COMPARISON OF COMBAT SYSTEM ARCHITECTURES FOR FUTURE SURFACE COMBATANTS

by

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(ABSTRACT)

Between the years 2010 and 2020 the majority of today's U.S. navy's surface combatants will reach the end of their expected service life. Concurrently, there is a planned reduction in the overall size of the U.S. Naval surface fleet. The net result is that there will be fewer ships available to accomplish the same set of requirements. Therefore, the combat system for any new surface combatant must support a multimission role. The characteristics of that combat system have not yet been determined. More importantly, the combat system architecture, the structure which governs how the various components are interconnected, is still undefined.

Several different concepts are being considered for this architecture. A comparison of two of these concepts, the current Aegis Baseline 4 architecture and a new architecture called the Combat System Superset concept, is the subject of this project. The study evaluates the two concepts against both force level and single ship level effectiveness measures. The investigation focuses on how well each design concept supports antisurface warfare, a representative mission area required of all surface combatants. The project concludes that, within the scope of the investigation, the Superset concept is preferred, and recommends areas for further study.

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LIST OF ABBREVIATIONS

AAW	Antiair Warfare
ACS	Aegis Combat System
ADS	Aegis Display System
ASUW	Antisurface Warfare
ASUWC	Antisurface Warfare Coordinator
ASUWCS	Antisurface Warfare Control System
ASW	Antisubmarine Warfare
AWS	Aegis Weapon System
BDA	Battle Damage Assessment
BGDBM	Battlegroup Database Management
C&D	Command and Decision
CCB	Change Control Board
C^3	Command, Control, Communications
CDS	Combat Direction System
CIC	Combat Information Center
CNO	Chief of Naval Operations
CO	Commanding Officer
CSC	Combat System Coordinator
CSSQT	Combat System Ship Qualification Trials
DOD	Department of Defense
EO	Engagement Order
EPS	Engagement Planning Supervisor

ESM	Electronic Support Measures
ESO	Extended Surveillance Operator
EW	Electronic Warfare
FOTC	Force Over the Horizon Tactical Coordinator
FSO	Fleet Support Operations
GFCS	Gun Fire Control System Gun Fire Control Supervisor
GWS	Gun Weapon System
HASM	Harpoon Antishipping Missile
HM&E	Hull, Mechanical and Electrical
HWS	Harpoon Weapon System
I&W	Indications and Warning
IDS	Interface Design Specification
IR	Infrared
IMAV	Intermediate Maintenance Availability
INT	Intelligence
LCO	Launch Control Operator
LOG	Logistics
LSD	Large Screen Display
MOB	Mobility
MSS	Missile System Supervisor
NAVSEA	Naval Sea Systems Command
nmi	nautical mile
NSWSES	Naval Ship Weapons System Engineering Station
OSDC	Ownship Display Coordinator

OPTEVFOR	Operational Test and Evaluation Forces
OTCIXS	Officer in Tactical Command Information Exchange System
OTH	Over The Horizon
OTH-T	Over The Horizon - Targeting
RSC	Radar System Controller
SRA	Ship Restricted Availability
SRO	Surface Radar Operator
STW	Strike Warfare
SWS	Surface Warfare Supervisor
TAO	Tactical Action Officer
TASM	Tomahawk Antishipping Missile
TIC	Tactical Information Coordinator
TWCS	Tomahawk Weapon Control System
VLS	Vertical Launching System

SECTION 1

INTRODUCTION

Rationale

The year 2030 is a major transition point for the U.S. Navy. By that time almost all of today's surface ships will have been retired. To maintain desired force levels new surface ships must be built to replace them. The form of the combat system for these new surface ships has not yet been determined. More importantly, the combat system architecture, the structure which governs how the various components are interconnected, is still undefined. Several different design concepts for that architecture are being considered. This project will conduct a feasibility study comparing two of the concepts under review for future ships.

It is important to view a combat system from a systems engineering perspective. The Navy has not ignored systems engineering principles in its combat system development efforts. In fact various military standards require the development of a system engineering management plan, various combat system and component level specifications, etc. But future combat systems will be much more complex and will be required to handle multiple warfare areas simultaneously.

A warfare area is a required mission which the combat system must support such as conducting antisubmarine operations or detection and destruction of mines. The move to multiwarfare surface combatants makes it necessary to closely integrate the various components of the combat system. The decision was made to build integrated combat systems where the various components communicate via digital means. As a result the combat system will become more and more complex through the use of computers, automation and increased operator workloads. To control and manage the combat system throughout its lifetime requires viewing the combat system as a system and treating it as such.

Background

A combat system typically is viewed as the sensors and weapons (radars, sonars, missiles, guns, and torpedoes, etc.) which are used to detect and engage the enemy. But a combat system also includes the communication links, the computers, the displays, and the men who operate them. More formally, combat systems are complex open systems consisting of men, equipment, and computer programs designed to fulfill the ship's required missions.

The Navy has combat systems for aircraft, submarines, and surface ships. Surface ships can be placed into three categories: aircraft carriers; support ships such as underway replenishment ships, amphibious landing ships and command support ships; and surface combatants. Surface combatants can be further categorized as cruisers, destroyers, or frigates.

The U.S. Navy built most of today's surface combatants during the 1970's and 1980's. These ships will be retired en masse between 2010 and 2020. Generally these ships were designed to counter one type of threat such as submarines or long range bombers. The current budgetary situation will preclude the Navy from replacing these ships one for one. Instead, the Navy will need to build fewer surface combatants, which can each handle a variety of threats simultaneously, as replacements for the retiring ships. Experience has shown that it takes ten to twelve years to take an integrated combat system from conceptual design to deployment in the fleet. To maintain the desired force levels, a decision must be made within the next five years as to what future combat system architectures will be employed.

Approach

The objective of this project is to compare and contrast combat system design concepts being considered for these future surface combatants. These combatants must function in a variety of situations from single ship operations to full battle group oriented operations. Therefore, the deployed combat system must be capable of concurrent multiwarfare operations. A full comparison of any concept under review should include all the major warfare areas that a surface combatants must support such as Command, Control, and Communications, Antiair Warfare, Antisurface Warfare, and Antisubmarine Warfare. A task of that scope would take a team of analysts several months working full time to complete.

To limit the scope of that task, this project will just concentrate on the Antisurface Warfare (ASUW) portion of the combat system only. ASUW is a required mission area for all surface combatants and therefore is suitable to use as the basis for a comparative evaluation of any design concepts. ASUW is officially defined in OPNAVINST C3501.2G [1] as " ... the destruction or neutralization of enemy surface combatants and merchant ships to deny the enemy the effective use of its surface warships and cargo carrying capacity." Therefore the top level measure of effectiveness will relate to how well the combat system design concepts support the ASUW mission from both force level and single ship perspectives. The force level comparison is concerned with the impact that a new combat system design would have on all surface combatants in terms of ASUW. The single ship comparison is concerned with the combat system architecture's support of ASUW in the areas of upgradability, maintainability, and battle organization.

Scope

This project will focus on only two different combat system design concepts, denoted baseline and alternative. The baseline design is currently under production as the Baseline 4 Aegis Combat System. Figure 1 shows a high level block diagram of that configuration. This design features a quick reaction antiair warfare system interfaced to the control portion of the other warfare area systems. It currently applies to only two ship classes. The alternative design concept is a proposed force level Combat System Superset.[2] Figure 2 provides a block diagram of the proposed superset configuration. This concept features a common command and control structure to which the required sensors and weapons to support any warfare area would be interfaced. The design would apply to all ship classes, however, based on its required missions only a subset of components would be selected for deployment on a given ship class.

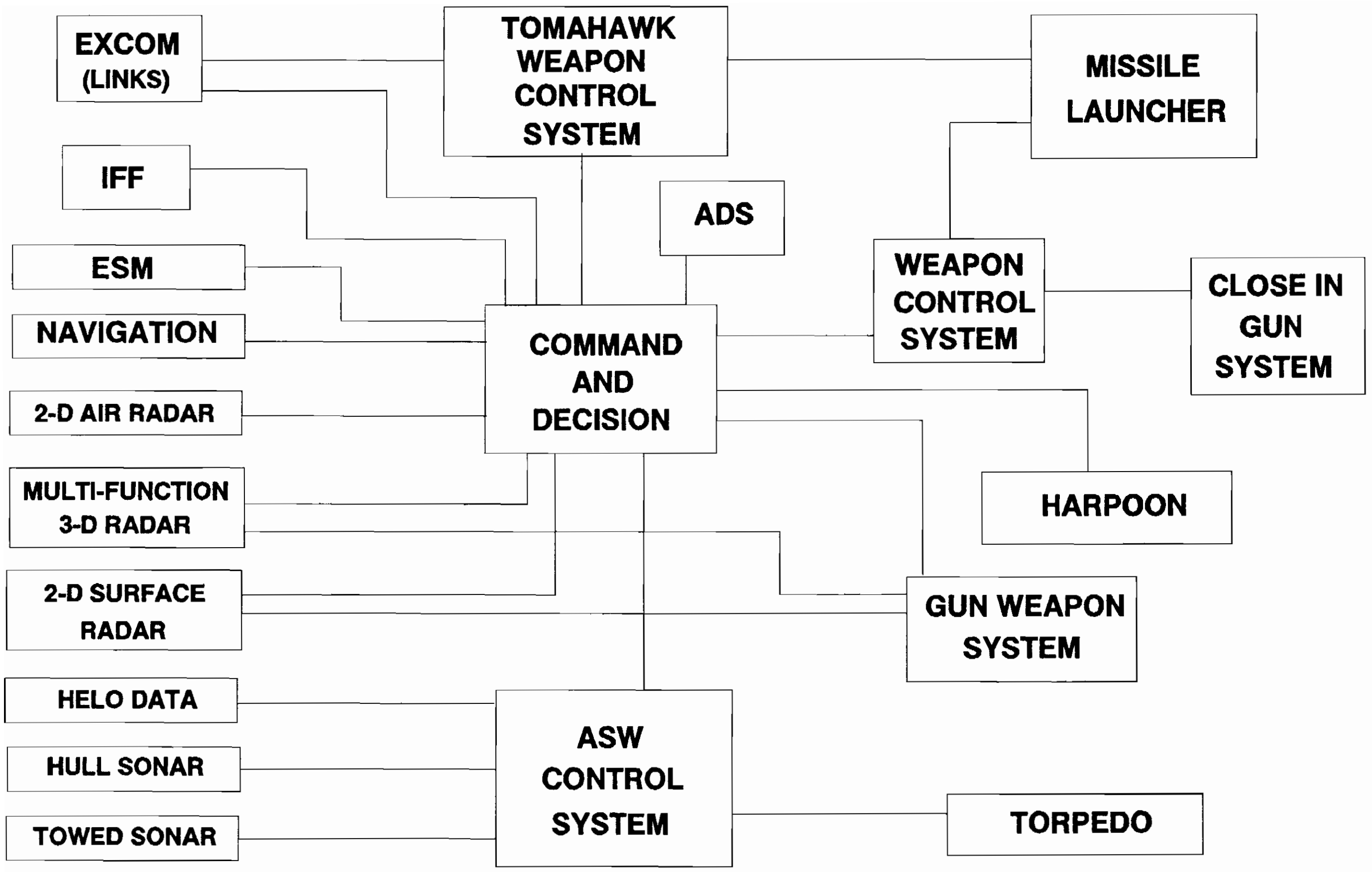

FIGURE (1): BASELINE 4 AEGIS COMBAT SYSTEM BLOCK DIAGRAM

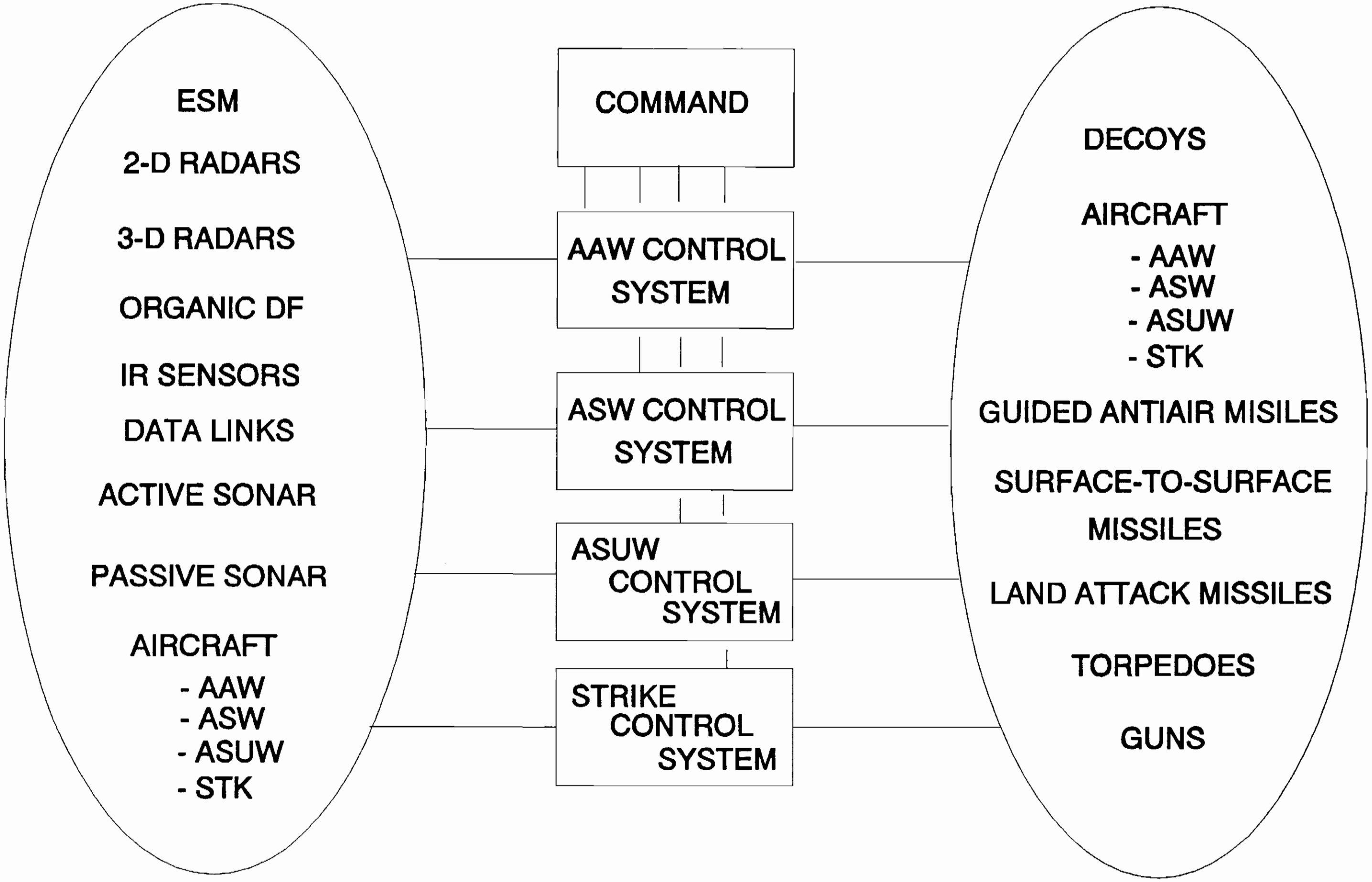

FIGURE (2): HIGH LEVEL BLOCK DIAGRAM OF SUPERSET CONFIGURATION

Constraints

For the purposes of this project the following assumptions will apply:

- The combat system is for a major surface combatant weighing between five and ten thousand long tons. This size is traditionally associated with cruiser and destroyer ship classes.
- The project is limited to ASUW implemented on a surface combatant using own ship weapons. It will not consider ASUW operations conducted by aircraft or by submarines
- While the actual equipment, computer programs, and force level command structure used in the fleet today are basically the same for both Strike warfare and Antisurface warfare, for this project it shall be assumed that shipboard Strike and Antisurface operations are totally independent warfare areas.
- This project is concerned with comparing at a high level two combat system architecture concepts. The concern is with functional allocation of tasks within the architecture. Therefore, this project will not be concerned with design implementation issues such as the use of local area networks and workstations.

SECTION 2

PROJECT BACKGROUND

This section provides a brief summary of the history of combat system development efforts and a description of the Antisurface Warfare process.

Overview of Combat System Evolution

Over the past fifty years the design and development of combat systems for naval surface combatants has changed. During World War II surface combatants served primarily as single mission area ships such as the anti-submarine destroyers. Immediately following World War II, weapons and sensors for any given mission were independent and manually coordinated and controlled. Integration consisted of crew training onboard the various combatants. The various pieces of the combat system were selected from those available from Navy supply which met the requirements for the ship. These pieces were never tested as a complete system until after they were installed on the ship.

With advent of radar directed antiair weapons the process from detection to engagement could no longer remain under manual control. Computers were necessary to perform the calculations for the feedback loops required to control and coordinate the radar and missiles. Instead of components being developed and selected, now a complete antiair weapon system consisting of a radar, missile and display was developed and tested. Rarely are all components of the combat system brought together in one location before they are installed on the ship.

In the late sixties, advanced concepts for a surface ship air defense system against a more severe antiship missile threat were developed and evaluated. This effort resulted in the development of the highly automated Aegis Weapon System (AWS). This antiair system consists of a phased array radar, a command control and display system, a weapon control system including several target illuminators, missile launchers, and missiles. Two unique aspects of the AWS are its own onboard automated training system and a shipboard equipment status and test system. Almost all the pieces of the AWS were bought together at a land based test facility to test the components and their interfaces. The exceptions were the missile and actual launcher mechanisms -- these were simulated at the land based site. An at-sea engineering development model of the system was produced and the concept proven through live missile firings. The initial AWS was successfully deployed on the Navy's new guided missile cruiser class in 1983.

Simultaneously with the AWS development effort, its command and control components were interfaced with the control elements for antisurface and antisubmarine warfare. This was done to satisfy a requirement for integrated multiwarfare operations on a surface combatant. The resulting system is known as the Aegis Combat System (ACS). What is important about the ACS's development is that the various components were integrated and tested at a land based test site before being delivered to the ship. While it was necessary to simulate some sensors and weapons at this test facility, all of the control elements were available for interface testing and integration. Several upgrades, in the form of equipment and level of integration to the ACS, have taken place within the past ten years. The ACS is now deployed on both the CG-47 and DDG-51 class ships. Therefore, the entire combat system on an "Aegis" ship is considered as a complete system. It was designed, developed, and is being maintained as such.

Unfortunately, the majority of the remaining surface combatants' combat systems have been designed at the component and subsystem level. These components are typically sensors, missiles, launchers, or weapon control systems for a single warfare area. Generally the major components of the combat system are not bought all together and tested until they are delivered to the ship. Some subsystems of these combat systems such as the Combat Direction System (CDS), Tomahawk Weapon Control System (TWCS), and the ASW Combat System AN/SQQ-89 have been developed as complete systems. They were designed, built, tested, deployed, and maintained as such. However, a total system perspective on the entire combat system was not taken.

