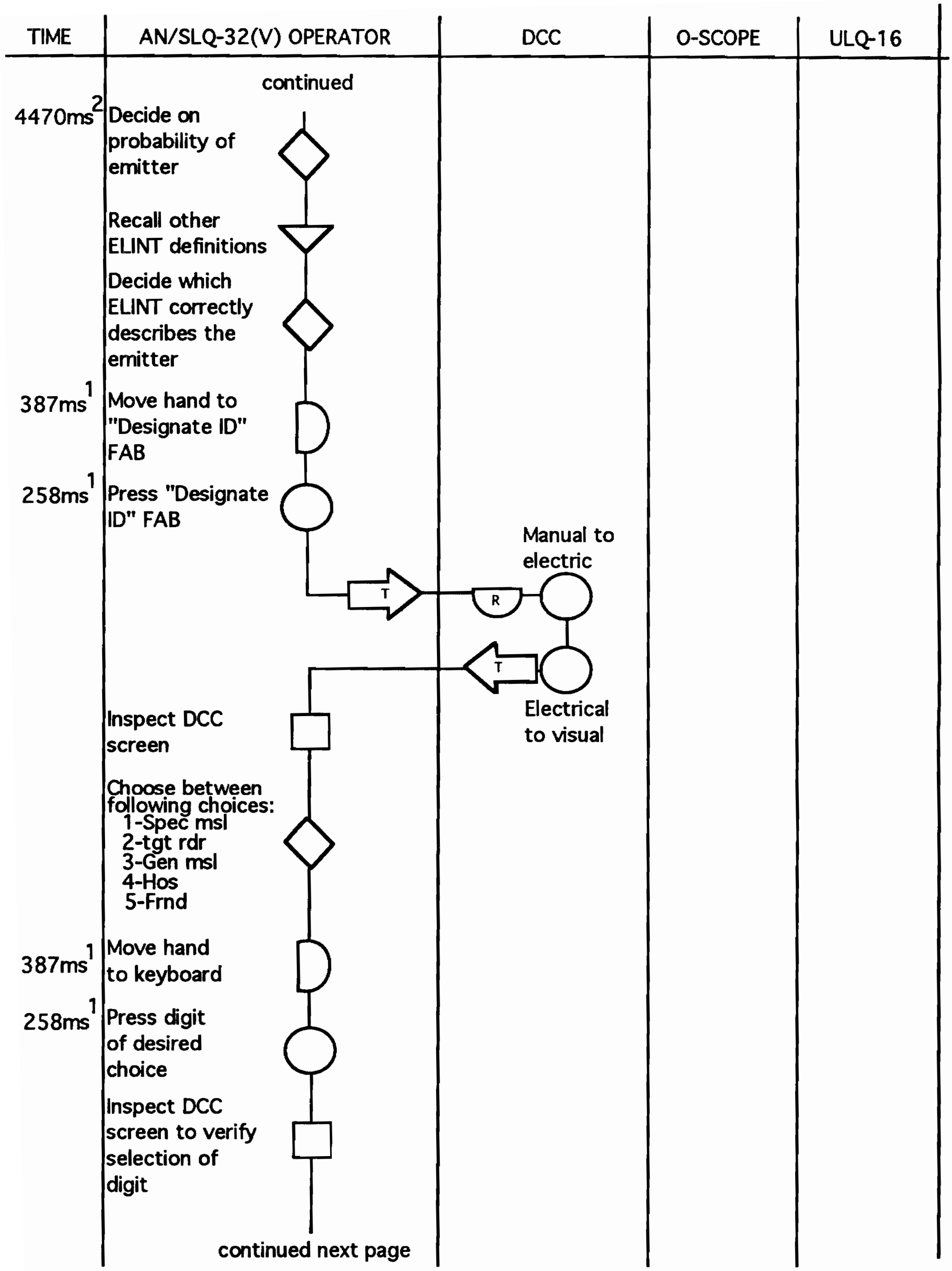


Figure 13 - Operational Sequence Diagram, page 8

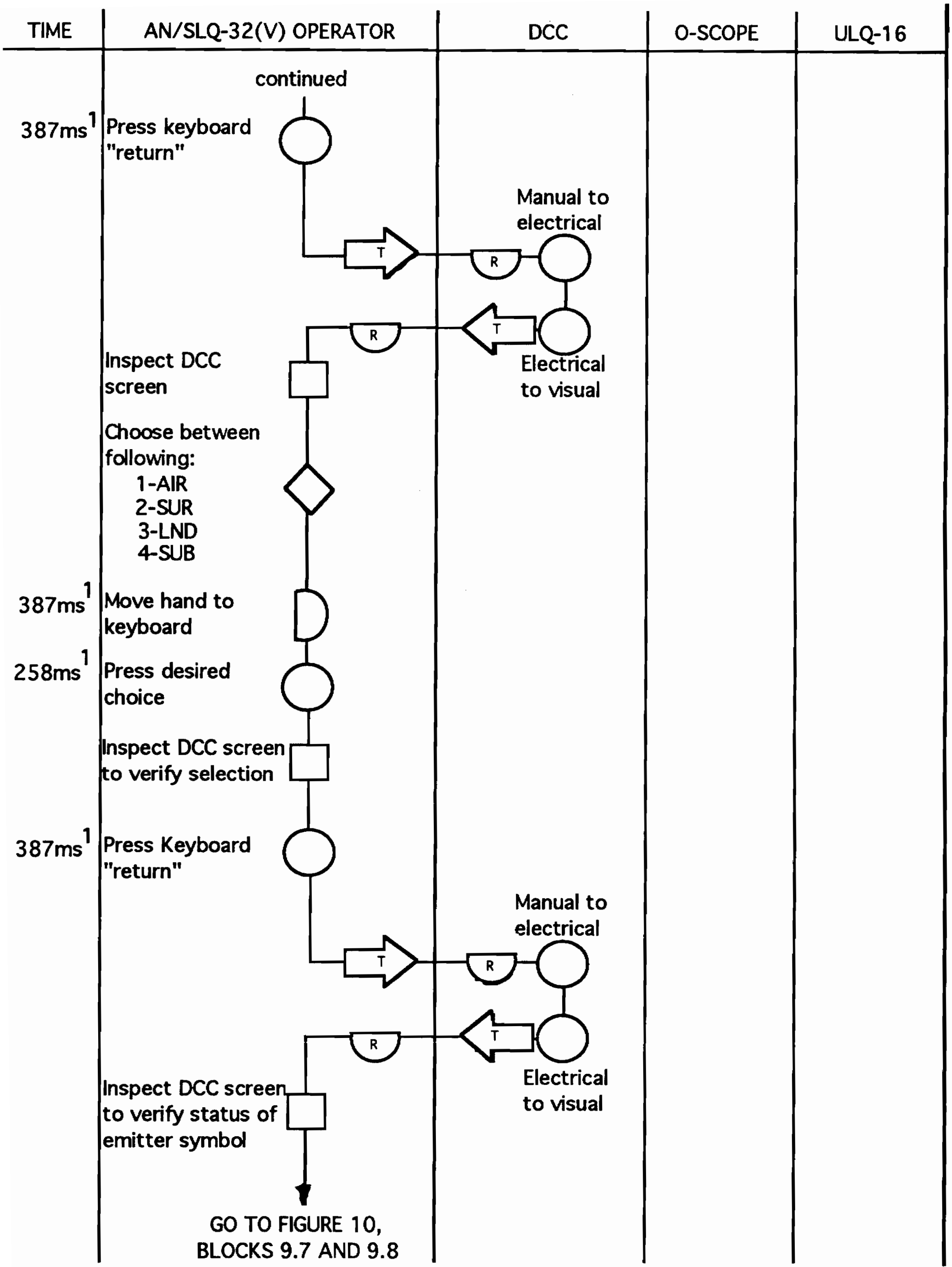


Figure 13 - Operational Sequence Diagram, page 9

III. SYSTEM TRADE-OFF EXPERIMENTS

Usually, there are many ways to perform a particular task. The goal of a trade-off study is to quantify the merits of task performance under varied conditions. The TQL process dictates that system design recommendations must be backed up with experimental or actual data. For this work, a trade-off study was performed to examine the effects of several variables on the reduction of total time and errors involved in the performance of a task on the AN/SLQ-32(V).

3.1 Input Device Trade-Off Experiment

An experiment was conducted in the Displays and Controls Laboratory at Virginia Polytechnic Institute and State University in June-July 1991 to compare cursor positioning devices given a simulated AN/SLQ-32(V) screen format. The following is a review of the input device study design plan.

3.1.1 Equipment and Methods

Ten participants were instructed to use various cursor positioning devices to locate a cursor on a highlighted emitter icon, depress a selector button, and subsequently enter a random numeral sequence-number into a data entry window. Following the data entry, either another highlighted emitter icon appeared for selection or another trial sequence was initiated.

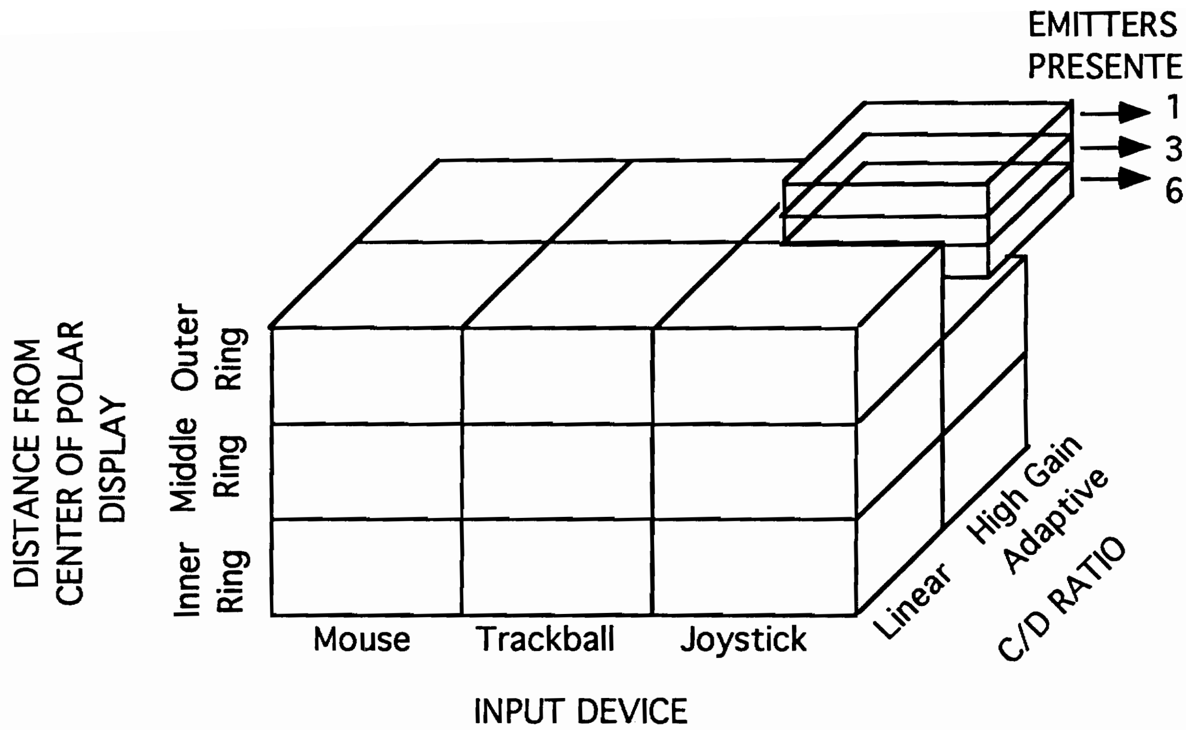


Figure 14. Experimental conditions used in the input device experiment.

The experiment was a 3x3x3x2 with-in subjects experimental design (Figure 14). The 54 total trials per participant were blocked by input device and C/D ratio. That is, participants received three random replications of three emitter presentations at each C/D ratio before changing to another input device type. Presentation order of C/D ratios and input device types was randomized uniquely for each participant. Each participant had to show a level of proficiency with each device and C/D ratio before they could proceed with the experiment. A simulated AN/SLQ-32(V) Polar Display was developed with a Macintosh IIfx. The highlighted emitters were generated randomly and uniquely for each trial.

Each participant subjectively rated the devices following the completion of the study.

The devices used in the study were standard civilian devices:

1. Trackball - Turbo Mouse ADB, Model 62360. Manufactured by Kensington Microwave Limited, New York, New York.
2. Mouse - Apple Desktop Bus Mouse
3. Isotonic Joystick - Gravis MouseStick and processing unit, manufactured by Advanced Gravis Computer Technology, Ltd., Bellingham, Washington.

The results of the experiment apply to the specific devices that were used. Specific mention should be made that the joystick used in the study was an isotonic (displacement) joystick and not an isometric (force) like the one used on the AN/SLQ-32(V). Due to cost constraints, procurement of an Apple Desktop Bus (ADB) compatible isometric joystick was not possible.

3.1.2 Results and Discussion

The time and error data were subjected to separate four-factor, within-subjects Analysis of Variance (ANOVA) procedures. Due to the low number of errors committed by the participants (i.e., <1%), the ANOVA results for this dependent variable were deemed to provide no useful information and, therefore, are not reported or discussed further herein.

The ANOVA for time is shown in Table 2. As shown, the main effects of Device, Area, and Sequence were significant ($p < 0.05$), as were the two factor interactions between Device and Area, Area and C/D Ratio, Device and Sequence, and Area and Sequence ($p < 0.05$). The three-factor interactions among Device, Area, and Sequence and Area, C/D Ratio, and Sequence also were significant ($p < 0.05$). Degrees of freedom for all within-subjects effects in Table 2 were adjusted according to the Greenhouse-Geisser (1959) correction for violations of sphericity. A full discussion of these statistical findings can be found in Beaton (1992).

The ANOVA in Table 2 indicated a P-value of .0001 for the main effect of device. Figure 15 shows a comparison of the three input devices used in the study. Each bar graph shows the mean time to select the highlighted emitters for all subjects. The small "T" located at the top of each bar indicates the standard error of the mean for each bar graph. There is no significant difference in emitter selection time between the mouse and the trackball. The joystick, however, is significantly slower. Based on this data, either the trackball or the mouse can be the recommendation for the input device for the AN/SLQ-32(V).

Based on interviews with AN/SLQ-32(V) operators, it was noted that the isometric joystick can be difficult to operate under