So, Naval weapon systems have evolved from manually integrated components to highly automated, digitally interfaced systems. Weapon control systems for the various warfare areas exist which are considered as complete systems. As weapon system integration has evolved, the required tasks which the combat system must support have also evolved from a single mission area to support multiple mission areas simultaneously. To coordinate the various warfare areas ownship Command must interface with the various weapon control systems. The systems engineering view of the individual warfare areas that prevails today must be extended to the combat system level as the requirement for multimission surface combatants expands. This has been done in the ACS but needs to apply to all future surface combatants.

Overview Of Antisurface Warfare

Antisurface Warfare (ASUW) has been a mission area for the U.S. Navy from its beginnings. Until the introduction of aircraft and torpedoes the primary threats to surface ships were the guns and cannons onboard the enemy's ships. A ship's mission was to sink or cripple enemy vessels before being sunk itself. ASUW is generally a more offensively oriented warfare area than Antiair Warfare (AAW) or Antisubmarine Warfare (ASW). ASUW deals with the elimination of the enemy's surface vessels. ASUW is different from Strike Warfare which is an offensive action taken against targets located ashore.

ASUW operations have traditionally fallen into two categories. The first is a self defense mode where the ship defends itself from another ship, usually through the use of a gun. The engagement range and system effectiveness depend on the characteristics of the weapon and its associated fire control system. The second tends to be more offensive in nature and involves engaging targets beyond the range of the ship's sensors, that is over the horizon (OTH). Aircraft first fulfilled this aspect of ASUW. However, after World War II, an OTH antiship missile was developed for shipboard use. Over the past fifteen years the OTH region has subdivided into two regions. There are two reasons for this: (1) a new requirement for a longer range antishipping missile and (2) the development of new systems that provide longer range OTH detections. So, today there are three general categories of ASUW: (1) self defense, (2) OTH engagements within 150 nautical miles, and (3) OTH engagements beyond that distance. Each is a function of the range of the shipboard weapons used and of the source of the data used in planning the engagement or developing the fire control solution.

Examples of current shipboard ASUW OTH weapons include the Tomahawk Antishipping Missile (TASM) and the Harpoon Antishipping Missile. Engagement planning, which is equivalent to developing a fire control solution, requires access to OTH information for both missiles. The Harpoon Launch Control System can automatically generate a plan for the missile's flight path. The operator can also manually develop the engagement plan. For TASM, the plan must be developed manually. All surface combatants have Harpoons and their associated launch control system installed; less than a third have Tomahawks and their weapon control system installed.

All surface combatants have some form of gun system. The most common gun in use is the 5 inch 54 caliber gun. Most gun systems are supported by at least one surface search radar for detections and gun fire control. The fire control solution for aiming the gun at the target is automatically generated by the gun system's computer. An operator provides for the human control of the gun system.

For ASUW, most OTH targeting data is received from off-board systems such as shore facilities and similar national assets. The only shipboard sensor with a possibility of obtaining an organic OTH detection is a long range radio direction finding system. Each shipboard OTH ASUW targeting system must correlate the data received from these different sources. Due to track reporting errors, ownship alignment errors, other positional errors, and different correlation algorithms it is possible for each OTH ASUW system to develop a different tactical surface picture. This is a battlegroup level problem which has been recognized and solved. All shipboard systems involved in OTH ASUW operations must comply with the rules laid out in the Battlegroup Database Management (BGDBM) specification. According to this specification there is one coordinating unit to whom all other OTH systems participating in the battlegroup report. A participating unit sends any surface track or contact it obtains to the coordinating unit. The coordinating unit merges and correlates data received from all such units into one common OTH surface picture. All participating units then receive this picture for use in their OTH surface operations.

Within the horizon, surface search radars develop and maintain their own tracks. These tracks are then exchanged throughout the taskforce via the Navy's standard battlegroup communication link. On an individual ship, the Navy's Shipboard Gridlock System (SGS) will calculate and apply gridlock pads, relative to the battlegroup reference point, to these surface tracks to create the within taskforce surface picture.

In the classic sense, all warfare mission areas follow a three step process of detect-control-engage. This three step process can be broken down into steps specific to ASUW. After detection, an object must then be identified. Identification involves both classification and recognition. For surface operations it is important to know what types of ships are out there, i.e. recognition, and whether or not they are considered friendly, hostile, neutral, or unknown, i.e. classification. Command also wants to know the result of an engagement, so any ASUW system must do engagement assessment. Thus, the process

Detect --> Control --> Engage

can be broken down into

Detect --> Classify --> Recognize -->
Control --> Engage --> Assess

Control can be divided into that needed for weapon control and fire control solutions, and that for command and control purposes throughout the ship and battlegroup. The command and control portion is more concerned with evaluating the data presented to it and what course of action should be taken. The process is now

Detect --> Classify --> Recognize --> Evaluate Situation -->
Decide --> Select Weapon --> Target --> Engage -->
Assess (--> Detect --> Classify --> Recognize -- >.....)

Any ASUW engagement, within horizon or OTH, must go through this type of process. Each step in this process could be examined in more detail. However this project will concentrate on the weapon control and command control aspects of ASUW only and how these functions interact in the combat system design concepts being evaluated.

SECTION 3

FEASIBILITY ANALYSIS

Statement Of Need

Today there are approximately two hundred surface combatants. Fifteen different classes of cruisers, destroyers, and frigates comprise these surface combatants. The oldest of these ship classes will be retired by the year 2000 leaving the Navy with 164 surface combatants in nine different ship classes. There will be no degrading of the fleet's capability since thirty six of the Navy's newest surface combatants will be commissioned within the same timeframe. The problem occurs around the year 2020 when approximately ninety ships commissioned in the late 1970's and early 1980's reach the end of their forty year life expectancy.

The U.S. Navy can no longer afford to build and maintain surface combatants whose combat system is optimized for just one or two warfare areas. Nor can the Navy support today's total numbers of surface combatants. However, if the Navy is to fulfill established requirements, it will require between 145 and 150 surface combatants [3]. Further, the overall performance capability of the fleet must be maintained. Therefore, the Navy will require a highly capable surface combatant whose combat system is capable of both offensive and defensive actions, alone or within a task force, in a multi-warfare environment.

System Operational Requirements

Mission Definition For Combat System

Primary warfare missions which the combat system must support include: antiair warfare (AAW), antisurface warfare (ASUW), antisubmarine warfare (ASW), command,control, and communications (C^3). Secondary warfare missions include: intelligence (INT), electronic warfare (EW), and strike warfare (STW). For a surface combatant the combat system must also support the mission areas of fleet support operations (FSO), logistics (LOG), and mobility (MOB). Formal definitions of these mission areas are found in [ ].

The combat system is therefore required to perform AAW, ASW, ASUW, and STW missions against the threat predicted for the early twenty-first century. Accordingly, the combat system must:

1) Be capable of performing air, surface, and subsurface detections

2) Be able to detect, localize, and classify targets within ship sensor's horizon.

3) Be capable of simultaneously developing engagement plans and controlling engagements in all warfare areas.

4) Have some means of evaluating the results of any engagement

5) Have basic self defense capability against air, surface, and subsurface threats

Mission Definition for Antisurface Warfare System

In support of the official definition of ASUW stated earlier, the shipboard antisurface portion of the combat system must:

- Provide surface tracks via organic sensors
- Support the ship's self defense via an appropriate weapon, traditionally a gun
- Have access to the Navy's standard general purpose OTH data links
- Have access to information available from the ship's own special intelligence system
- Support the engagement planning, weapon control, and firing of at least one type of long range OTH antishipping missile

Performance and Physical Parameters For the Combat System

The combat system must meet the requirements outline is the following paragraphs.

Given today's budget environment the combat system shall be easy to maintain and to upgrade. The combat system design shall be modular where possible to allow for ease of component upgrade and for actual system production.

Since this surface combatant must serve a multimission role, no individual warfare area shall be given preference within the combat system design. The combat system shall efficiently and effectively support the battle organization through the proper displays and database connections. The combat system must support the overall battle force structure. A key attribute of this structure is the Force Coordinator who oversees the operation of a specific warfare area throughout the entire battle force. The combat system must be capable of assuming the role of Force Coordinator in different warfare areas. The command and control structure implemented in the combat system must support higher level command structures.

The design shall be survivable and allow for graceful degradation of performance in the event of battle damage or component failure.

The combat system shall be required to follow applicable Department of Defense (DOD) software engineering standards in all computer program development. All hardware shall meet military and DOD standards as influenced by the Hull, Mechanical and Electrical (HM&E) requirements.

The combat system design shall provide for efficient and streamlined operations. It shall be capable of easily passing data between the various combat system components.

Each operator's console display shall be clear, concise, and optimized for the task. The system shall be simple in design and easy to use, thereby simplifying training.

The combat system design shall minimize the use of personnel. However, human operators shall be required to maintain final control over all combat system activities. The combat system design shall require approval by the appropriate operator before engagement can occur. Final control shall rest with the ship's captain. Operators shall be responsible for the maintenance of all shipboard equipment and computer programs, as necessary. The design shall allow operators to monitor the tactical situation via console driven displays and to enter data at those consoles.

Combat system communications shall be accomplished through standard navy communications networks, including the use of satellite communications.

The combat system shall be capable of developing a coherent tactical picture. This shall include both force level and individual warfare area displays. The combat system design shall support the dissemination of this picture to the appropriate users.

Performance and Physical Parameters For AntiSurface Warfare

Since ASUW is just one part of the surface combatant's mission, the ASUW control system shall be a fully integrated subsystem of the combat system to which it belongs. The ASUW control system shall interface with ownship command.

The ASUW control system shall be able to obtain OTH data on air and surface targets. If the surface combatant is assigned an OTH role then the ASUW control system must respond in accordance with the Battlegroup Database Management (BGDBM) rules which have been imposed by the fleet commanders on OTH systems. In this role, the ASUW control system will <u>not</u> be responsible for generating the force level OTH surface picture. This picture will be provided by the force ASUW coordinator according to BGDBM rules. The ASUW Control System shall require approval from the force ASUW coordinator before initiating any OTH ASUW engagements.

The ASUW control system shall require one or more operators who will be responsible for transmitting and receiving OTH information with the force ASUW coordinators and for planning and controlling ASUW engagements.

Operational Deployment

The combat system shall be installed on surface combatants which will be replacing the ships retiring in the post 2010 timeframe. This will insure that by 2030 the majority of the surface combatants have this new combat system design. The combat system is considered fully subsystem of the combat system to which it belongs. The ASUW control system shall interface with ownship command.

The ASUW control system shall be able to obtain OTH data on air and surface targets. If the surface combatant is assigned an OTH role then the ASUW control system must respond in accordance with the Battlegroup Database Management (BGDBM) rules which have been imposed by the fleet commanders on OTH systems. In this role, the ASUW control system will not be responsible for generating the force level OTH surface picture. This picture will be provided by the force ASUW coordinator according to BGDBM rules. The ASUW Control System shall require approval from the force ASUW coordinator before initiating any OTH ASUW engagements.

The ASUW control system shall require one or more operators who will be responsible for transmitting and receiving OTH information with the force ASUW coordinators and for planning and controlling ASUW engagements.

Operational Deployment

The combat system shall be installed on surface combatants which will be replacing the ships retiring in the post 2010 timeframe. This will insure that by 2030 the majority of the surface combatants have this new combat system design. The combat system is considered fully operational after the first ship passes standard Navy tests established by the Operational Test and Evaluation Forces (OPTEVFOR), concluding with the Combat System Ship Qualification Trials (CSSQT). After analysis of CSSQT data indicates adequate performance the ship will be deployed in the active fleet. Between 2010 and 2030 approximately one hundred ships will receive the new combat system.

One complete combat system will be located at a facility designated by the Navy for the development and combat system level integration and testing. It will be necessary to simulate certain portions of the combat system, such as live ordnance, at this facility. This development facility must be operational at least three years prior to the final land based testing of the combat system. This event must occur eighteen to twenty-four months prior to the desired fleet introduction date. Therefore this facility must be on line between 2005 and 2006. This or a similar site must be maintained for future software maintenance.

One complete system must be maintained on each coast at the Navy's two major facilities for combat system level training. These facilities must be on line at least one year prior to the commissioning of the first ship and must be maintained throughout the life of the combat system.

To meet this schedule the combat system must be produced to match the production profile shown in figure 3.

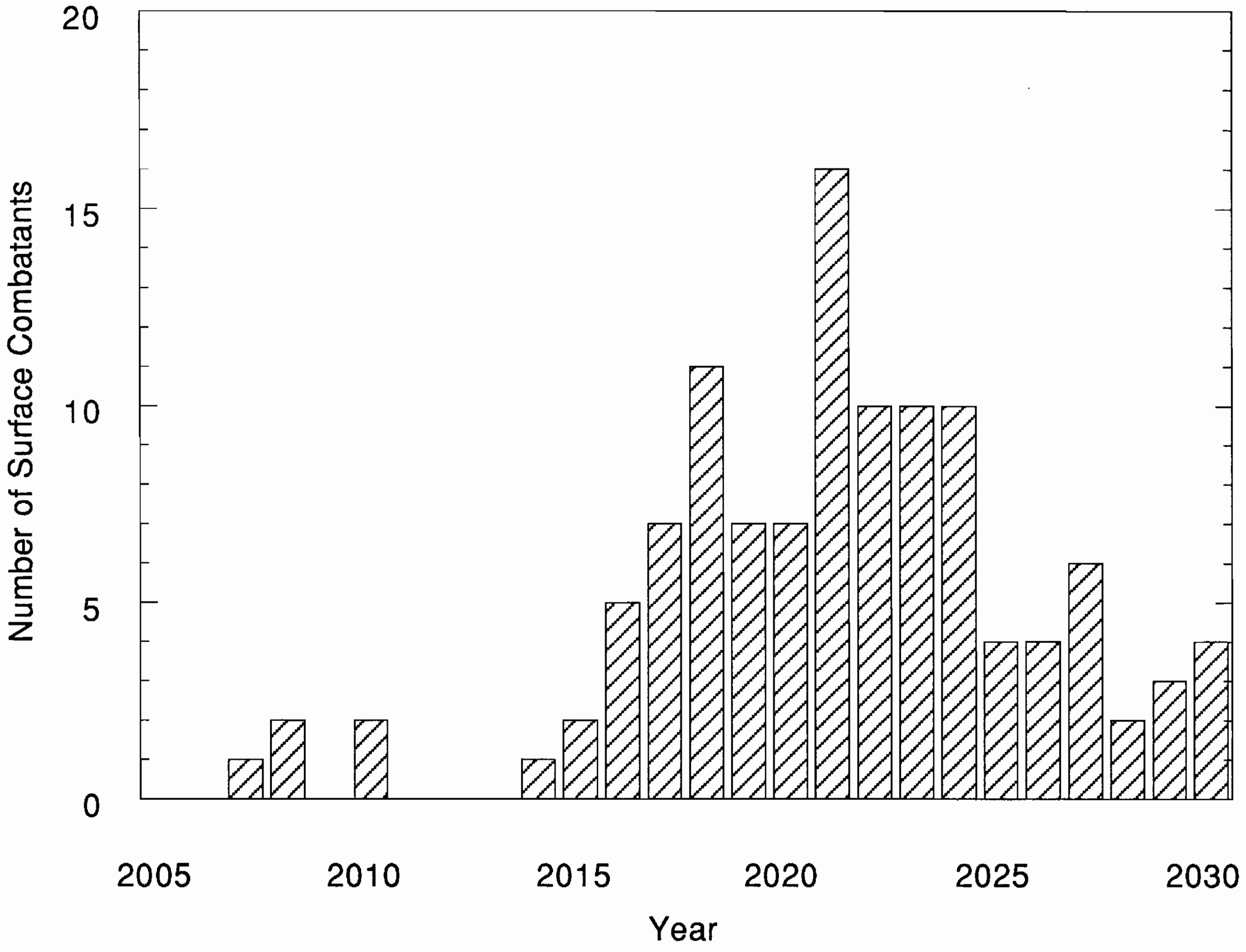

Figure (3): NUMBER OF NEW SURFACE COMBATANTS REQUIRED TO MAINTAIN DESIRED FORCE LEVELS

Operational Life Cycle

The combat system's useful life must be comparable with that of the ship, roughly forty years. Over the operational life of the ship, the threat which the combat system was initially designed to counter may evolve and/or deficiencies in the combat system design may be recognized. The combat system must contain margins to allow for growth and changes such that it will support the operational life of the ship.

The ships will be deployed in cycles of active service for seven years followed by a scheduled seven month overhaul period at the shipyard. The combat system must support this schedule. Within this seven year period the ship typically will undergo periods of six months out of port followed by six months in port with a three month period of limited availability every eighteen months.

Utilization Requirements

The combat system must be operational 24 hours a day. The combat system must support the following standard Navy system readiness and utilization conditions. The assumed percentage of time spent in each state is also shown.

Condition of Readiness	Percentage of Time
V - Port Readiness	40%
IV - Peacetime Cruising	35%
III - Wartime/Deployed Cruising	20%
II - Battle Ready - Limited Action	5%
I - Battle Ready	10%

Environment

All components of the combat system will be located either topside or below decks.

All combat system equipment placed topside must be designed to meet current Navy HM&E standards for nuclear and battle damage survivability and signature. Signature includes electromagnetic, infrared, and acoustic. All shipboard equipment must also meet all current military standards for all operational environmental conditions such as underwater shock, humidity, and temperature.

The combat system equipment and computer programs must operate without any degradation in performance up to sea state 6.

System Maintenance Concept

These new surface combatants have a planned service life of forty years. Regular ship overhauls are typically scheduled for every seven years. Each overhaul is planned to last at least seven months. The second overhaul will occur at the ships's expected midlife and may last up to one year. The seven year deployment period is divided up into four cycles lasting approximately twenty months. Each of these cycles is preceded by a pre-deployment intermediate maintenance availability (IMAV) and followed by a post deployment scheduled restricted availability (SRA).

Software maintenance shall be done at the shore based life cycle support site by government personnel and/or their designated contractors. The specific logistic support measures designed to support this maintenance concept will depend on which combat system design concept is finally selected.

Levels of Hardware Maintenance

The combat system design shall comply with the following levels of maintenance:

1) Organizational - Corrective and preventive maintenance performed by the ship's personnel. The actual maintenance performed shall be within the capability of the ship's crew.

2) Intermediate - This level of maintenance includes combat system calibration, repair or replacement of damaged or unserviceable modules and emergency manufacture of unavailable parts.

3) Depot - This level includes major overhauls to the combat system and/or a complete rebuild of parts and assemblies which requires the ship to go into dry dock and major components to be shipped to the manufacturer for repair.

Maintenance Responsibilities

The following outlines general hardware maintenance responsibilities at each maintenance level for the combat system.

<u>Organizational</u> - The number of hours allocated to the preventive and corrective maintenance for each component of the combat system will depend on the

individual needs of each component. However, the ship's personnel are responsible for all onboard tests, minor repairs to the combat system and the general care of all topside equipment. These personnel shall have received at least the Navy's minimum period of formal training in the care of the assigned specific component, typically two to three months.

Intermediate - This level of maintenance is performed by Navy personnel on tenders, repair ships, aircraft carriers, and fleet support bases such as Naval Ship Weapon Systems Engineering Station (NSWSES). Intermediate level maintenance will occur at IMAVs and SRAs. Prior to each scheduled IMAV, the ship will have submitted a list of required repair items so the tenders and repair ships will have the necessary parts.

Depot - This maintenance is the responsibility of both public and private shipyards as designated by the Navy. Depot level maintenance will occur at the regular overhauls and at some extended SRAs. The actual work performed will be determined by a team comprised of personnel from NAVSEA and the appropriate shipyard plus field teams of support combat system and HM&E engineers. Major combat system equipments such as sensors and ordnance will be returned to the manufacturer.

Functional Analysis

Functional flow diagrams for ASUW operations for both within the horizon and over the horizon engagements are provided in Appendix A. Figure 12 shows the basic functions that apply to both types of engagements. The subsequent figures illustrate in more detail the particular characteristics of within horizon flows and over horizon flows.

Evaluation Factors

There are various criteria that can be used to evaluate different combat system concepts. These include performance measures such as number of targets engaged, reliability measures such as system availability or total system failure rate, and cost measures such as an estimate of life cycle cost. Because the Superset Concept is presently defined only at a high level, detailed comparisons between the two concepts would be difficult and in many ways meaningless. Therefore, in order to limit the scope of evaluation to something tractable, we will focus our assessments in those areas that our experience tells us will produce the largest differences between the concepts.

Since the principal differences between these two combat system design concepts are in their architecture, i.e. how the components are interconnected, and in their use of common standard components, e.g. consoles; effectiveness measures sensitive to these differences will be selected.

Since the Combat System Superset concept is a force level concept there must be several force level comparisons. The overall payoff, in terms of life cycle affordability and increased interoperability, of the superset concept can be properly assessed only at the force level. This project will look at two areas of the combat system which will be impacted by the superset design. These areas of comparison are: (1) differences in the types of ASUW command and control interfaces at the force level, which are a measure of the effects of the architecture differences, and (2) differences in the required number of spare parts for operator consoles, which is a measure of the benefits of standard components. These areas affect the production and operational support costs of the combat system's life cycle.

Additionally we can qualitatively assess the differences that the two combat system architectures make at the single ship level. This will be done by comparing the proposed Superset destroyer derivative with the Baseline 4 DDG configuration in the areas of:

1) The impact of upgrades to the combat system
2) The ease of software maintenance
3) Support of the ship's battle organization; i.e. how the crew is organized in support of the ship's mission

These areas of comparison were selected because they qualitatively reflect how well the architecture supports future improvements to various subsystems' capabilities and supports the operator in terms of data and displays. These tasks can be easy or difficult depending on the original architecture. The evaluation of each of these areas will focus on the combat system architecture's support of ASUW.

To assess the combat system upgradability we will conduct both a quick look assessment for ASUW related upgrades and a detailed examination of several specific ASUW upgrades. In the quick look investigation we are concerned with the number of interfaces which may be impacted by an upgrade and the percentage of the total number of interfaces impacted. For the detailed examination we will make an estimate of the impacts in the following areas for both design concepts:

- Number of subsystems requiring software modifications
- Number of subsystems requiring hardware modifications
- Number of interfaces requiring modification and retesting
- Type of Changed Subsystem Documentation (e.g B1, B2 specifications)
- Impact on training (none/minor/moderate/major)
- Changes to manuals (yes/no)

Training impacts occur at the individual subsystem level, at the ASUW level, and at the combat system level. Combat system level training is typically called CIC team training. Manuals include technical, operator's and maintenance manuals.

For the ease of software maintenance, we will look at several high level comparisons. The comparisons will assess how well the two combat system designs implement, at the combat system level, the following:

1) A software maintenance plan

2) A software change control board

3) Choice of Programming language

4) Software design standards

The existence of a software maintenance plan and software change control board reflect on how the combat system design is managed through its life cycle. The choice of programming language will determine how easy it will be to make future modifications to the design. The same applies to the software design standards used in its development.

The ideal situation would be have the following attributes:

1) There is a combat system level software maintenance plan which ripples down to the various subsystems and their software maintenance plans

2) There is a change control board (CCB) which handles the entire combat system and all subsystem interfaces

3) There are subsystem CCBs which feed into the combat system level CCB

4) Only one programming language is used throughout the combat system

5) A standard interface protocol is used and all code would be designed, developed, tested and maintained following one standard.

As part of the assessment we will then determine how well the design concepts match this ideal for ASUW.

For surface operations the CO or the TAO needs to see the ASUW missile engagement plans, projected projectile path for the gun, and surface targets of interest. Enough data must be available at both the CO's and TAO's displays for either to make an informed decision. This data includes threat classification, present location, and future intent. Given a ship's battle organization, there are several questions which must be addressed. These are:

1) How does each design provide support to the CO's decision making process?

2) How does data get passed between the various levels of command?

3) How do the displays compare at each level of the battle organization?

The answers to these questions will yield insight into how well the combat system design concept provides support to the battle organization for ASUW operations.

After comparing and contrasting the various combat system design concepts against these criteria, one will be recommended for further consideration as the combat system design architecture for the next generation of surface combatants.

SECTION 4

COMBAT SYSTEM DESIGN CONCEPTS

This section provides a description of each of the design concepts under consideration. Discussion will include an overview of the combat system and of ASUW operations for each concept.

Baseline 4 Aegis Combat System

The most recent version of the Aegis Combat System is found on the last nine ships of the Ticonderoga Class Guided Missile Cruisers, CG-65 through CG-73, and the first thirteen ships of the Navy's new Arleigh Burke Class Guided Missile Destroyers. This version is the fourth step in an evolution of the combat system development that began with the initial deployment on USS Ticonderoga, CG-47 in 1983. Each of these steps is termed a baseline. A selection of upgrades to the components of the combat system are grouped together, interfaced with the previous configuration, tested, and then deployed on a block of ships as the next combat system baseline. The result is that, all ships within a particular baseline have the same equipment configuration and the same computer programs. Introducing upgrades through baselines prevents the piecemeal introduction of upgrades to ships which would complicate maintenance and logistics efforts.

Baseline 1 consists primarily of the antiair warfare system known as the Aegis Weapon System (AWS), an ASW system interfaced with the AWS, and surface operations in the form of a gun system and the Harpoon antishipping missile system. Both of these systems are controlled through the AWS. Baseline 2 introduced both a new missile launcher system allowing for the addition of the Tomahawk Weapon Control System (TWCS) for long range surface and land strikes, and new improvements to the ASW system. There was, initially, no digital interface between TWCS and the Command and Decision (C&D) element of the AWS. However, one was later implemented and became part of Baseline 2. The upgrade to the long range, three dimensional, multifunction radar (AN/SPY-1B) constituted the major portion of the improvements forming Baseline 3. Computer and console upgrades to the AWS, upgrades to TWCS and the ASW system, and a modification to the combat system architecture created Baseline 4.

The first three combat system baselines apply to just Aegis Cruisers, CG-47 through CG-64. Baseline 4 is unique in that it applies to two ship classes, Aegis Cruisers CG-65 through CG-74 and Aegis Destroyers DDG-51 through DDG-64 and that it is considered to be a superset. These unique characteristics result from the combat system design effort in the early 1980's for a new class of destroyers. The role of Combat System Design Agent for this new destroyer class was awarded to the same contractor, General Electric (formerly RCA) that held the design agent role for the earlier Cruiser combat system baselines. RCA proposed creating one configuration that applied to both the new destroyers and the remaining cruisers. This allowed for development and production efforts to apply to both ship classes. This yielded a cost savings for research, development, and production. Creation of a single configuration was possible since the primary missions of the two ship classes are similar.

The same development and production specifications apply to both ship classes. These specifications have yielded one combat system design which contains all the equipment and computer programs necessary to fulfill both ship classes' top level requirements. While the exact equipment configuration does not apply to both ship classes, the computer program specifications and computer interface documents do. The resulting computer source code is considered to be a superset computer program. From this source code two different tactical computer loads are generated, one for each ship class to handle the equipment differences between the two ship classes. Figure 1 provides a high level block diagram of this superset configuration.

Characteristics of the Baseline 4 Aegis Combat System

The Baseline 4 combat system design evolved from a single warfare engagement system for AAW interfaced with ownship command. In this case, C&D is equated with Command. This basic architecture remains such that all AAW sensors and the various weapon control systems for the other warfare areas must also interface with C&D.

C&D contains the combat system level database, display drivers, and threat and weapons doctrine. The tactical database is generated and maintained in C&D. This same database is used to produce the tactical picture on the majority of consoles in CIC. A track cannot be engaged unless C&D has it in its database; no engagement can occur without C&D's involvement.

Aegis Display System (ADS) is the command level display system. It consists of a large screen projection system driven by a console set and computer. ADS was originally conceived as the CO's personal display suite, but as the combat system has evolved, ADS's capabilities have grown. The most important capability is the ability for the CO to automatically issue an engagement order (EO) via his console. ADS data input is limited to just the C&D database and manual data entry. ADS is connected only to C&D. If data is not in the C&D database ADS will not receive it and the CO will not see it. The CO can only issue engagement orders on the information displayed on his console.

C&D, not ADS, is connected to the standard battlegroup digital communications link, Link-11. C&D correlates ownship sensor data with that received over Link-11. Neither C&D nor ADS has access to the standard character oriented OTH links. Only TWCS does. OTH data correlation occurs only in TWCS for targeting purposes. There is no way to get OTH indications and warning (I&W) information displayed to command at ADS except through manual data entry

AAW control is split between two components of the combat system. C&D correlates all incoming air tracks and performs the necessary threat evaluation functions. After ADS issues engagement orders C&D provides all necessary track data to the missile controller. The Weapon Control System (WCS), given an engagement order on a target, calculates when the missile can be launched, schedules illuminator times, calculates midcourse missile guidance commands and provides data to the missile launching system to prepare the missile for firing. In the event of a complete C&D failure (i.e. all backups also fail) one could not get an AAW engagement off even though C&D contains no missile guidance functions.

All ASW correlation functions, fire control calculations, and display drivers are contained within the ASW Control System (ASWCS). ASWCS interfaces with C&D to receive additional ASW data from Link-11, to provide ASW tracks to C&D, and to handle the command control aspects of ASW engagements. All organic ASW sensors provide input just to the ASWCS. The ASWCS directly controls all ASW engagements.

Characteristics of ASUW operations in the Baseline 4 Aegis Combat System

In Baseline 4 the ASUW OTH configuration applies to both the Aegis Cruiser and Destroyer classes. However, there are two gun weapon system (GWS) configurations within the Baseline 4 design. The Cruiser configuration has a dedicated surface radar associated with it while the Destroyer configuration does not. Both configurations provide for the transmission of tracks from the AN/SPY-1 radar to the gun computing system and the acceptance of engagement orders from the AWS. Figure 4 shows the resulting ASUW configuration which will be used throughout this project.

Surface data is received over Link-11 and entered into the C&D database. This data includes battlegroup surface

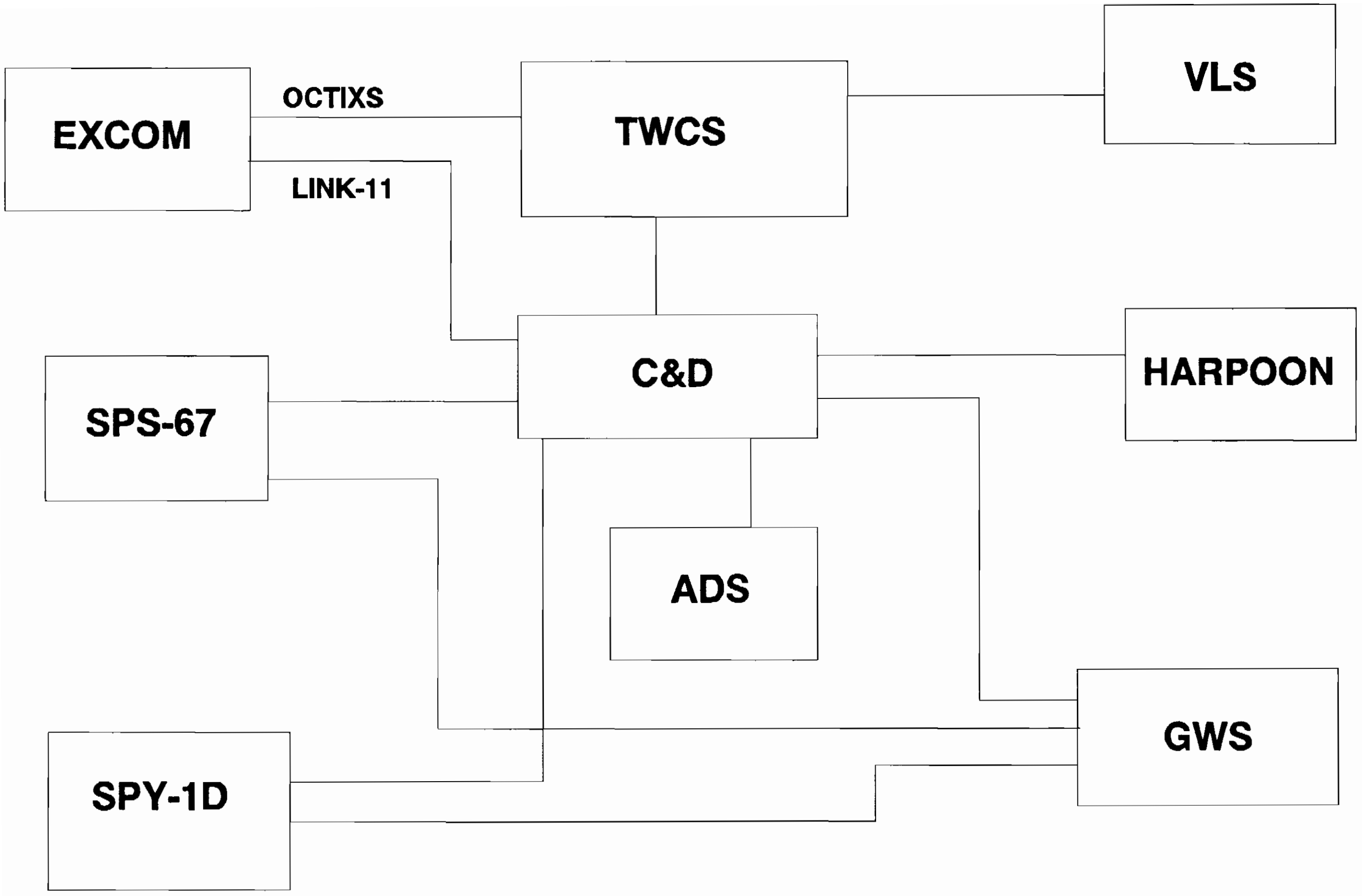

FIGURE (4): BASELINE 4 ASUW CONFIGURATION data correlated with other data already in C&D's database. radar tracks and OTH tracks. This data can then be Surface radar tracks are entered into the C&D database from both the SPS-67 and SPY radars. Surface video is sent to switchboards for display. C&D can correlate this data with Link-11 data. C&D sends surface tracks to the GWS. Surface video from both the SPS-67 and SPY-1D is provided to the GWS operator. GWS also receives radar tracks directly from its fire control radar, SPY-1.

OTH surface contacts are received over the Navy's standard OTH data link, OTCIXS, and entered into the TWCS database. This includes contact traits and parameters which allow for correlation into a surface track. TWCS operates within the BGDBM rules for OTH engagements. Even though C&D controls Harpoon which is an OTH ASUW missile, C&D does not follow the BGDBM rules.

C&D and TWCS exchange data including surface tracks according to an agreed message protocol. Data received from the other can be merged or correlated according the rules established in that protocol. This interface allows TWCS access to the surface data found on Link-11. If the interface is down, TWCS will passively tap the interface between the Link-11 receiver and C&D.

C&D sends all surface tracks in its database to ADS for Command display. Special data points such as data received over secure phones can be manually entered into ADS. This data cannot be automatically entered in either C&D or TWCS database.

ADS, via C&D, will issue an EO on a surface track to be engaged by the gun. C&D will send the track and associated parameters to the GWS. GWS will develop a fire control solution on that track. This solution is sent back for approval. GWS will then initiate the firing of the gun. The surface fire control radar will track the projectiles and provide input to the GWS to correct the gun's aim.

Based on the tactical situation the CO will either receive orders over Link-11 to engage a surface track with Harpoon, or will initiate engagement himself. Upon ADS's order C&D will send the surface track and associated parameters over to the Harpoon Launch Control Set. The Harpoon Launch Control Set will calculate a fire control solution and display that proposed flight plan on the control panel in CIC. The Antisurface Warfare Coordinator (ASUWC) can manually modify that plan. He can also enter the desired flight path directly into the computer. The ASUWC must turn the firing key to allow ignition at the approved time.

A TASM engagement can be initiated either from C&D or TWCS. C&D can ask for an engagement plan on a particular surface track which it has provided. The TWCS operator will develop the plan. That plan is sent back to C&D and then to ADS for display and approval. A hardcopy of the engagement plan must be signed by the CO, approving the mission and the launch time. Then TWCS will prepare the missile, providing it the required data via the shipboard missile vertical launching system. At the approved time the missile will ignite and begin to leave the launcher.

TWCS can receive a force level engagement order over OTCIXS on an OTH track. This track may or may not be held by C&D. If not, that track must be entered into C&D and ADS before approval will be given for the engagement. Then the steps are basically the same as for a C&D initiated engagement.

The CO can also select to use the primary antiair missile against a surface target. C&D sends an engagement order to WCS. WCS responds with the earliest and latest times to launch and begins to schedule illuminator time. In this missile's surface mode, the target must be continuously illuminated so the missile can home in on the signal. Range of the engagement is limited to the illuminator's radar horizon.

Combat System Superset Design Concept

One of the designs for future surface combatants is called a force level Combat System Superset. The idea behind the superset concept is that future combat systems need to be designed and developed at the force level. While common sensors and weapons are used throughout the fleet today, no single integration methodology to connect these sensors and weapons prevails. The superset concept provides a methodology for the functional connectivity between elements. The proposal is to create one master combat system, at a fleet level, from which the combat systems for all surface combatants would be derived.