Table 2. ANOVA Summary Table for the Input Device Study

Type III Sums of Squares

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F-Value	P-Values	Greenhouse Geisser Correction
Subject	9	4.601E2	51.1243			
Device	2	2434.7	1217.35	2.319E2	.0001	.0001
Device * Subject	18	94.5048	5.2503			
Area	2	8.341E2	417.0693	1.28E2	.0001	.0001
Area * Subject	18	58.6433	3.2580			
CD_Ratio	1	14.5828	14.5828	4.1089	.0733	.0733
CD_Ratio * Subject	9	31.9415	3.5491			
Sequence	2	1.189E4	5.9472E3	5.966E2	.0001	.0001
Sequence * Subject	18	1.794E2	9.9694			
Device * Area	4	90.3417	22.5854	20.2973	.0001	.0001
Device * Area * Subject	36	40.0582	1.1127			
Device * CD_Ratio	2	99.0667	49.5334	14.1862	.0002	.0015
Device * CD_Ratio * Subject	18	62.8498	3.4917			
Area * CD_Ratio	2	41.1377	20.5688	20.6910	.0001	.0001
Area * CD_Ratio * Subject	18	17.8937	.9941			
Device * Sequence	4	8.959E2	223.9714	1.288E2	.0001	.0001
Device * Sequence * Subject	36	62.5911	1.7386			
Area * Sequence	4	3.369E2	84.2332	77.7865	.0001	.0001
Area * Sequence * Subject	36	38.9836	1.0829			
CD_Ratio * Sequence	2	1.5696	.7848	.4219	.6621	.5532
CD_Ratio * Sequence * Subject	18	33.4824	1.8601			
Device * Area * CD_Ratio	4	13.1647	3.2912	3.7393	.0121	.0306
Device * Area * CD_Ratio * Subject	36	31.6854	.8801			
Device * Area * Sequence	8	37.3820	4.6727	7.4317	.0001	.0003
Device * Area * Sequence * Subject	72	45.2708	.6288			
Device * CD_Ratio * Sequence	4	25.0104	6.2526	3.0697	.0283	.0910
Device * CD_Ratio * Sequence * Subject	36	73.3285	2.0369			
Area * CD_Ratio * Sequence	4	16.6145	4.1536	6.1353	.0007	.0035
Area * CD_Ratio * Sequence * Subject	36	24.3722	.6770			
Device * Area * CD_Ratio * Sequence	8	13.2726	1.6591	2.4571	.0206	.0843
Device * Area * CD_Ratio * Sequence * Subject	72	48.6159	.6752			

Dependent: Time

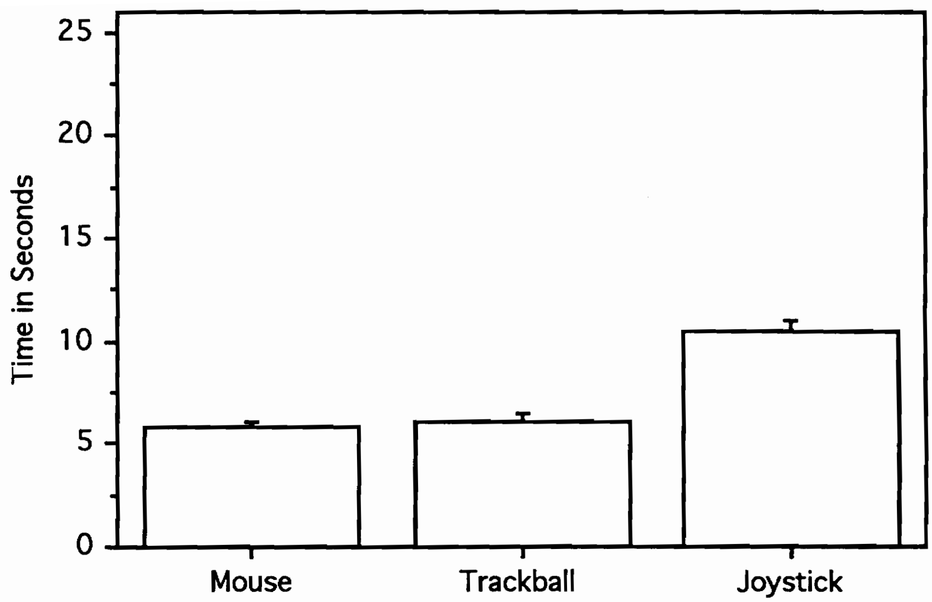


Figure 15. Main effect of device in display trade-off experiment.

conditions of excessive ship movement (Interviews with Petty Officer Clark and Petty Officer Williams). Although operators can stabilize their forearm and palm on the DCC; excessive ship roll, pitch, and yaw makes it difficult to position the cursor precisely and quickly. Under these conditions, operators often defer to the use of the SEQ FAB (Sequence Fast Action Button) to place an emitter into close control. However, when in a dense emitter environment, the operators interviewed preferred to manipulate the cursor with the input device to place the emitter in close control (Beaton, 1991).

The unavoidable presence of ship movement has implications for the selection of alternate devices for cursor positioning on the AN/SLQ-32(V) DCC. It is likely that any input device that allows rapid cursor movement (i.e., high control/display ratio) will be susceptible to ship movement and vibration. Thus, an operator adjustment for device sensitivity is warranted. Also, it is important to recognize that forearm and palm stabilization are important workstation design features that minimize operator fatigue and misplacement of cursors under ship movement conditions. Certainly, input device types (i.e., light pens, touch screens, data gloves) which do not provide forearm and palm stabilization should be avoided.

In a larger study of input devices conducted by Brian Epps (1986), five cursor control devices were compared on a target acquisition task. The devices included the following: trackball, mouse, relative touchpad, displacement joystick (isotonic), and a force joystick (isometric).

The results from the Epps study showed that, in general, subjects performed the best with the mouse, trackball, and relative touchpad; the worst performance was obtained with rate controlled joysticks. When the devices were compared across target size, a measure of positioning accuracy, differences among devices were very pronounced at the smallest target sizes. For example, the mouse and trackball were significantly better than all other devices at the smallest target size. Results at the second smallest target size were very similar, with the exception that the absolute touchpad improved relative to the trackball and the mouse, in terms of target positioning performance. As the target size increased, differences among devices became less pronounced and, in fact, were not significant at the largest target size.

3.2 Display Trade-Off Experiment

The following display features of the DCC were identified as areas in which trade-offs could be examined:

- Primary display format (Polar vs. Range)
- Emitter symbology (Existing symbols vs. New iconic symbols)
- Color (Achromatic vs. Multicolor display device)

These three areas were examined in the context of operator performance during the Integrated Task (IT) performed under three emitter densities. The IT task consists of the actions that the EW performs to evaluate and identify an emitter on the AN/SLQ-32(V). The criteria for performance were time-to-complete the task and errors in hooking emitter icons.

3.2.1 Equipment and Methods

The primary mission of the AN/SLQ(V) operator is to maintain a known electronic environment. The operator's basic task includes:

- recognizing that a new emitter is present
- evaluating information about that emitter
- determining the appropriate Electronics Intelligence number (ELINT) for the emitter and designating the emitter with the proper ELINT (AN/SLQ-32(V) Operator Manual, 1983).

This IT was the primary task used to test changes to the user interface design. The IT consists of the following steps:

1. Operator hears an alert and new emitters appear on the display.
2. Operator selects an emitter with the input device.
3. Operators uses the following sources of information to evaluate the target emitter:
   a. Close control parameters (information assigned by the system, which like the real system, may or may not be accurate)
   b. Signal Select (an audio presentation of the hooked emitters scan)
   c. A frequency spectrum analyzer (for acquiring an accurate pulse repetition frequency or PRF)
4. Operator searches through publications and/or on-line library of emitter parameters for an identification and confirmation
5. Operator designates the emitter with the proper ELINT.

The trade-off study was designed to test the effect of several variables on time to complete the integrated task and the number of errors made by the operator. The variables manipulated were:

- Primary display format (Polar vs. Range)
- Emitter symbology (Existing symbols vs. New iconic symbols)
- Color (Achromatic vs. Multicolor display device)

The eight possible combinations of these display features were tested under three different emitter density situations. A synopsis of some of the issues for the selected display features for this effort is given below.

3.2.1.1 Primary Display Format. The Range display employs a known method for displaying range information. The Range display provides an operator with a top-down view of the battlegroup operating area. Currently, the AN/SLQ-32(V) operator uses a Polar display which does not have range information. Rather, range information must be retrieved from other system operators to help him ascertain the criticality of an emitter. While the Polar format was designed to aid the operator in quick detection and identification of missiles through location coding with respect to emitter type, the Range display assists the EW interpretation of the overall "picture" of the tactical environment by providing range information for emitters. The Range display is consistent with FAA radar scopes and the NTDS system in the CIC. Compatibility between the AN/SLQ-32(V) and the other CIC systems would be improved with a Range display. Color coding and descriptive icons were used to identify emitters in a Range display.

3.2.1.2 Emitter Symbol Set. Research in icon design shows that representative pictures of the information elements are more likely to be remembered and understood. The current symbol set for the AN/SLQ-32(V) consists of abstractions that do not represent the emitters in a pictorial manner. The trade off study tested the current symbols and a set of symbols that are less abstract. For example, current icons for missiles () were compared to new, more representative symbols (), and current icons for hostile airplanes (), were compared to symbols which look like aircraft ().

Figure 16 shows a comparison between the current and new symbols. All friendly symbols have curved faces, while the hostile symbols use straight lines. Airborne emitters have a top face, while subsurface emitters use the lower face. It is assumed that this implies an altitude rule for determining where the face of the icon belongs. Surface and Land symbols use a diamond shape enclosure. Missiles are a convoluted "X", and an unknown is represented by an inverted-U with squared corners above a dot.

3.2.1.3 Color Coding. Color coding may facilitate the EW tasks by reducing errors and search/detection times for the presence of new emitters. The current system uses location coding in concentric rings to distinguish missiles, friendly targets, and hostile/unknown targets. Considering the large amount of information presented to the operator and the need for efficient processing of information, the trade-off study investigated the impact of color on the performance of the operator.

3.2.1.4 Emitter Density Levels. Three density levels were used in the trade-off study:

- Caribbean - Low density
- Persian Gulf - Medium density
- Armageddon - High density

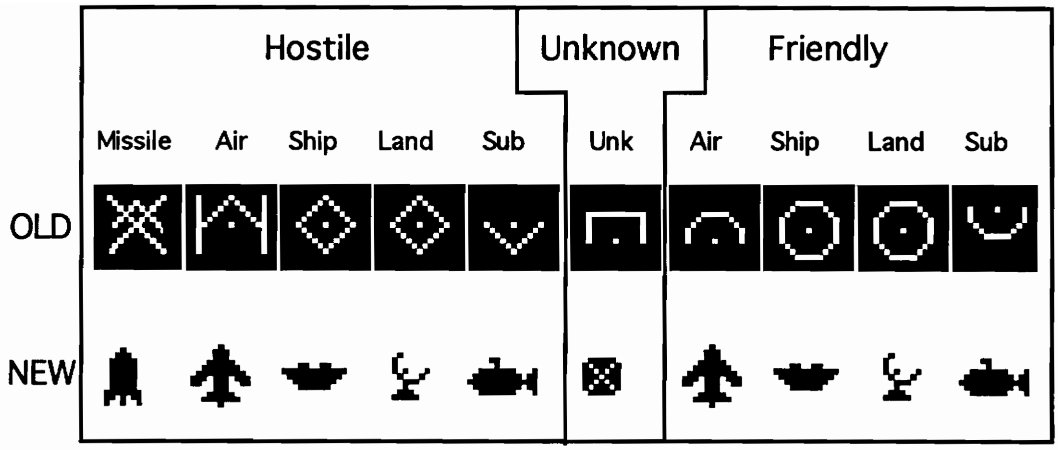


Figure 16. Emitter symbol set used in the display trade-off experiment.