The Combat System Superset is a design concept; the entire superset will never be installed on a single ship. What will be developed and produced are called combat system derivatives of the original superset. At a high level the combat system superset is defined as the set containing all warfare area missions and supporting functional elements. These mission areas and support functions are then allocated to the various U.S. Navy surface vessels. The superset allocation process assumes that any combat system must possess an effective command and control structure for intraship and intership operations and must provide for basic self defense of the ship. The required missions of the Navy determine the final allocation of sensors and weapons to the various derivatives. A key point is that regardless of which sensors and weapons are selected for deployment on any derivative, the information and control flows between command and the warfare coordinators and the connectivity of the sensors to the weapons are the same on any derivative.

There are four characteristics of the force level Combat System Superset which must be found in all combat system configurations derived from it. These are:

(1) the same functional connectivity exists between elements

(2) the same command and control structure exists on all derivatives

(3) all derivatives support a multi-mission environment through an appropriate set of weapons and sensors

(4) a set of information links exists that supports that command and control structure.

These characteristics are required to be common to all combat system superset derivatives. Other functions and attributes such as a specific sensor or the ability to control aircraft will be unique to each derivative.

Figure 2 provided a high level functional diagram of a combat system superset. This concept is in support of more conceptual combat system architecture goals as outlined by Cullen [4] and Pollard [5]. The superset needs to support a wide variety of active and passive sensors covering much of the electromagnetic and acoustic spectra. The information from these sensors must be reported directly to the appropriate warfare coordinators. Each warfare area coordinator must be capable of controlling all long, medium, and short range weapons at his disposal. Each warfare area coordinator must interface directly with Command. Information such as sensor data, engagement recommendations and weapon status flows up to command from the various warfare coordinators. Control in the form of engagement orders and doctrine, and data such as dissimilar source correlations and I&W information, flow down from both ownship and force level command.

Young [2] presents three postulated combat system derivatives. Two of these are for surface combatants: strike cruiser and destroyer. The strike cruiser derivative involves controlling ASUW and Strike aircraft while the destroyer derivative does not. Since this project is limited to surface warfare operations involving only surface combatant assets, the destroyer derivative will be used for the remainder of this project. Figure 5 provides a high level block diagram of this derivative's configuration.

Characteristics of the Destroyer Superset Derivative Combat System Configuration

- Laid out in a detect-control-engage philosophy, but within a single warfare area "control" is that of weapon control. Command control is done through the warfare area coordinator.

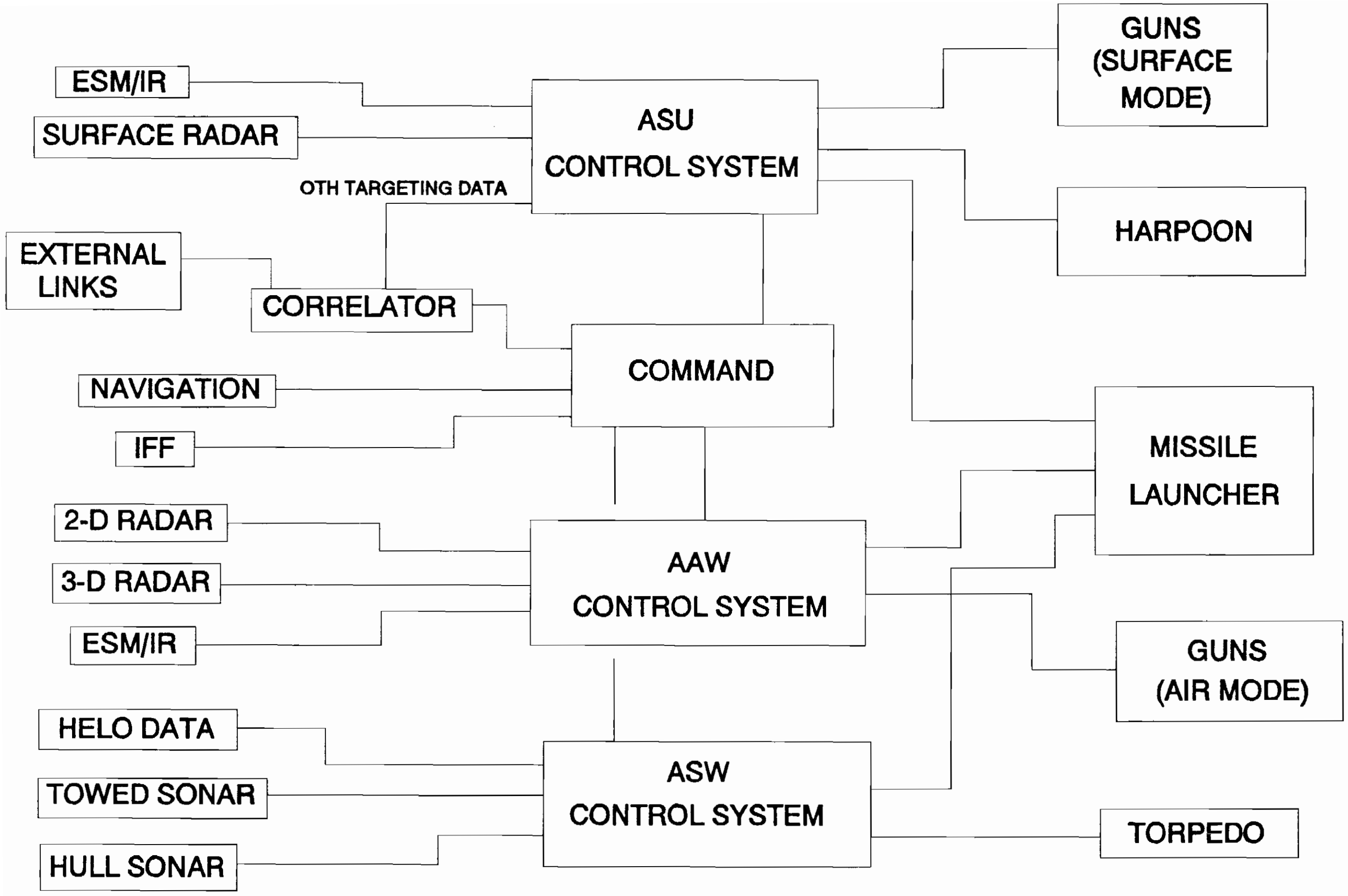

FIGURE (5): DDG SUPERSET DERIVATIVE BLOCK DIAGRAM

- All warfighting paths follow a clear trail from sensor detection to weapon control to weapon engagement
- Specific sensor or weapon operators within an individual warfare area report to that warfare area coordinator. All warfare area coordinators report directly to ownship command.
- Command level database is flexible in its partitioning to adjust to a particular deployment.
- There is no separate Electronic Warfare (EW) mission area. EW now falls directly under Command's control.
- Each warfare area coordinator is charged with the controlling all available weapons in that warfare area and with recommending the most suitable weapon for an engagement to Command. Command accepts or rejects the recommendations and issues engagement orders.
- Battle group data link information is handled by a command level function called System Information Coordination. OTH data links and direction finding data are also handled at this level. This function will correlate the information from those various sources and provide I&W information to command and OTH targeting to the ASUW system.
- Command has direct access to all data links
- System Information Coordination and System Readiness Function are command level functions for use by the entire combat system. The System Information Coordination function

handles the correlation and transfer of data between the various sensors. The System Readiness function monitors the status of all combat system components.

Characteristics of the ASUW system for the Destroyer Superset Derivative

Figure 6 shows the ASUW system for the Destroyer derivative. The surface search radar searches for, detects, and tracks surface targets within its radar horizon. Firm tracks will be passed to the central ASUW Control System (ASUWCS) and updated as needed or requested. This radar is used for fire control involved in gun engagements. ESM and/or IR sensors provide either line of bearings or crossfixes on surface targets to the ASUW control. OTH targeting data is provided by the command level System Information Coordination function. This data consists of: a contact localization, an uncertainty ellipse, track history, and predicted future movement.

At this level of design the ASUWCS contains both the function of ASUW weapon control of individual weapons and the function of ASUW command control which governs all ASUW operations and interfaces with Command. The ASUWCS will:

- support BGDBM rules for all OTH engagements
- accept battlegroup organic surface radar tracks and merge them into its own database

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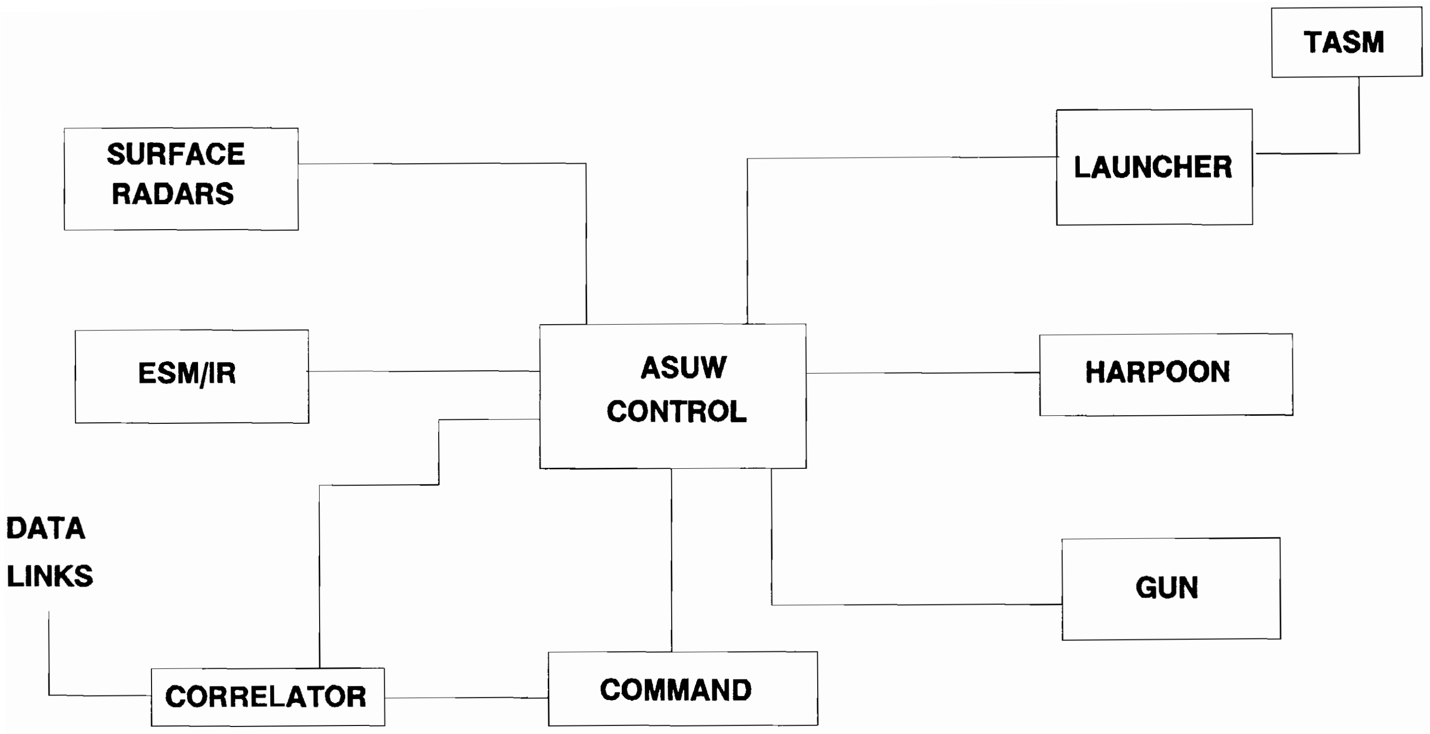

FIGURE (6): DDG SUPERSET DERIVATIVE ASUW CONFIGURATION

- maintain a database of both local and OTH surface tracks
- accept the correlation of local organic surface radar tracks with the ESM/IR lines of bearing. (correlation of OTH tracks is done at the command level)
- provide updates on any track in its database upon Command's request
- perform threat evaluation of all tracks in the database.
- do the engagement planning of OTH engagements including the selection of the appropriate OTH missile.
- perform all preparation for launching an OTH missile
- calculate a fire control solution for surface gun engagements.
- initiate surface gun engagements and serve as the gun fire control system
- drive the surface operators' displays
- provide for operator training at the ASUW system and combat system levels
- do kill assessment of local surface engagements and request BDA information on OTH engagements.

The ASUWCS will send Command threat evaluations of tracks in its database, provide Command with local surface and OTH targets of interest, and send developed OTH targeting plans for Command's approval. Command will send the ASUWCS engagement orders for a specified target and approval of OTH engagement plans. These operations require that the two systems implement a track numbering scheme.

The gun will accept commands from the ASUWCS. This includes tracks to engage (range, bearing, target speed) and a fire control solution on the engaged target. The missile launching system(s) will interface with the ASUWCS to transfer mission flight plans and other necessary information to the various OTH missiles. This interface will also govern the protocol necessary between a weapon control system and a launcher for selection, initialization, and launching of a missile.

SECTION 5

AREAS OF COMPARISON OF THE COMBAT SYSTEM CONCEPTS

In order to understand what the force level Combat System Superset Concept means to future surface combatants we will conduct comparisons on two levels: the force level and the individual ship class level. This section will explore the impact of a combat system superset for all surface combatants. The following sections will compare the proposed Superset Destroyer Derivative with the Baseline 4 Aegis combat system design.

Force Level Comparisons

The anticipated payoff, in terms of life cycle affordability and increased interoperability, of the Superset concept will be achieved at the force level. However, single ship interoperability should also improve due to the use of common equipment and standardized computer programming characteristics. We will examine two areas of the combat system which will be impacted by the superset design. These areas relate to the production and operational support costs of the combat system's life cycle.

Command and Control Interfaces

The concern here is how the variety of interfaces between sensors, weapon control systems, command systems, and launchers are implemented today. The specific areas of concern are the interfaces between the gun fire control systems and command systems. Each different interface, once developed, must be maintained as each side of the interface undergoes its own software evolution. Operators must be trained in any modification of the interface. Each interface represents development testing, training, and both hardware and software maintenance efforts. How each interface is implemented will be reflected in the organizational structure of the combat system design. Thus, we must look at how the sensors and launchers interface with the weapon control systems and how the weapon control systems interface with Command.

The required reaction time from detection to engagement is continually decreasing, driving the need for more automation. So digital interfaces are being developed to connect sensors to weapon control systems and to connect Command to weapon control systems. Since the command and weapon control systems vary among ship classes, these newly developed interfaces also vary. This means that there is more code to maintain and that combat system operators must be trained in different operations. If a new interface is added then operators on both sides must be trained for the system to work properly.

Digital communication between two pieces of equipment is governed by an Interface Design Specification (IDS). The following paragraphs discuss several ASUW related interfaces.

For all surface search radars the method of integration is basically the same. Video from the radar is sent to a repeater for display in CIC. Data is then manually entered into the command system database. Only the SPS-67(V)3 and the SPY-1 automatically send surface tracks directly into a command level database via a digital interface.

All surface combatants basically have the same IDS between ownship Command, C&D or CDS, and the Harpoon Weapon Control System. One IDS, CDS/SWG-1 [6], covers the situation when a guided missile launcher, which also fires antiair missiles, is used. Another IDS, C&D/CDS to SWG-1A [7], is used when a free standing canister launching system is employed. This IDS allows Command or his designated representative to review, modify, and approve the Harpoon engagement plan.

Two different launchers are used to fire Tomahawk missiles, a free standing armored box launcher and a vertical launcher which can also fire antiair and antisubmarine missiles. A different variant of the launch control portion of the weapon control system is required for each launcher type. Two variants of the vertical launcher system interface exist depending on the type of cabling, NTDS parallel or low level serial, used between the TWCS Launch Control Group and the launcher. The interface between the track control and launch control portions is standard for all surface combatants.

The interface between TWCS and Command, however, is not as standardized. An IDS has been written, agreed to, coded and tested between the TWCS and the AEGIS C&D command system. This same IDS would apply to CDS ships, but no CDS has yet completed that side of the interface. With the interface between C&D and TWCS the ship's CO can initiate a TASM engagement. TASM engagements can also be initiated by force level commanders. The CO must approve all TASM engagement plans. He can also evaluate the use of Harpoon in the same tactical situation. Without the interface active between TWCS and Command, the CO cannot view the necessary data, which is stored in the TWCS database, to evaluate the current tactical situation. Neither can he initiate a TASM engagement nor easily compare the use of a Harpoon versus a TASM.

The situation gets a lot more confusing when looking at the various Command and gun fire control systems (GFCS) interfaces. Only one surface sensor directly inputs data to any GFCS. The SPY-1D provides input to the MK 34 GWS on the DDG-51, but this is the only case out of 201 actively deployed surface combatants. Currently there are fifteen gun fire control related interfaces. One is the SPY-1D interface on the DDG-51. Another is for air target input and control from the SPY-1 on the CG-47 class ships; the SPG-60 or SPG-53 perform that function in a similar manner on other ship classes. A third is between the GFCS and Command on a ship which is not a surface combatant. That leaves twelve different IDSs for interfaces between GFCS and Command. This variety of interfaces is unusual since almost all surface combatants use the same type of gun mount.

Table 1 provides the IDS number, the GFCS, the interfacing element, and the applicable ship classes for these twelve IDSs [8]. Even by the year 2000, when the DDG-2 class is retired, only two IDSs can be completely dropped from this list. Note that the GFCSs interface either with command systems or with the AAW weapon control/direction systems. One IDS rarely applies to just a single ship class. Instead, several IDSs are necessary to support all GFCS/Command interfaces for a specific ship class. The MK 86 GFCS is the most prevalent gun system and different models of the MK 86 GFCS are deployed on the various surface combatants. More importantly, different models of the MK 86 are also found within a single ship class.

TABLE 1

GFCS AND INTERFACES

IDS NUMBER	GFCS (MK/MOD)	INTERFACING ELEMENT	APPLICABLE SHIP CLASS
WS-13588	MK 86 MOD 3 MK 86 MOD 3/10	CDS M4.0 CDS M4.0 via CFU	DD-963 CGN-36
SEA 0967-LP-029-1530	MK 86 MOD 5	CDS M4.0	CGN-38, DDG-993
SEA 0967-LP-029-1560	MK 86 MOD 5	GMFCS MK 74 MOD 5	CGN-38, DDG-993 w/ WDS MK 13
WS-16676A	MK 86 MOD 8	CDS M4.0/ DDG TDS	DDG-2 MOD
WS-16677A	MK 86 MOD 8	WDS MK 13 MOD 4	DDG-2 MOD
WS-19961/A	MK 86 MOD 9	WCS MK 1	CG-47 B/L 1-3
WS-19961/1	MK 86 MOD 9	WCS MK 8	CG-47 B/L 4
WS-20447	MK 86 MOD 12	WDS MK 14/SM	DDG-993, CGN-38
WS-24386	MK 86 MOD10/12	CDS M4.0, M4.1, M5.1	DDG-993, DD-963, CGN-38
WS-21324A	MK 34	C&D MK 2	DDG-51
WS-17678	MK 68 DIGITS MK 68 VIA CFU	WDS MK 14 NTU WDS MK 14/SM	CG-26 only CG-27, DDG-37
CSE 83-36	WDS MK 14 NTU (FOR MK 68)	CDS M4.1, M5.1	CG-16, CGN-9, CG-26/27, CGN-36/38, DDG-993

Different models have different interfaces resulting in the large number of IDSs. The weapon control and weapon direction systems that interface with the GFCSs in turn interface with the command system. Table 1 does not include the fifty-one FFG-7's which have only a single MK75 76 mm gun for its gun system. On these ships the interface is a three step process from CDS to the MK 92 AAW missile fire control system to the gun.

From this we see that there is no consistent methodology to connect the numerous GFCSs with the various command systems on today's surface combatants. Each of these interfaces represents different maintenance, both hardware and software, and training efforts. This means that the Navy's Operational and Support funding must subsidize duplicate work efforts for similar situations.

The Superset concept provides a focal point for each of these weapon control systems in the form of an ASUW warfare control system (ASUWCS). An important function of the ASUWCS will be to resolve potential overlap between Harpoon and TASM engagement plans.

Today there are sixteen different situations for ASUW weapon control and Command interfaces. The one ASUWCS/Command interface and three ASUWCS/weapon control interfaces in the superset architecture should require less training for operations and overall maintenance efforts.

The most payoff would be in standardizing the gun fire control interfaces since the Harpoon and TWCS command interfaces are already standardized.

Spare Parts Requirements

One principle of logistics engineering is to use standard components whenever possible. This reduces the maintenance training requirements and minimizes spares inventories. The Navy follows this principle by using standard computers and consoles in its various systems. However the computer room on any surface combatant contains AN/UYK-20s, AN/UYK-43s, AN/UYK-7s, and AN/UYK-44s, which are all Navy standard computers, albeit from two different generations. Additionally, various non-standard computers such as HP-9020's and other forms of personal computing systems are also in use. Each of these computers has its own needs in terms of preventive and corrective maintenance.

The same situation exists for consoles. Four to five different consoles or console variants can be found in a surface combatant's CIC. There are approved standard Navy consoles, variants of which have been developed for specific systems. New subsystems added to the combat system tend to use one of the latest versions of the approved consoles.

Except in a major combat system upgrade, the older consoles are not replaced with newer ones. Ship supply must support each type of console on board.

There has been a proposal for a new standard Navy console. This console is more of a computer workstation than the traditional Navy console, which consists of a display and keyboard and few other capabilities. This single console would replace all varieties of the consoles that exist today.

Our interest is in estimating the benefits of having one standard console for all operator stations as compared to the four or five different console types in use today. Three areas in which benefits could accrue are maintenance training, maintenance costs, and spare parts requirements.

Since the proposed new console has not been designed, a detailed analysis of the above areas is not possible. We can, however, make a qualitative assessment of the benefits of a standard console based on the workstation concept and the assumption that the new consoles are no more complex than those they replace. This assumption is reasonable since the workstation concept allows flexibility of function to be achieved through software and permits complexity to be reduced by using modern technology. Based on this assumption, we make the following claims:

1. Maintenance training for the console should take no longer than for any of the current consoles. In fact, since the console is based on a workstation concept, computer-based training and diagnostics should reduce the training time. Since the proposed console would replace the several varieties in use today, the maintenance training for the additional consoles would be eliminated. This would result in further significant savings.

2. Preventive and corrective maintenance time should likewise be shorter because of enhanced on-line diagnostics and repair procedures, minimal scheduled maintenance requirements, lower parts counts and increased reliability due to larger scale integration, and standardized components.

3. Spare parts inventory requirements should be much less because of fewer unique parts per console and the need to have spares for only one type of console rather than four or five. In addition, it is likely that the console components would be more reliable than the older technology, which would further reduce spares utilization.

Summary

The Superset concept does appear to provide the U.S. Navy with force level benefits when compared to today's surface combatants. The main benefit is the potential for an overall savings in the Navy's operational and supply money. Through these two examples we have seen several ways that this savings can be achieved at the force level. These include:

- lower software maintenance costs through less variety in the type and number of computer programs which must be supported,
- lower training costs in not having to establish and maintain as many types of classes for operators and maintenance personnel,
- lower documentation costs through common interfaces and equipment, and
- lower logistic support costs because of common equipment.

Before a final conclusion can be reached the research, development, and production costs for the Superset concept must be investigated, and the impact of any increase over that of Baseline 4 on the likelihood of reaping this operational and supply savings must be assessed.

SECTION 6

COMBAT SYSTEM UPGRADABILITY

Combat systems are designed to go on ships whose expected lifetime is thirty to forty years. Over that timeframe the threat which the combat system was designed to counter will likely change. That means that the combat system must be capable of being upgraded over its lifetime and that the equipment and computer programs must be maintained for that timeframe.

Combat system upgrades can be equipment improvements, computer program enhancements, or a combination of the two. When ever any subsystem is upgraded the improvement must be implemented and tested first at the subsystem level. It is important at this stage to identify potential changes to other subsystems which occur as a result of this upgrade. Otherwise, potential conflicts between subsystems will not be recognized until the upgraded subsystem is tested with the rest of the combat system.

When planning for a major upgrade to the existing combat system, it is necessary to identify the resulting ripple effects to the rest of the combat system. This information is necessary to develop a cost estimate for the upgrade. Given today's budget climate the magnitude of the impact may prevent that upgrade from taking place. If the impact is not realized until later in testing it will cost more to fix, potentially creating a cost overrun.

This section will examine the impact of ASUW related upgrades in each design concept. This examination begins with a quick look, high level investigation of the impact of upgrading any subsystem involved in ASUW. It continues with an assessment of the effect of specific ASUW related upgrades against the evaluation criteria discussed in section 3 for each design concept. An important concern is whether an ASUW upgrade affects just the ASUW warfighting path or also impacts ownship command and other warfare areas of the combat system.

First Order Evaluation of Combat System Upgrades

The first step in assessing the ease with which each design concept can be upgraded is to look for initial inter-subsystem impacts. These are the changes in any subsystems which must be made to accommodate the upgrade of any other subsystem. This very high level evaluation represents the worst case impact of any upgrade. As an upgrade is further defined the initial assessment of the impact will change. Generally, the more modular the design the fewer potential inter-subsystem impacts there are and the lower the cost of any upgrade.

Tables 2 and 3 are cross reference matrices showing the impact sites for ASUW subsystem upgrades for each design concept. Because of the difference in the top level design architecture there are several differences in the column headings. For the Baseline 4 ASUW configuration, the headings 'TWCS', 'HWS', and 'GWS' include both the weapon/fire control functions and the actual ordnance. In the Superset derivative 'ASUW control' contains all necessary surface weapon/fire control functions. TASM and HASM indicate just ordnance. 'Gun' represents both the launching mechanisms and projectiles. An 'x' in the box indicates that the subsystem being upgraded may impact another subsystem. The number of 'x's generally reflects the number of interfaces between subsystems. The charts are typically symmetric along the diagonal. The more 'x's, the more interfaces which must be checked at the system level test and the more time must be spent examining other subsystems for potential impacts.

The Baseline 4 ASUW design has ninety potential interface changes. Only twenty three must be examined for impact. There is an odd number of possibilities because the TWCS/Link 11 interface is via a passive tap. TWCS does not transmit over Link-11. So a TWCS upgrade will not directly

TABLE 2

BASELINE 4 ASUW SYSTEM IMPACT MATRIX

SYSTEM UPGRADED	SUBSYSTEM IMPACTED									
	OTH LINK	LINK 11	SPS-67	SPY-1	TWCS	C&D	ADS	VLS	HASM	GWS
OTH LINK					X					
LINK 11					X	X				
SPS-67						X				X
SPY-1						X				X
TWCS	X					X		X		
C&D		X	X	X	X		X		X	X
ADS						X				
VLS					X					
HASM						X				
GWS			X	X		X				

TABLE 3

SUPERSET DDG DERIVATIVE ASUW SYSTEM IMPACT MATRIX

SYSTEM UPGRADED	SUBSYSTEM IMPACTED							
	COMMAND	ASUWCS	GUN	HASM	VLS	TASM	DATA LINKS	SSS*
COMMAND		X					X	
ASUWCS	X		X	X	X	X	X	X
GUN		X						X
HASM		X						
VLS		X				X		
TASM		X			X			
DATA LINKS	X	X						
SSS*		X	X					

*SSS = Shipboard Surface Sensors

affect Link-11. The Superset destroyer derivative has fifty-six potential changes. This configuration has twenty possible areas of impacts, fewer than that for Baseline 4. What is interesting is the percentage of total interfaces which must be investigated. That number is larger for the DDG superset Derivative, thirty-six percent to twenty five percent for Baseline 4. One reason for this is the centralization of all ASUW command and control and weapon control functions in one box, 'ASUW Control'. All data sources and weaponry must then be interfaced with that box. In the Baseline 4 design ASUW command and control functions are divided between ADS, C&D, and TWCS. So, impacts would also be spread among those three subsystems.

There are two things not indicated by these tables. One is the magnitude of the change. While the Superset design may have a smaller number of changed interfaces, the impact of a specific change maybe quite large. An improvement to a surface sensor would cause a modification to the fire control solution in the ASUW Control. The verification of the modified ASUW Control will require more resources than the same change to the Baseline 4 design.

The other is that consequential impacts are not shown. These tables only show the first step of a possible sequence of changes rippling throughout the combat system. An example is the C&D/ADS interface. Since the ADS database is basically the same as the C&D database, any change to that database causes a change to the ADS database. If changes which impact both C&D and ADS, are included, Link 11 for example, the percentage of the interfaces that must reviewed increases by five percent. Since ADS has only that one interface with C&D, that five percent increase is accounted for in the C&D/ADS interface.

Another example is an increase in the number of VLS cells. TWCS tells C&D the number and type of Tomahawk missiles in VLS, not the total number of cells. C&D does not interface directly with VLS, but if the number of VLS cells changed both C&D and ADS would require modification.

So an initial evaluation has C&D suffering the greatest impact in the Baseline 4 design. Seven out of the nine subsystem upgrades potentially impact C&D. However, it must be remembered that C&D changes are almost guaranteed to be ADS changes also. For the DDG Superset Derivative the ASUW Control System is impacted by every subsystem upgrade. Command suffers only two possible impacts.

So, on the surface it appears that the core of all ASUW related impacts have shifted from C&D (and ADS) to ASUW Control System. However it is preferable that improvements of sensors and weapons impact the related weapon control system, rather than ownship command. In the Superset DDG Derivative these impacts are limited to the major weapon command/control system. This is unlike the Baseline 4 design where these improvements affect major subsystems, C&D and ADS, which contain ownship command and control functions rather than specific weapon control functions. Since it is desirable to limit the impacts to a single warfighting path without changes to ownship command, the initial judgement is that the Superset DDG Derivative is preferable to Baseline 4.

Impact of Specific Upgrades on Combat System Designs

The next step to examine the upgradability of each design is to look at a specific upgrade and determine the impacts at the next level down in detail. There are four proposed upgrades which have impacts on ASUW operations. These upgrades are:

1) Improvement to the Harpoon Weapon Control System
2) Introduction of a new battlegroup data link
3) Introduction of a new gun fire control function
4) Introduction of a new OTH Missile

We are going to examine how each of these upgrades would be implemented in each combat system design against the criteria described earlier in section 3. The following paragraphs will contain a brief description of the proposed upgrade, a discussion of the impacts for both concepts, and a table summarizing those impacts as they relate to the evaluation criteria.

In this evaluation it must be remembered that in the Baseline 4 design concept, because there is no centralized collection of ASUW systems, ASUW level training is equivalent to CIC team training. This is not true for the Superset design concept. Changes to CIC team training are related to training impacts outside of ASUW; in particular with Command and the other warfare areas.

Case 1: Improvement to Harpoon Weapon Control System

These are changes to the fire control algorithm such that it incorporates an 'area of uncertainty' of the target's position. This requires that such data be provided to the control system.

Baseline 4 Impacts

This upgrade requires modification to the Harpoon/C&D IDS. Link 11, C&D's primary OTH source, provides track information in a latitude/longitude positional format. Link-11 does not support a track's area of uncertainty in its message format. C&D provides data in the same format in its interfaces with other combat system components, including Harpoon.

The C&D database is structured to support the Link-11 data format. The database contents are considered to be tracks, not contact points with an associated area of uncertainty. For C&D to store data in the latter format would require a major restructuring of its database format. Since ADS is based on the C&D database structure, ADS would also have to be modified.

Because TWCS is connected to OTH data links it receives and stores data in the format being requested by this upgrade. C&D has access to required data from TWCS via the interface. To provide additional support for Harpoon engagement planning C&D must request the data more often than it currently does.

DDG Superset Derivative Impacts

In the Superset design the Harpoon Weapon Control System is contained in the ASUW Control System. So the Harpoon fire control solution segment of the ASUW Control System would have to be modified. The ASUW Control System already stores tracks with an associated area of uncertainty that is used in ASUW calculations, so that is not an issue with this concept. The whole control system must then be tested in the Superset to insure that the impact of the upgrade is limited to the control system and the Harpoon missile. This includes retesting of the ASUW Control/Command Interface.

Case Summary

Table 4 summarizes the impact that this upgrade has on both designs. To accomplish this change in Baseline 4 requires modifying both the C&D and ADS databases and three IDSs - C&D/HWS, C&D/TWCS, and C&D/ADS. Both C&D and TWCS computer programs would have to modified to establish more of a two-way communication path. The software impacts in the Superset DDG derivative are basically limited to ASUW Control System, implying a more modular design. The Baseline 4 training impacts are more severe because of the necessary coordination between the C&D, TWCS, and Harpoon operators to support this upgrade. In the Superset DDG Derivative only the ASUW Control operator needs retraining in the nuances of the modified algorithm in order to provide manual feedback of the fire control solution.

Case 2: Introduction of a new battlegroup data link

This is a new digitally oriented data link which increases the number of usable track numbers within the battlegroup and expands the coding system used for track identification. It will also provide target coordinates in a latitude/longitude format rather than in an x-y format

TABLE 4

SUMMARY OF IMPACTS DUE TO IMPROVEMENT TO THE HARPOON WEAPON CONTROL SYSTEM

Type of Impact	Baseline 4	DDG Derivative
Number of subsystems with software mods*	Four - C&D, TWCS,Harpoon, ADS	One - ASUW Control
Number of subsystems with hardware mods	Zero	Zero
Number of Interfaces that must be modified*	Three - C&D/ADS C&D/HWS C&D/TWCS	Two - ASUW Control/ Harpoon, ASUW Control/Command
Changed Subsystem Documentation (B1, B2, B5, etc)	Yes, all software specs for C&D, ADS, HWS, and TWCS	Yes, software spec for ASUW Control
Impact to: CIC Training ASUW Level Training Subsystem Training	 Moderate Moderate Minor	 None Minor Minor
Change to manual: Technical Operator Maintenance	 Yes Yes NO	 Yes Yes NO

* Modifications include retesting at both subsystem and combat system level

relative to reporting ship. This link will provide information for use in all warfare areas.

Baseline 4 Impacts

Currently, the primary battlegroup data link provides input only to C&D. C&D then transfers the data link information to any other subsystems that need it. The major characteristics of this data link, track identification methodology, track numbering scheme, and track position, provide the structure for C&D's database. C&D's various IDSs with other subsystems follow that same structure.

To fully implement the new data link in the combat system, C&D's database must be restructured. Because of its relationship to the C&D database, ADS's database must also be restructured. Since the amplifying information on any track contains track number, track position, and target identification, the display drivers for all C&D and ADS consoles must be modified. Thus all IDSs containing these characteristics must be modified. Companion changes must be made to the subsystems on the other side of those interfaces.

Harpoon has a fixed space allocation in memory for the track numbers. To implement this new track numbering scheme requires a physical change in its computer memory allocation. TWCS maintains a passive tap on the current battlegroup data link for the local track picture in the event of a C&D failure. The new data link has a much faster data reporting rate than the old link which is beyond the capacity of the existing passive tap unit. TWCS's passive tap system would have to be upgraded to handle that faster rate.

DDG Superset Derivative Impacts

By using common equipment throughout the combat system, hardware related problems in introducing the new data link would be eliminated. The data link correlator would have to be modified to handle the changes in the data link's characteristics. It might be possible to limit the impact to the modified data link correlator only. If the impact could not be limited to the Correlator because of a specific characteristic, such as the expanded threat identification, the Correlator's interface to Command, the Command display drivers, and interfaces between Command and the various Warfare Area Coordinators would have to be modified. The databases for Command and each Warfare Area Coordinator would require restructuring. After all changes have been made and tested the modified Command and Warfare Area Coordinator's computer programs would have to be redelivered to the entire fleet.

Case Summary

Table 5 summarizes the worst case impacts for this new data link. The worst case situation occurs when the impact goes beyond C&D for Baseline 4 and the Correlator for the Superset DDG Derivative. So, considering only those subsystems involved in ASUW for Baseline 4, five interfaces must be modified. These are the ones between C&D and TWCS, HWS, GWS, ADS, and SPY. The major cause for these changes is the track number. Also the C&D and ADS databases must be restructured. For the Superset DDG Derivative all interfaces involving information from the Correlator must be modified. For ASUW that would be the Correlator's interface with Command and the ASUWCS and the Command/ASUWCS interface.

Subsystem level training, in general, needs the most changes because all operators must receive training in the new data display formats and their contents. At higher levels, new training must provide for refresher training of old procedures but using the new data. Because the Baseline 4 design requires hardware changes for this upgrade its maintenance manuals must be changed. All other operator related documentation for both design concepts must change to reflect the extensive software modifications of this upgrade.

TABLE 5

SUMMARY OF IMPACTS DUE TO A NEW BATTLEGROUP DATA LINK

Type of Impact	Baseline 4	DDG Derivative
Number of subsystems with software mods*	Five - C&D, ADS, SPY, TWCS GWS	Three - Correlator, ASUW Control, Command
Number of subsystems with hardware mods	Two - Harpoon and TWCS	None
Number of Interfaces that must be modified*	Five - C&D/ADS, C&D/TWCS, C&D/GWS, C&D/HWS C&D/SPY	Three - Correlator/Command Correlator/ASUW Ctrl Command/ASUW Control
Changed Subsystem Documentation (B1, B2, B5, etc)	Yes for C&D, ADS, GWS, SPY, TWCS C1's for HWS and TWCS	Yes for Correlator, ASUW Control, Command
Impact to:		
CIC Training	Minor	Minor
ASUW Level Training	Minor	Minor
Subsystem Training	Moderate	Moderate
Change to manual:		
Technical	Yes	Yes
Operator	Yes	Yes
Maintenance	Yes	NO

* Modifications include retesting at both subsystem and combat system level

Case 3: Introduction of a new Gun Fire Control Function

It has been decided that the SPS-67 radar will now provide track data for gun fire control, relieving the SPY-1D of that function. The SPS-67 would then provide surface tracks and projectile tracks for use by the Gun Weapon System in controlling surface engagements. In a generic sense, this upgrade is really just the reallocation of the gun fire control function from one surface sensor to another.