During any one session, an initial block of emitters was presented to the subject. Subsequently, additional blocks of emitters were presented at fixed time intervals. The initial number of emitters in each block and the time interval was different for each emitter density level. The specific information on each emitter density level is shown in Table 3.

Table 3. Emitter Density Levels in Display Trade-Off Experiment

	Initial Emitter Density (dummy emitters)	Time between blocks (secs)	Number of Blocks (during a trial)	# of Starting Blocks (initially presented)	Number of Emitters (in a block)	Total Emitters (at the end of the trial)
Carrib	10	60	7	2	4	38
Gulf	40	45	9	1	4	76
Armag	70	30	14	1	4	126

3.2.2 Results and Discussion

Table 4 shows the mean times to hook an emitter over the range of different conditions. These values include the time that operators took to look at the threat summary list and the primary display, to move the cursor to the desired emitter, and to select the emitter.

Table 4. Mean Time to Hook Emitters in Trade-Off Experiment

Format	Symbols	Color Condition	Density	Time (sec)
Polar	Old	B/W	Carribean	5.282
Polar	Old	B/W	Gulf	5.743
Polar	Old	B/W	Armag	6.719
Polar	Old	Color	Carribean	3.342
Polar	Old	Color	Gulf	4.481
Polar	Old	Color	Armag	5.247
Polar	New	B/W	Carribean	4.591
Polar	New	B/W	Gulf	4.297
Polar	New	B/W	Armag	5.318
Polar	New	Color	Carribean	3.707
Polar	New	Color	Gulf	4.576
Polar	New	Color	Armag	5.371
Range	Old	B/W	Carribean	3.433
Range	Old	B/W	Gulf	4.132
Range	Old	B/W	Armag	4.704
Range	Old	Color	Carribean	4.122
Range	Old	Color	Gulf	4.671
Range	Old	Color	Armag	4.497
Range	New	B/W	Carribean	3.625
Range	New	B/W	Gulf	5.146
Range	New	B/W	Armag	5.571
Range	New	Color	Carribean	3.320
Range	New	Color	Gulf	4.191
Range	New	Color	Armag	5.194

The Range display provides the operator with more information than the Polar display. He basically has two coordinates to search for the emitter; range and bearing. The Polar display provides bearing information, and the type of emitter which can direct him to a portion of the Polar display. However, when the densities of the emitters increases in the Polar display, the operator may have more than one emitter of the same type along the same bearing. This can lead to mistakes by the operator and increases the search time. Figure 17 shows that the Range display is significantly faster than the Polar display.

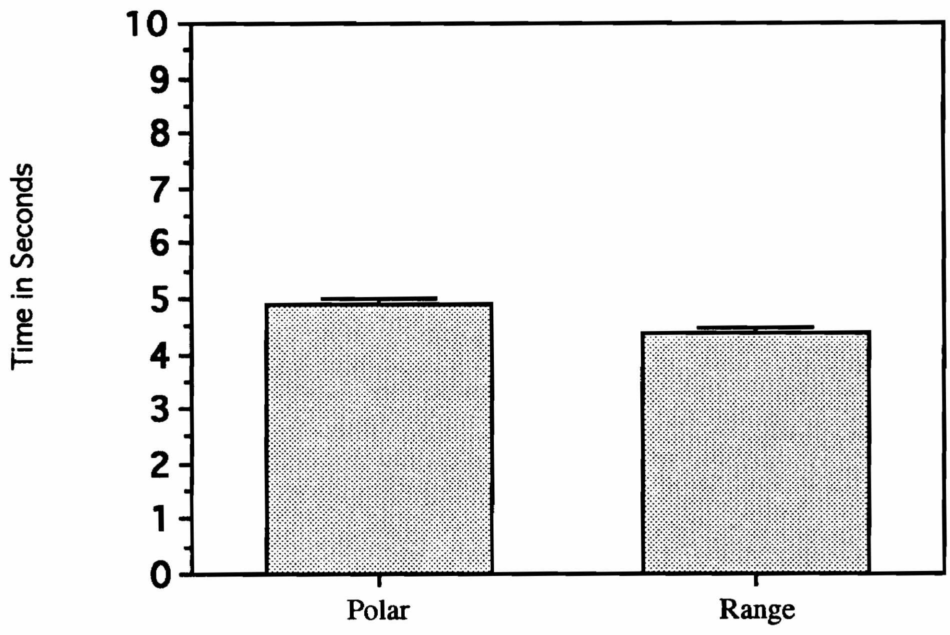


Figure 17. Main effect of display format in display trade-off experiment.

The current symbol set is a cryptic grouping of lines and dots that represent different types of emitters, as shown in Figure 16. The trade-off study compared a new iconic symbol set to the current symbol set. Figure 18 shows that the new symbols were significantly faster than the old symbol set.