Baseline 4 Impacts

The SPS-67 originally provided just video for C&D to display to CIC operators. Now, SPS-67 tracks enter the C&D database as vehicular tracks. C&D send tracks and engagement orders to the GWS. The SPS-67 and the GWS will have no direct interface. For the SPS-67 to act as a fire control radar it must send tracks to C&D which in turn will pass them to GWS. This means that the SPS-67, C&D and GWS computer programs and the existing IDSs must be modified and tested at both the subsystem and system level. If the SPY-1D to GWS interface is removed then both the SPY-1D and GWS computer programs would require modification and retesting. So four subsystems must be modified, two IDSs modified and one IDS deleted.

DDG Superset Derivative Impacts

In the Superset design the gun fire control portion of the ASUW Control System would have direct access to any surface sensor. If the sensor selected to provide gun fire control provided only video to the ASUW Control System then a formal IDS for digital communications between it and ASUW Control System must be first be agreed to and written. Then the controlling software for both the sensor and the ASUW Control System must be modified. This new connection must be tested to verify the IDS and then to verify that sensor's performance as a fire control radar. In this design the sensor could directly provide inputs on gun projectile's position error to the ASUW Control system.

If the fire control function is being reallocated among surface sensors then the existing interface must be removed. The ASUW Control System would no longer recognize inputs from the original surface sensor for use in gun fire control. It may be possible to modify the original IDS for use with the new surface sensor. The controlling program for that new sensor must implement the IDS. Again both subsystems must be tested separately and then together to verify the ASUW system level changes.

Case Summary

Figure 7 shows the resulting gun fire control loop for both designs. They are identical except for the feedback loop. For the Baseline 4 design, SPS-67 radar tracks on the outgoing gun projectiles must pass through C&D before GWS can determine the gun's pointing error. C&D does not have to process these SPS-67 tracks because GWS needs the data as points, not firm tracks for error correction. This means that the radar data does not have to be entered into C&D's database like other radar tracks. C&D could simply pass the radar data through to GWS, but special data routing code in C&D would be required and the process would not be instantaneous. This upgrade, implemented in this manner, is an example of another task which results in the expenditure of C&D resources (computer memory, timing, etc). To have the SPS-67 provide tracks directly to the GWS would be counter to existing combat system design architecture which has all surface radar tracks entering the C&D database. In the Superset design the surface radar would provide the gun projectile error position directly to the gun fire control portion of the ASUW Control System. The only delays would result from the actual design and implementation of the ASUW Control System.

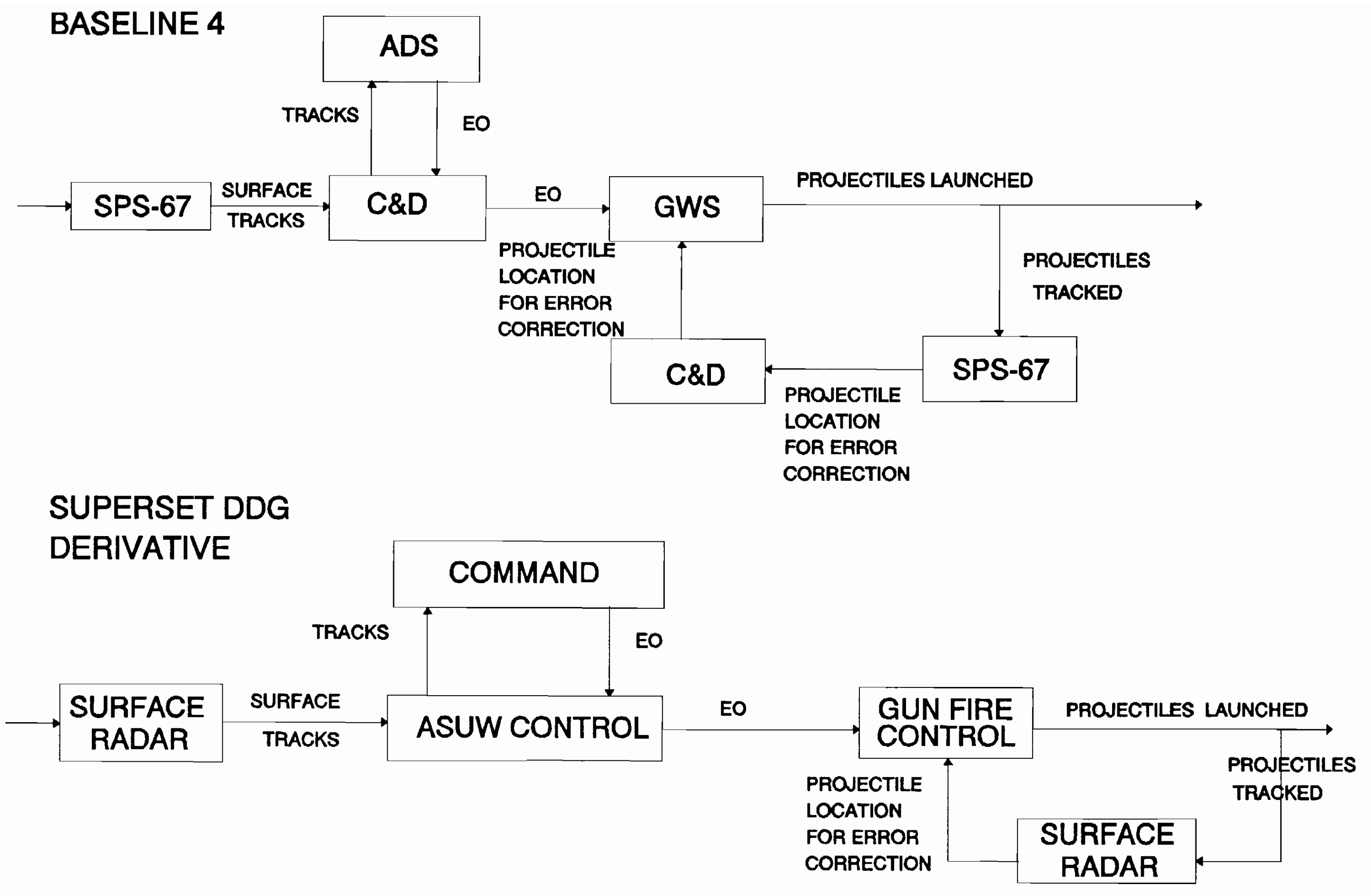

FIGURE (7): COMPARSION OF THE GUN FIRE CONTROL LOOPS

Table 6 summarizes the impact for this new fire control function. The impacts assume that cable modifications to establish or disestablish communications are minimal. Therefore there are no necessary hardware impacts in either design. This table assumes the deletion of one IDS and the creation of a new IDS for both designs.

Subsystem level training in the Baseline design is significantly impacted by this upgrade. This upgrade removes a task from one operator and assigns it to another. Both operators require retraining. More training is required at the ASUW level to train operators in the required coordination of the various subsystems. There is no real change between ownship command and the weapon control loop, so CIC team training should be minimal. But ASUW level training is the same as CIC team training for Baseline 4 so the impact is the same. The training impact for the Superset DDG Derivative is trivial.

Case 4: Introduction of a New OTH Missile

This is a new variant of the Tomahawk missile. The changes are primarily improvements to the missile guidance set and the use of navigational data from the newly implemented Global Positioning System.

TABLE 6

SUMMARY OF IMPACTS DUE TO A NEW GUN FIRE CONTROL FUNCTION

Type of Impact	Baseline 4	DDG Derivative
Number of subsystems with software mods*	Four - SPS-67, C&D, GWS, SPY	Three - Surface Radar 1 Surface Radar 2 ASUW Control
Number of subsystems with hardware mods	None	None
Number of Interfaces that must be modified*	Three - SPS-67/C&D C&D/GWS SPY/GWS	Two - Surface Radar 1/ ASUW Control, Surface Radar 2/ ASUW Control
Changed Subsystem Documentation (B1, B2, B5, etc)	Yes for C&D, SPY, GWS, SPS-67	Yes for Surface Radar 1, Surface Radar 2, ASUW Control
Impact to: CIC Training ASUW Level Training Subsystem Training	 Major Major Moderate	 None Minor Minor
Change to manual: Technical Operator Maintenance	 Yes Yes NO	 Yes Yes NO

* Modifications include retesting at both subsystem and combat system level

Baseline 4 Impacts

The VLS will require hardware changes to support the new missile, plus the missile canister must be modified. The VLS computer program must be modified to accommodate changes in missile inventory and changes in missile initialization data input. The engagement planning portion of TWCS must be changed to take advantage of the new missile's capabilities. The launch control portion must accept the new navigational input and download that information to the missile via VLS.

To fully integrate this new missile and it capabilities into the combat system requires that changes be made in the display that the CO and TAO see. This cannot happen without major modification to the C&D/TWCS and C&D/ADS IDSs and changes to the ADS computer program.

DDG Superset Derivative Impacts

For this derivative there will still be changes to launcher system and to the OTH weapon control portion of the ASUW Control system similar to those described for Baseline 4. The complexity of this upgrade comes in developing, testing, and implementing weapon selection and fire control algorithms for the various blocks of Tomahawk missiles and for Harpoon. Adequate time must be allocated for the development for the portion of the ASUW system. The interface between the ASUW Control system and Command must be modified to allow the CO and TAO to see the engagement plans.

Case Summary

Table 7 summarizes the impact of this new OTH missile. This is one upgrade where the Superset DDG Derivative incurs more changes than does Baseline 4. A reason for this is that the existing mindset in Baseline is that TWCS can make as many upgrades as it wants as long as there are no major modifications to the TWCS/C&D IDS. Part of this missile upgrade involves coordinating missile arrival times, something which the CO should see and understand before approving the engagement plan. Therefore C&D and ADS should also be modified. Since these changes likely will not occur, CIC team training takes on a significant role to work around this inability to transfer display information in the Baseline 4 design.

Summary

For any particular ASUW related upgrade the Baseline 4 design incurs more extensive software and computer interface impacts than the Superset DDG Derivative. The Superset's impacts are generally limited to the ASUW Control System. Because so many functions are contained in the ASUW Control

TABLE 7

SUMMARY OF IMPACTS DUE TO NEW OTH MISSILE

Type of Impact	Baseline 4	DDG Derivative
Number of subsystems with software mods*	Two - TWCS, VLS	Three - ASUW Control, VLS, Command
Number of subsystems with hardware mods	Two - VLS, Missile	Two - VLS, Missile
Number of Interfaces that must be modified*	Two - TWCS/VLS, VLS/Missile	Three - ASUW Control/VLS ASUW Ctrl/Command VLS/Missile
Changed Subsystem Documentation (B1, B2, B5, etc)	Yes for TWCS and VLS C1's etc for VLS, Missile	Yes for ASUW Control, VLS, and Command C-1's, etc for VLS, Missile
Impact to:		
CIC Training	Major	None
ASUW Level Training	Major	Minor
Subsystem Training	Minor	Minor
Change to manual:		
Technical	Yes	Yes
Operator	Yes	Yes
Maintenance	Yes	Yes

* Modifications include retesting at both subsystem and combat system level

System it might turn out to be easier to modify and retest the Baseline 4 design. But will that depend on the actual design configuration of the ASUW Control System which still must be determined. The use of a common programming language in the Superset may also counter that possibility. Because of the use of similar equipment and computer protocols, the Superset DDG Derivative does not have the hardware related problems that Baseline 4 does.

In the Baseline 4 design, C&D is impacted by almost every ASUW upgrade. An upgrade to the OTH data link or to the missile launcher does not directly impact C&D only because they have no direct interface with C&D. C&D, together with ADS, forms the equivalent of the Superset design's Command function. C&D contains no ASUW weapon control functions yet it must be involved in every ASUW operation. There is no focal point for ASUW operations in Baseline 4 except for C&D. This point manifests itself also in the area of training. Because there is no focal point, ASUW training becomes CIC team training. An example is training and coordination between a TWCS operator and a Harpoon operator. These two operators have no way to automatically share data or train in ASUW operations together. They require the assistance of the Antisurface Warfare Coordinator, who functions within C&D, because he is the only interface between these two operators. This is just one of the problems caused by Baseline 4's lack of modularity in ASUW.

Modularity is one of the principles of the Superset concept. Just how modular the ASUW Control System ends up will depend on the final design. Because ASUW operations are focused on the ASUW Control System rather than at the Command level, upgrades tend to impact the specific weapon subsystem and the ASUW Control System. Sensor and weapon improvements do not directly impact the Command function. Therefore, upgrades tend to have less of an impact on other components and in turn should cost less to implement on a single ship.

One way to select between the two concepts is to consider these four upgrades as forming the basis of a block upgrade to the combat system. Based on an estimate of the total impact one concept may be clearly preferred. First, every individual upgrade requires changes to technical and operator's manuals in both designs. So this comparison is negligible. Changed documentation is really a reflection of software and hardware modifications rather than a separate measure. Table 8 summarizes the total software and hardware impacts identified in the previous subsections for the four upgrades for each design concept.

TABLE 8

SUMMARY OF MODIFICATIONS IN BLOCK UPGRADE FOR EACH CONCEPT

Type of Impact	Baseline 4	DDG Derivative
Number of Subsystems with Software Modifications	8 subsystems out of 10	6 subsystems out of 8
Number of Subsystems with Hardware Modifications	Four	Two
Number of Interfaces that must be modified	9 interfaces out of 12	8 interfaces out of 10
Total Number of Modifications	8 + 4 + 9 = 21	6 + 2 + 8 =16

A crude measure of the total impact can be obtained by assigning a point for each subsystem or interface requiring modification. As a result twenty-one points are assigned to Baseline 4 and sixteen to the Superset DDG Derivative which on the surface favors the Superset concept. Admittedly this does not consider the magnitude of the modifications which may be required to the ASUW Control System. However final resolution requires more detailed definition of the changes than is currently available. Similarly to get an estimate of the total training impact assign 0 points to no change, 1 to a minor change, 3 to a moderate change, and 5 to a major change. Table 9 shows how each design concept fairs in training modification. Overall, the training impact due to ASUW upgrades is moderate for Baseline 4 and minor for the Superset DDG Derivative. More importantly Baseline 4 has a higher CIC team training impact while the Superset DDG Derivative has more subsystem level impacts. This is a result of the modularity of the Superset concept.

TABLE 9

TRAINING IMPACT AVERAGES FOR EACH CONCEPT

Type of Training	Baseline 4	DDG Derivative
CIC Team	0 + 1 + 3 + 10 = 14 3.5 avg	0 + 1 + 0 + 0 = 1 0.25 avg
ASUW	0 + 1 + 3 + 10 = 14 3.5 avg	0 + 4 + 0 + 0 = 4 1.0 avg
Subsystem	0 + 2 + 6 + 0 = 8 2 avg	0 + 3 + 3 + 0 = 6 1.5 avg

The modularity of the Superset design concept reveals itself through fewer numbers of interfaces which must be modified and lower training impacts. Improvements are limited to the ASUW warfighting path. Changes to ownship command level functions are rarely necessary. The drawback to the Superset design is the potential requirement for major software modifications and related training to the ASUW Control System. This will be resolved with further definition of the ASUW Control System. For these reasons, the Superset DDG Derivative design is the preferred design from combat system upgradability perspective.

SECTION 7

SOFTWARE MAINTAINABILITY

A surface combatant typically deploys for six months and then spends the next six months in port getting ready for the next deployment. Given this type of operational profile the traditional breakdown of maintenance efforts into organizational, intermediate, and depot levels of maintenance can be defined, but only for hardware. This same breakdown does not apply to software. Typically software is delivered to the ship in an executable format; not as source code which can be edited. So, sailors cannot perform maintenance of the supporting software. Therefore, software maintenance must be done ashore.

One problem with software maintenance as compared to hardware maintenance is that software does not "break" in the same sense as a piece of hardware. One can perform preventive maintenance on hardware or the hardware can be designed to be very reliable. Transferring these concepts to software is not straight forward. "While software doesn't break in the sense that a piece of hardware can fail, it can become non-functional or faulty due to changes in the environment in which it must operate, the size or sophistication of the user community, the amount of data it must process, or damage to code which is the result of other maintenance efforts on other parts of the system." [9]

Software maintenance is important to the life cycle of the combat system. It is generally accepted that thirty percent of all computing resources are spent on design and development while the remaining seventy percent are spent on maintenance. [10] One reason that the combat system software should be designed with future maintenance in mind is that the combat system will be in existence for a long time -- typically thirty to forty years. The entire combat system, including the software, must be upgraded to account for changes in the threat over the combat system's lifetime. But it must be remembered that "software tends to deteriorate with age as a result of numerous fixes and patches. If a system is more than seven years old then there is a high probability that is outdated and expensive to run. ... After seven to ten years of maintenance, many systems have evolved to where additional enhancements or fixes are very time consuming to make." [11] It is important that the combat system's software be maintainable for a longer period than seven to ten years.

Software maintenance has been divided into three categories: perfective, adaptive, and corrective. A definition of software maintenance and the three types of software maintenance have been established in IEEE STD 729-1983 [12]. These are:

> Software Maintenance: (1) Modification of a software product after delivery to correct faults, (2) modification to a software product after delivery to improve performance or other attributes or to adapt the product to a changed environment.
>
> Perfective Maintenance: Maintenance performed to improve performance, maintainability, or other software attributes.
>
> Adaptive Maintenance: Maintenance performed to make a software product usable in a changed environment.
>
> Corrective Maintenance: Maintenance performed specifically to overcome existing faults.

These terms must be related to actual combat system software maintenance efforts. After the combat system is deployed the various subsystems are improved in response to a change in the threat or to add desired enhancements. This is perfective maintenance. Changes to fix problems such as program crashes found in operational use are corrective maintenance. Adaptive maintenance results from an upgrade to the operating system or from new hardware induced changes in the software.

One problem with software maintenance for a combat system is there are no standards dealing with software maintenance. The current Defense System Software Development standard does not explicitly address the maintenance phase of the software portion of the system. If the software developers follow the standard and produce the required documentation for the development, then that documentation can form the basis for a software maintenance plan. The National Bureau of Standards has published a Guideline on Software Maintenance [9]. It states that the guideline should be used "whenever Federal departments or agencies are: developing or maintaining software; developing policies and procedure for developing or maintaining software; or considering alternatives to continued maintenance of a software system." The key point here is that this publication is a guideline which people can be encouraged to use rather than a standard. This guideline applies to all Federal agencies, particularly those involved in Automated Data Processing (ADP) programs. While the software in a combat system is frequently automated data processing, the maintenance needs for a combat system differ from those required for other federal agency' database programs if in no way other than their respective life cycles.

Maintainable software exhibits the characteristics of testability, understandability, modifiability, portability, reliability, efficiency, and usability. Martin and McClure [13] provide checklists for each of these characteristics. By answering 'yes' or 'no' to the questions in each checklist one can achieve an estimate of the software's maintainability. At the Requirements/Specification Phase of software development Martin and McClure suggest using the usability checklist to help determine what the software's maintainability requirements are. However, this checklist, like the others presented, assumes at least one level of detail more than that to which the Superset concept is presently defined. In fact, most software maintenance evaluation criteria involve specific code design techniques. That is, these criteria assume that we are assessing the maintainability of production software systems. This also applies to checklists available for determining the impact of a specific software maintenance action.

Therefore, this project will only use high level comparisons because of the conceptual nature of the Superset design. The following sections will discuss how well each design concept supports those high level comparisons described earlier for software maintenance.

Baseline 4 Evaluation

The Baseline 4 Aegis Combat System is composed of twenty-nine subsystems. The combat system can be viewed as being composed of two groups: the seven subsystems belonging to the AWS and those that do not. Software maintenance for the entire combat system can be viewed along the same line.

Software Maintenance Plan

Eight years after the deployment of the initial version of the AWS and coinciding with the deployment of the Baseline 4 AWS, a document outlining computer program maintenance at NAVSWC was published [14]. The purpose of this document is to define the NAVSWC computer program maintenance process and environment. Four major functional processes compose this maintenance methodology: establish program library, computer program change request, upgrade/backfit, and quick update. The upgrade/backfit process applies to both perfective and adaptive maintenance. The computer program change request process handles corrective maintenance actions. This process feeds into the upgrade/backfit process. The quick update process is to remedy a problem on a ship via a patch to the code. For non-AWS subsystems the existence of a software maintenance plan is left up to the individual subsystem. There is no interrelationship between the software maintenance plans for AWS and non-AWS subsystems of the ACS.

Software Change Control Board (CCB)

For the AWS there is an established change control process for software maintenance. First there is an element CCB for each AWS subsystem. This board approves and recommends changes to the AWS Change Review Board (CRB).

The AWS CRB handles computer program changes at the AWS level. Approved changes then go to the Life Cycle Support Engineering Agent (LSEA) CCB. The LSEA CCB handles both equipment change proposals for hardware and computer program changes.

The change control process is up to the individual non-AWS subsystem. TWCS, for example, has its own change control process with proposed changes to its two major components being individually evaluated and then evaluated at the weapon control system level. However, there is no combat system level requirement levied on the existence or mode of operation of a non-AWS subsystem CCB.

The LSEA CCB accepts the results of any non-AWS's own version of a software CCB. A proposed non-AWS change must be evaluated at the LSEA CCB level if there is any known impact to the AWS. The LSEA CCB assumes that any non-AWS subsystem has resolved potential impacts to other non-AWS subsystems by the time the change reaches the LSEA CCB. So, the LSEA CCB functions at the combat system level although it basically considers non-AWS impacts on AWS.

Choice of Programming Language

For the combat system and specifically for ASUW, the majority of the programs involved are coded in CMS-2Y, a language which is specific to Navy systems only. While this language is widely used throughout the Navy, it is not one that a computer science major would learn in college. A programmer hired by the Navy would have to learn this assembler-like language as part of his/her training.

TWCS, on the other hand, is programmed in FORTRAN. This choice reflects TWCS's requirement to interface with character oriented data links. While FORTRAN is considered a high order language and courses in FORTRAN are readily available, there are still software maintenance problems. Systems coded in CMS-2Y and systems coded in FORTRAN cannot talk directly with each other. A translator is required to allow communications between TWCS and C&D making the task of software maintenance more difficult.

Harpoon creates another problem for ASUW software maintenance. The computer memory location of several pieces of information necessary for an engagement such as track number is a fixed length. While this was advantageous initially, this limits the amount of perfective maintenance that can be done at the combat system level without requiring modification to the existing memory allocations.

Software Design Standards

Today's Defense Department Software Development Standard, DOD-STD-2167A [15], was established in 1988. All new software development programs must follow this standard.

The first issue of this standard replaced the old military standard, MIL-STD-1679A [16], created in 1983. Most of the components of the ACS have their roots in development prior to 1983. MIL-STD-1679 was not applied to the earlier versions of the AWS, which form the core of the ACS. Perfective maintenance of any subsystem would be done under the rules of whichever development standard was used. The standard was never applied at the combat system level, only at the subsystem level. Proposed additions to the Baseline 4 configuration have to be developed under DOD-STD-2167A.

This results in three different software development situations for the combat system. Subsystems of the combat system would be developed according to 1) the current DOD software development standard, DOD-STD-2167A; 2) the first military wide software development standard MIL-STD-1679; or 3) a variety of standards established for specific programs. This situation is not good for future software maintenance. The most important aspect resulting from this situation is the different methodologies used to assign priorities to errors that will require corrective and perfective maintenance.

DDG Superset Derivative Evaluation

Given that the Superset is a high level concept it would be easy to assume that follow-on detailed design work would lead to perfectly maintainable software. Doing so would show a lack of foresight and a poor job of systems engineering. Because of the complexity of the Superset concept and the creation of actual combat system derivatives, it is important that maintenance be considered in the early stages of design. This is very important because any change to the code at the superset level will trickle down to the derivatives. Any proposed change at the derivative level must be added into the Superset and be evaluated for the need to add that change to another derivative in order to maintain the desired software commonality.

Software Maintenance Plan

It will be critical that there be an established software maintenance plan for the Superset derivatives. That plan should be the same for all combat system derivatives and should reflect the software maintenance plan at the superset level. Subsystems will be allocated to meet the various unique requirements of each combat system derivative. Each subsystem must be maintained in accordance with the same software maintenance plan on all derivatives. This will be a configuration management nightmare if a systematic approach is not taken.

Software Change Control Board

It will be necessary to have a change control board at the superset level. This board will be fed by subsystem or warfare area level change control boards. Since the warfare area implementations will vary by combat system derivative it will be necessary that those boards be held at the force level. A change control board at the warfare area level would find and investigate potential problems affecting the various weapon system within a warfare area. An example of this is a proposed change to the gun fire control system. If this change is proposed for a derivative that has no other ASUW systems onboard there may be no problem in implementing the change. However, this same change may impact other ASUW systems on derivatives with several ASUW systems onboard. Again, this will make configuration management a difficult task.

Choice of Programming Language

All new defense system weapon programs are directed to be coded in ADA. There is a grandfather clause in that directive that allows current systems to do their perfective maintenance using the existing design language. Most programs use the cost of converting the existing code to ADA as the main reason for the continued use of older languages. However, we are talking about a system concept that will be deployed in fifteen to twenty years. That is enough time to develop new weapon systems in ADA. The actual language selection and its unique maintainability traits are not the issue here, any single language can be mandated. Also most computer science students are learning higher level languages such as ADA and "C" now. These will be the languages that future programmers will know and therefore can maintain. The objective is that one language be used on common computers for all combat system derivatives.

Software Design Standards

The same concern about language selection applies to the use of design standards. Given time to develop the follow-on versions of the subsystems found on today's surface combatants, all should be in accordance with the latest version of DOD-STD-2167A. The key will be that the software development folders required by DOD-STD-2167A contain the same types of information and, preferably the same level of detail for all subsystems of the combat system.

Summary

Baseline 4 has a change control process is in place for its various subsystems but not completely at the combat system level. Also, there is no overall combat system level software maintenance plan in place to support the Baseline 4 design. Therefore, software maintenance activities are still oriented to the individual component or specific weapon system level, rather than at the combat system level. This flaw is more one of the management and implementation of the Baseline 4 design concept than of the design concept itself.

The choice of programming languages in the Baseline 4 design was based on the characteristics of the data link that the specific subsystem interfaces. Generally there is little wrong with this selection. However when two such systems have to communicate using different languages, future software maintenance efforts are difficult. A further complication of software maintenance activities results from any additions or upgrades to the Baseline 4 design which must be developed using DOD-STD-2167A.

The management of software for the Superset concept may be difficult and time consuming because of the desire to maintain a common set of computer programs for the entire fleet. The use of a common programming language developed against a single standard should make the actual maintenance of the software a much easier task. The Superset concept does not guarantee that design and logic errors, the major sources of corrective maintenance actions, will be eliminated. This must be done through planning in the early stages of the Superset concept's development.

Ranking both concepts for each evaluation criteria is one way to develop an idea of how conducive to software maintenance each design concept is overall. Table 10 outlines the point criteria by which the concepts will be ranked.

Two points are assigned to Baseline 4 for both Software Maintenance Plan and Software CCB; a four point total. Each of these are implemented at some degree at the combat system level. However the emphasis is on the impact of the non-AWS subsystems on AWS subsystems. Three points are then added because two different programming languages are used in ASUW. Because at least two software design standards were used in the development of Baseline 4's ASUW subsystems another three points are assigned. So, Baseline 4 has a total ranking of ten.

One programming language should be used in any Superset derivative's development in accordance with one design standard. Two points are accordingly assigned. At this stage of development it is definitely too early to assume that both a combat system level Software Maintenance Plan and Software CCB will exist but its is unlikely that things will be worse than Baseline 4. So add two to six points to the ranking. The Superset concept ends up with a ranking

TABLE 10

POINT ASSIGNMENTS FOR EACH SOFTWARE MAINTENANCE EVALUATION CRITERIA

Points	Criteria
Software Maintenance Plan	
1	A software maintenance plan exists which covers the entire combat system; individual subsystems software maintenance plans exists.
3	There is no combat system level software maintenance plan; individual subsystems software maintenance plans exists.
5	No software maintenance plan exists at any level
Software Change Control Board (SCCB)	
1	SCCB exists at combat system level; feed by subsystem SCCBs
3	No combat system SCCB exists, only subsystem SCCBs exist
5	No SCCBs exist at any level
Choice of Programming Language	
1	One language used in ASUW subsystems
3	2 or 3 languages used in ASUW subsystems
5	More than three languages are used in ASUW
Software Design Standards	
1	One standard used in ASUW development
3	2 or 3 standards used in ASUW development
5	More than 3 standards used in ASUW development

that varies from four to eight depending on how further design details are implemented. The previous discussion is summarized in Table 11.

TABLE 11

SUMMARY OF POINT TOTAL FOR SOFTWARE MAINTENANCE

Criteria	Baseline 4	DDG Superset Derivative
1	2	1 to 3
2	2	1 to 3
3	3	1
4	3	1
Total	10	4 to 8

The lack of a combat system software maintenance plan and the variety of software developmental standards used in the Baseline 4 design does not recommend the use of the existing Baseline 4 architecture for our future surface combatant. If the development of a combat system superset software maintenance plan is undertaken in the next level of design of the Superset <u>and</u> a combat system superset level CCB is guaranteed after the system is deployed, then the Superset concept should be further investigated. However, this will require a serious commitment by both the system developers and maintainers to ensure that this does happen. For software maintenance, the management of the implementation of the combat system design may be more important than the actual design.

SECTION 8

SUPPORT TO BATTLE ORGANIZATION

A battle organization is how the various ship personnel are organized to operate the ship to fulfill the ship's mission. " A battle organization shows the authority for command, control, direction, guidance, and employment of available resources and assets in battle. It includes the chain of command; allocation of duties and responsibilities to units and to levels if command; and functional interfaces, interactions, and communications. [17]" There is no standard format for a ship's battle organization.

It should also support CNO's operational philosophy for surface ships as outlined in 1976 [18]. There has been no countering guidance issued since then. The gist of this guidance is that for a specific ship class, the battle organization must reflect the need for tactical command and coordination, information management, and weapons control at both the single warfare area level and at the combat system level. This organization must permit Command to delegate tasks to specific warfare areas, allow for both simultaneous and independent warfare area actions, and maintain Command's right to final control by negation.

The supporting combat system databases must reflect that some positions in the battle organization are multi-warfare area command level functions, some are single warfare area command functions and the rest are sensor and weapons operators positions. The databases must support the required warfare functionality of each position. Therefore, some positions need access to more than one database in order for the operators to do their jobs properly.

The sensor and weapon operators need to communicate with the warfare area coordinator. He, in turn, must relay information to ownship Command and receive tasking orders from Command. The warfare area coordinator needs access to what the sensor and weapon operators see on their individual displays. At each level of the chain of command, the operator needs to see more of a big picture view than those at the levels below. An example of this is a sensor operator working with just sensor contacts while his warfare area coordinator is concerned with all tracks in that warfare area. In turn, ownship Command deals with tracks from all warfare areas that are in a specified area of interest.

The combat system designers have to realize that in addition to ownship <u>command</u> needs and operations there must be <u>control</u> of operations which have impacts across several warfare areas. These controls cannot be embedded within a warfare area but must be considered at a command level.

Many shipboard systems, although assigned tasks in one warfare area must sometimes provide support to other warfare areas. Guns are fired against both air and surface targets. Certain radars have both air and surface tasks to perform. Sonars have a requirement to detect surface ships in addition to submarines. The battle organization must be flexible enough to support multiple roles and the supporting combat system design must account for this.

A battle organization reflects a reporting structure/scheme for the chain of command. The combat system should account for the functions to be performed and should be designed to allow for an easy flow of data through the structure.

The battle organization established for a specific ship class must reflect that ship's mission as stated in its top level requirement. A battle organization is first proposed by the combat system designers. This reflects their interpretation of the organization required to support the ship's mission. The proposed battle organization is then modified to reflect the actual structure of the operational Navy. Developing and getting approval for a new battle organization is a time consuming task. This project will, therefore, just use the Condition I Battle Organization (figure 8) for the DDG-51 as shown in its combat system top level specification, WS-21200 [19].

Figure 9 shows the warfare mission functionality as supported by the Condition I Battle organization. There are several interesting facts about this organization:

1. Combat System Coordinator (CSC) assists the Tactical Action Officer (TAO) in managing the combat system and therefore is a command level function.
2. All radar controllers, identification supervisors and ownship electronic warfare system operators report to the Tactical Information Coordinator (TIC)
3. The sonar operators support the ASW Coordinator, not TIC
4. The Gun Fire Control Supervisor (GFCS) is under the ASUW command hierarchy while the gun supports both ASUW and AAW missions.
5. The Missile System Supervisor (MSS) controls the multi-warfare launcher while being under the AAW hierarchy.
6. All of the warfare area coordinators and TIC support both ownship and warfare area command functions.

Given this background, the following two sections will discuss how each design supports the battle organization. This project is particularly concerned with the ASUWC branch of the battle organization and its upward connections.