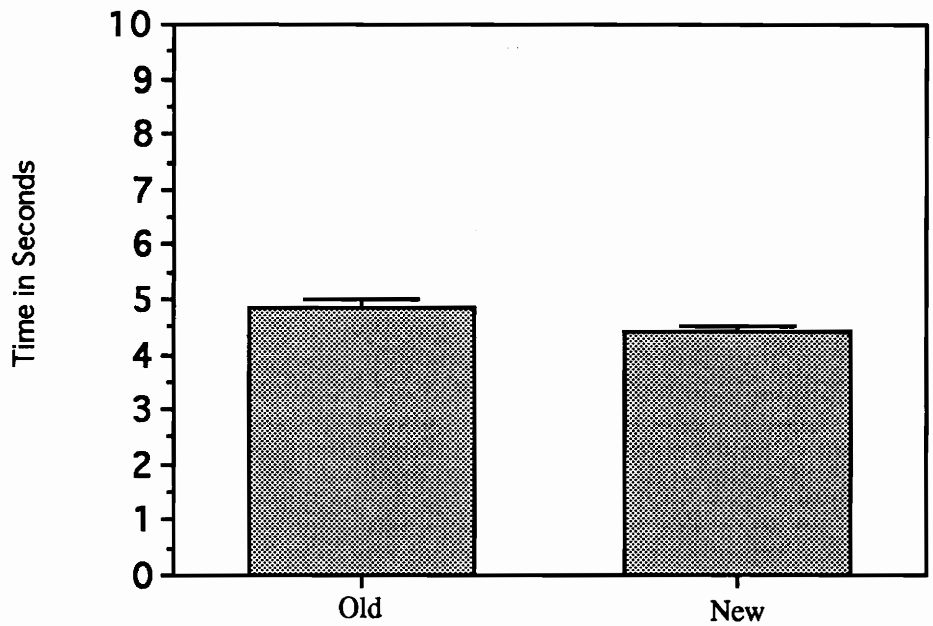


Figure 18. Main effect of symbols type in the display trade-off experiment.

In a study of visual coding, Smith and Thomas (1964) used four different types of visual codes in a counting task (i.e. aircraft shapes, geometric forms, military symbols, and colors). The object of the task was to count the number of a given item from a large display which included many other items of the same class. The results showed a clear superiority for the color codes through all density levels. The same study also found that iconic representations of a military symbol to be superior to the geometric form of the same symbol (Sanders and McCormick, 1987). Although the task was different, the results can be utilized for the AN/SLQ-32(V) application. Figure 19 shows that the color emitters were significantly faster than the black and white emitters.

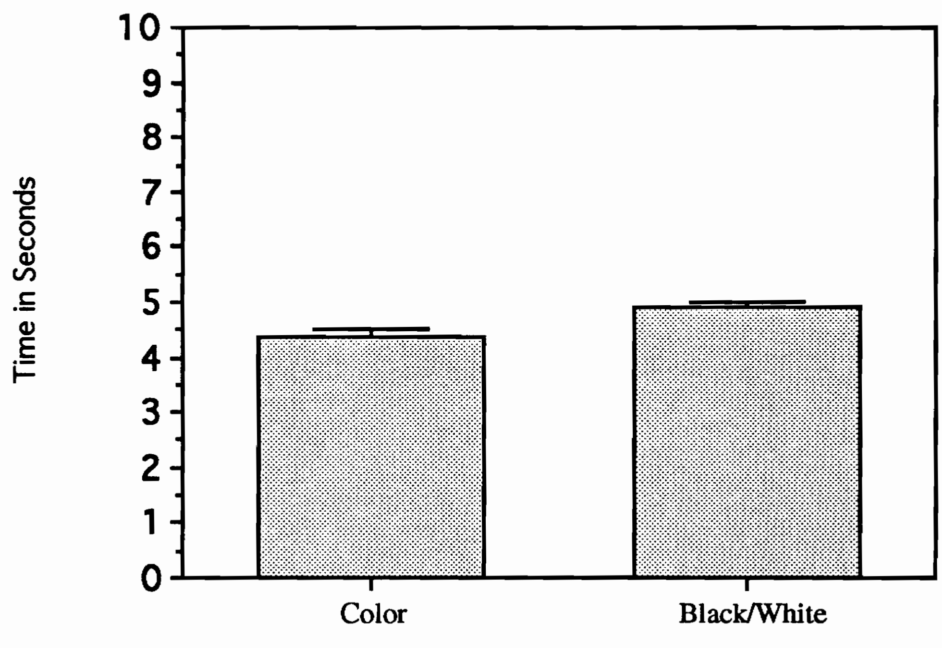


Figure 19. Main effect of color coding in display trade-off experiment.

V. CONCLUSIONS

4.1 Recommendations

4.1.1 Input Device

Since the trackball and mouse rated highly in the input device experiment and in the Epps study, several subjective observations can be made concerning the selection of an input device. These subjective comments were taken as auxiliary ratings to the input device study and from EW operator interviews. Overall, a highly-damped trackball may be suited best for use with the AN/SLQ-32(V). First, it allows the operator to maintain forearm and palm contact with the console for improved stability under rough sea conditions. Wrist and forearm support can be built into the device. The use of a recessed trackball in future devices is a design option. Second, a trackball can be configured with finger-activated switches that do not require the operator to raise the palm out-of-contact with the device to activate the "hook" FAB. The joystick on the AN/SLQ-32(V) requires the operator to move the hand away from the joystick to activate the Hook FAB.

Based on the results of the input device study using a simulated AN/SLQ-32(V) screen, the results from the Epps study, and subjective criterion, the use of a trackball is recommended as the cursor positioning input device. The trackball was used in the

OSD, and the time estimate for hooking the target came from the input device study.

4.1.2 Displays

A Range display is a recognized way to display range information and rate of travel to the EW operator. Currently, range information is acquired from NTDS or other CIC operators. The Range display facilitates the EW understanding of the overall "picture" of the tactical environment by giving a true representation for the location of emitters. The range display also is consistent with other display systems in the CIC (e.g., the NTDS). Thus, the use of a range display on the AN/SLQ-32(V) would improve the compatibility between the AN/SLQ-32(V) and the other CIC systems. The AN/SLQ-32(V) operator would not have to ask other NTDS operators the ranges of emitters. This would cut down on the amount of communications needed within a noisy CIC. The range display provides the operator more information about the emitter and helps him select the emitter more quickly.

4.1.3 The Use of Color

In a redesign of the AN/SLQ-32(V), only a few colors are needed to differentiate the threat level of emitters. A color coding scheme based on a compatibility between color and threat was established; red for missiles, orange (similar to red) for hostile emitters, yellow for unknown emitters (caution), and green (okay) for friendly emitters. The colors should be easy to discriminate from each other and the background. The use of the new symbols provide faster selection times for the operator at all emitter densities.

4.1.4 Function Allocation

An analysis of the operational sequence diagram in Section 2.4 was performed to examine the allocation of the operator's attention resources. The EW operator receives most of the information needed to process new emitters from the CRT display of the DCC. This allows him to concentrate his primary attention resources on the IT task. The additional pieces of equipment added to the AN/SLQ-32(V) have diverted the attention resources of the EW operator away from the CRT display. This is critical if the operator misses a visual cue from the system. It could also add to the operator's fatigue during the conduct of his watch. Table 5 shows where the operator's attention resources are allocated during the IT task:

Table 5. EW Operator Attentional Resource Allocation

Area of EW Work Space	% of Operator's Attention
AN/SLQ-32(V) CRT screen/DCC	20
O-Scope / Listen to Audio Signal	6
ULQ-16	11
Publications	63

This breakdown shows the large percentage of time that the operator spends reviewing the publications. Although a large number of emitters are known to exist world–wide, the AN/SLQ–32(V) main and on-line library facilities hold only a small portion of this information. Consequently, the operator must maintain access to a series of hard–copy publications that contain databases of known emitter parameters. These publications are stored along side the AN/SLQ–32(V) workstation where the operator can scan their contents to identify emitters (See Figure 8 for pubs holder).

The process of manually scanning publications for emitter identification information is tedious and time consuming. Moreover, since the operator often needs to review these publications during critical periods of the watch, the current method of publication usage may lead to undesirable and hazardous consequences. Clearly, the storage capacity of the AN/SLQ–32(V) must be increased to eliminate the need for manual scanning and memorization of published emitter databases.

4.2 Future Directions

The recognition and documentation of a problem is an essential first step in system development. The operational sequence diagram for the AN/SLQ-32(V) and related trade-off studies showed how improvements in current system performance could be implemented.

There are advanced concepts that impact on system performance and deserve future attention. The use of the publications in emitter identification is a problem area which has an impact on operator performance.

The limited AN/SLQ-32(V) library facilities force the operator to spend considerable time scanning and memorizing emitter parameters from hard copy publications. A complete, on-line emitter database is required to alleviate this problem. Note, however, that it is important to consider how the database is implemented. In other words, simply adding a large capacity hard disk to store emitter parameters will not solve the problem completely. Rather, a software interface designed as a structured query language is needed to facilitate access to the enormous number of emitters likely to be placed in the database. In related fashion, a software interface should be provided for the automatic data logging opportunities that accompany installation of large capacity hard disks.

The addition of a large capacity hard-disk to store all of the library would solve a few important problems.

1) Updates can be distributed via floppy disks or by a satellite uplink.
2) There will not be any publications to clutter the work area.
3) Search times for emitter types would be improved.

4) The need for an additional workstation to enter library information would not be necessary.

5) The majority of library updating would be done off-ship, with less likelihood of errors in entering the emitter information.

The allocation of more functions to the machine may cause the atrophy or loss of critical EW operator skills, the loss of job satisfaction, and boredom on long cruises with little EW activity. An additional area of future concern is the use of embedded training in the system. This embedded training could be used by the operator to maintain vigilance while on watch, it could also be a integral part of the operator's training sustainment program. The use of embedded training should be designed to give the EW operator and his supervisor feedback on his watch performance.

Any changes in the AN/SLQ-32(V) should consider the impact and integration of the EW work environment with the other systems in the CIC. The requirement for clear and concise communications in the CIC is essential. For example, the incorporation of range into the EW system may give the AN/SLQ-32(V) operator more information about his environment. This would give the operator information that he currently must ask for and would cut down on the noise level generated inside the CIC.

The AN/SLQ-32(V) Electronic Warfare system will continue to play an important role in the U.S. Navy well into the twenty-first century. Documentation of current problems and the accumulation of objective data is essential to system redesign efforts.

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