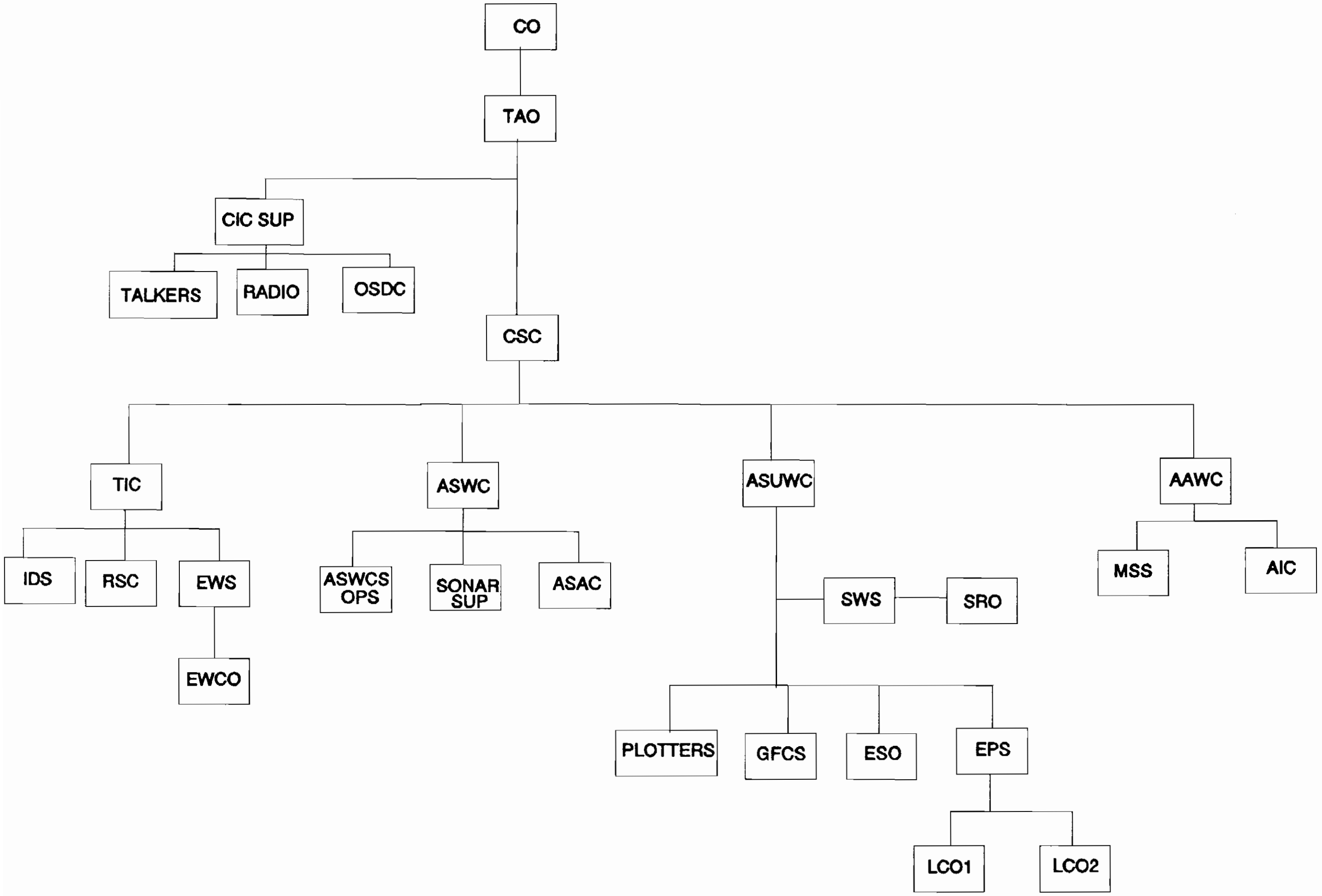

FIGURE (8): DDG-51 CONDITION I BATTLE ORGAINZATION

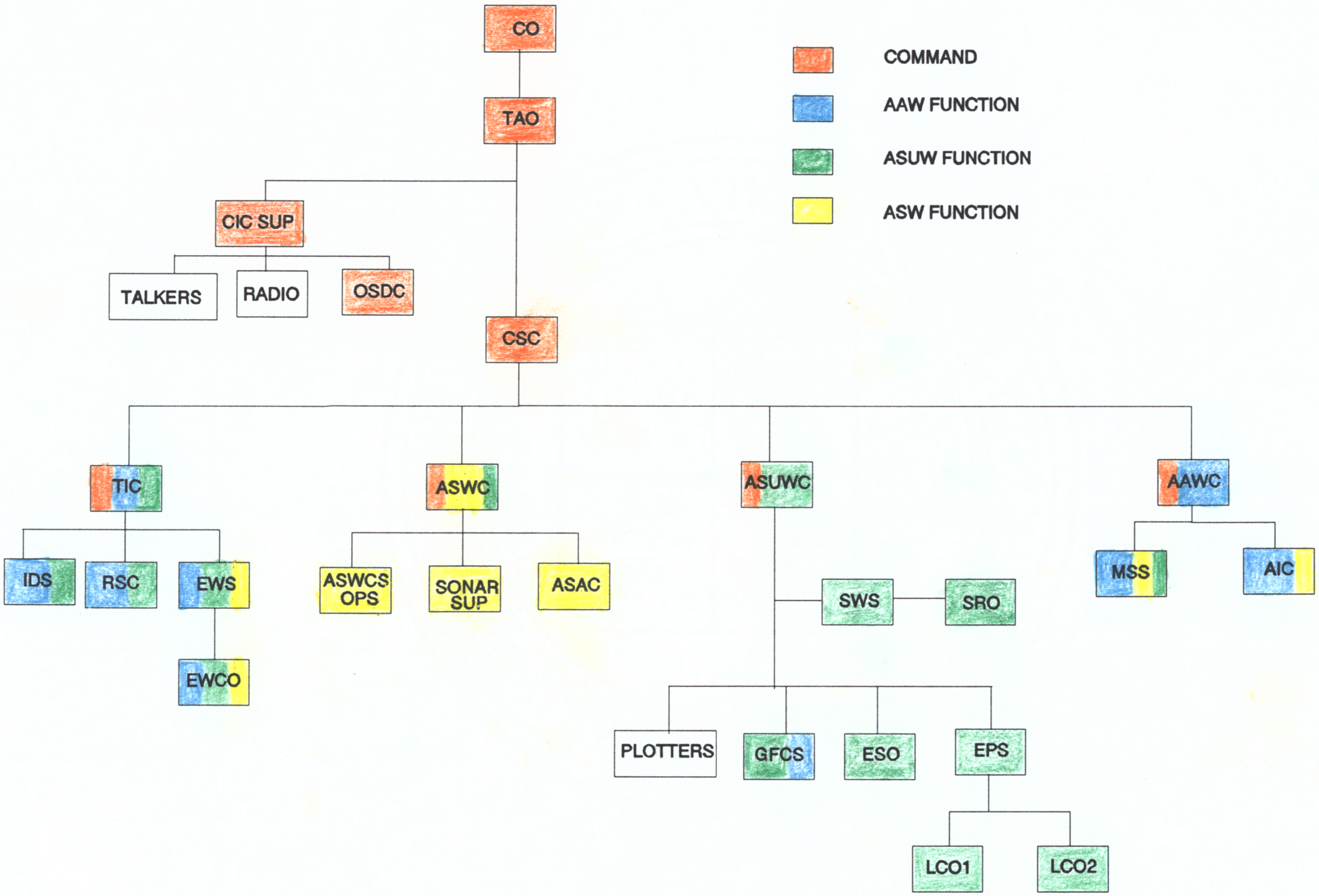

FIGURE (9): FUNCTIONS PERFORMED WITHIN BATTLE ORGANIZATION

Baseline 4 Support of the Battle organization

Figure 10 shows which Baseline 4 databases support which positions within the battle organization.

The CO, TAO and Ownship Display Controller (OSDC) console positions are driven off of the ADS database. The OSDC maintains the automated status boards and the large screen displays (LSD) for the CO and the TAO. The ADS database is almost an exact replica of the C&D database. Special points can be manually entered into the ADS database. These points will not automatically be sent back to the C&D database.

TIC controls the Link-11 interface. Surface tracks from Link-11 can easily get to the ASUWC and to the CO. Link-11, SPY-1D, and SPS-67 surface tracks all directly feed into the C&D database. However, OTH links feed directly into TWCS. The TWCS database manager has the responsibility for controlling the various OTH data links.

All the warfare area coordinators and TIC work off of the C&D database. This also includes the Surface Warfare Supervisor (SWS). The combat system design allows ASWC direct access to both the C&D and ASW combat system (SQQ-89) databases. Neither the Antisurface Warfare Coordinator (ASUWC) nor the SWS has direct access to the TWCS database. One reason for this is the use of different computers, operating systems and consoles. This drawback is

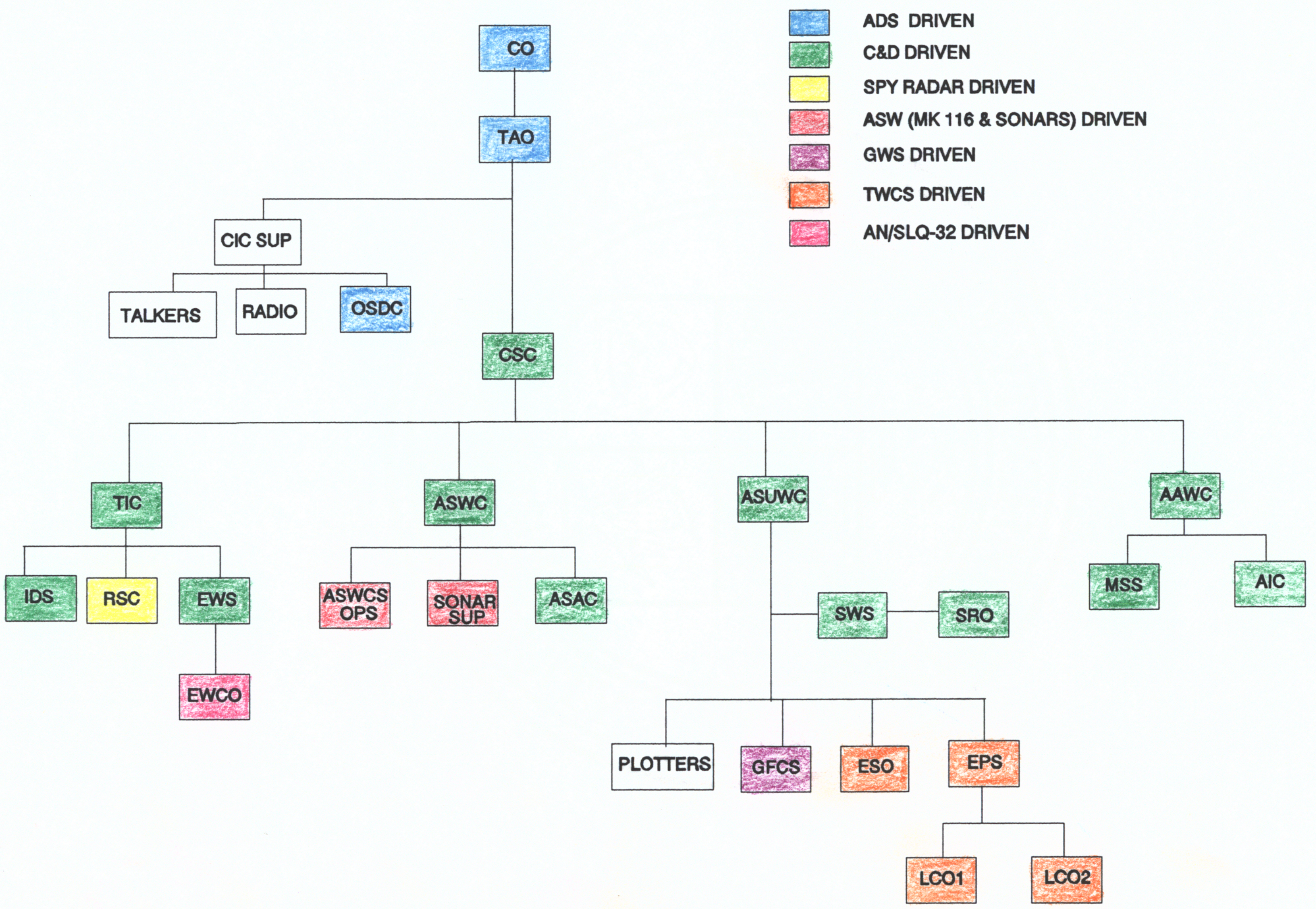

FIGURE (10): BASELINE 4 DATABASE SUPPORT OF BATTLE ORGANIZATION compensated for by positioning the SWS console next to the Extended Surveillance Operator (ESO). This position which corresponds to the TWCS database manager who controls the OTH data links. He can display all OTH tracks for the SWS to view.

It is important to recognize that the TWCS database cannot automatically enter a new track into the C&D database. This requires a manual action on the part of the TWCS operator. Otherwise to get TWCS tracks displayed, C&D must request tracks in a certain area and the standard OTH target motion model parameters for those tracks. Once in the C&D database, TWCS can update the track without an area of interest request. This data is then passed to ADS. ADS uses those target motion parameters to calculate the next likely track position. What will be displayed on the LSD will be termed the last reported position while the TWCS display will call that solution a projected position. C&D does not perform the calculations for the target motion model for use on its displays. Neither the ASUWC or SWS can directly see the predicted target motion model's solution for an OTH track. Thus the TWCS operator's display will not match either the ASUWC's or SWS's display and neither set of displays will match the CO's and the TAO's displays.

The GFCS console position is driven by the GWS database. That database receives data from the C&D

database. The characteristics of the GFCS display may not match that of a C&D driven display but it is the same type of console and is part of the C&D console back up scheme. The ASUWC does have access to the GFCS display since the same inputs drive both of the supporting databases.

The Radar System Controller (RSC) is primarily connected to the AN/SPY-1 database. However SPY must support the operations of the GWS controlled by the GFCS. Note the Surface Radar Operator (SRO), who is responsible for operation of the surface search radar, is part of the ASUW hierarchy.

The battle organization is not clear about who controls Harpoon. The definitions in WS-21200 given to the Extended Surveillance Operator (ESO), Engagement Planning Supervisor (EPS), and Launch Control Operator (LCO) positions imply that these positions do. However, these positions correspond to the TWCS operator positions of Database Manager, Engagement Planner, and Launch Control. These positions are not connected to the Harpoon Launch Control Unit. Harpoon is designed to interface with the other systems such as C&D. TWCS operators have access to data more appropriate in developing a Harpoon fire control solution. That data can be orally supplied to either the SWS or the ASUWC, depending on who is verifying the Harpoon Engagement Plan.

What we see is that the ASUW related consoles are driven from three different databases: C&D, TWCS, and GWS. The database that drives the console is also the one that "owns" the console. The databases cannot automatically be shared between the three systems except by manually entry. So the displays are different due to the implementation differences.

Destroyer Superset Derivative Support of the Battle Organization

Figure 11 shows how the destroyer derivative's databases provide support to the battle organization.

All data links will come into a command level correlator which falls under TIC's control. This correlator will then feed targeting information to the ASUW system; long range track information to both ASW and AAW systems; and the force level commands, indications and warnings information, and other command control related messages to the CO/TAO. This eliminates the problem of a system requiring information found on a single data link without having direct access to that link.

This design results in an ownship command database which will include all the information necessary to control the ship (navigational data, ship motion data, etc.) and any

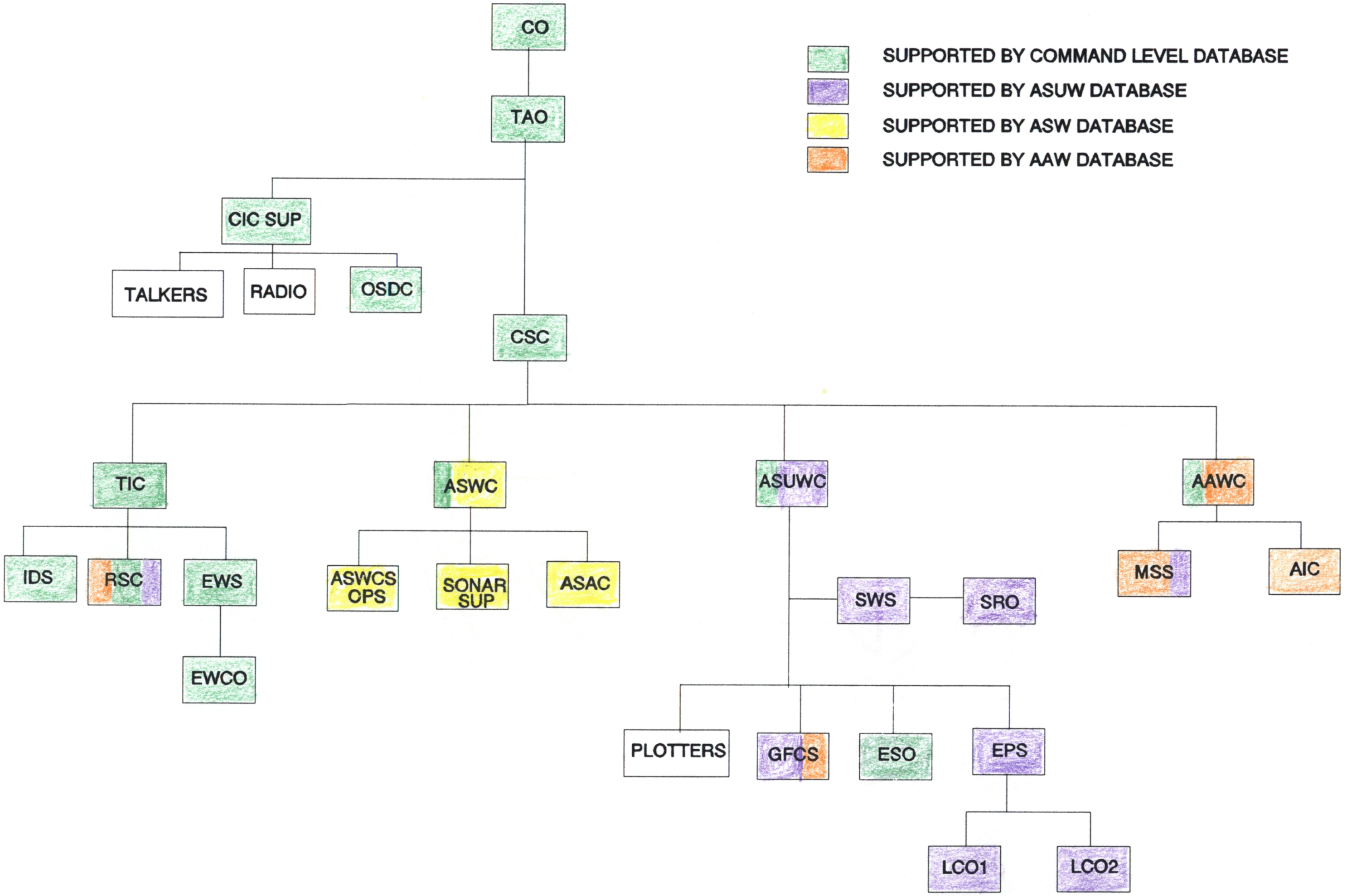

FIGURE (11): DDG SUPERSET DERIVATIVE SUPPORT OF BATTLE ORGANIZATION data required to monitor the tactical environment to allow for command's control by negation. That portion of the command database is based on the various warfare area databases.

Several things happen in the ASUW hierarchy from the superset's perspective. One is that the ESO position, which maintains the non real time OTH database, falls better within the TIC hierarchy. Since the gun must support two required mission areas it must have access to both ASUW and AAW data. The RSC position in the superset covers both air search and surface radars. The supporting database must reflect that fact. For tactical information coordination the RSC must still provide support to TIC.

The ASUW Control System will drive all console positions found in the ASUW hierarchy of the battle organization. The design should support the ASUWC having access to both the command level database and the database found in the ASUW Control System. The targeting information from the correlator and the organic data from the shipboard sensors will form the basis of the ASUW control database. Since all surface operations will be based on this one database there should be no problems with display differences.

The question regarding which is the best CIC operator to control Harpoon still is not resolved. However, all ASUW operators should have access to all available surface data. The chosen operator can easily select the most appropriate data for use in a Harpoon fire control solution calculation.

Since common equipment, particularly computers and consoles, is used in the superset derivatives and therefore throughout the ASUW hierarchy, there will not be the physical constraint on displaying the same surface picture to the necessary operator positions. The superset concept emphasize the use of the same command and control structure with common interfaces. So data can easily pass between the ASUWC and the CO or the TAO even though they are operating from different databases.

Summary

In the Baseline 4 design, the CO does not have ready access in his supporting data base to all surface data available in the combat system. This can limit the CO's decision making process in evaluating OTH engagements plans. ASUW information is displayed on four different types of consoles. So there is no consistent ASUW display format throughout the combat system. Because a preprocessor is required to handle communications between TWCS and C&D ASUW data passage is not always that simple.

In the Superset design all ASUW related consoles will be driven by the ASUWCS so all displays will be similar.

With the ASUWCS currently encompassing ASUW command control functions and the weapon control functions for both gun and OTH weapons there should be no problems with getting data transferred through the basic ASUW chain of command. This may change as the exact structure of the ASUWCS is further defined. The superset design structure allows for the easy data passage between ASUWCS and Command. This will be realized if the implementation does not keep the same communications barriers that exist today.

To achieve an overall perspective of how well each design concept support the battle organization for ASUW, points can be assigned in the following manner.

Support to Decision Making Process
Does the CO have ready access in his database to information such that he can issue an EO for:
    surface gun engagement?
    Harpoon engagement?
    TASM engagement?
No points for a 'yes' response; One point for a 'no' response

Ease of Data Passage
Does the ASUWC have direct access to all data available from ASUW sensors?
 1 point if he automatically receives the data
 2 points if he must sometimes request the data
 3 points if he must always request the data

Displays
Assign a point for each subsystem that drives ASUW related displays for command level purposes, weapon control purposes, and sensor operations

In the Baseline 4 design the CO does not have immediate access to all available data to initiate a TASM engagement. He does have the data for both gun and Harpoon engagements. The ASUWC might request OTH surface data from the TWCS data base in a specific 'area of interest'. He does not automatically receive such tracks. ADS, C&D, and TWCS, for OTH correlation purposes, drive command level displays. TWCS, GWS, and HWS data bases drive the weapon control displays. There are two sensors which provide surface data displays, SPY and SPS-67. So the Baseline 4 point total is eleven.

In the Superset concept, the CO should have direct access to all data necessary to issue an EO for an engagement using any available antisurface weapon. The ASUWC should automatically have access to all available sensor data. This does not mean that he will receive <u>all</u> data but that he does have the capability to set filters such that he receives all track that interest him. Command ASUWCS will provide data for the command level displays. This includes the Correlator's database since that is a command level function. At this stage of design the ASUWC database provides for weapon control functions and displays. The actual number of sensor operators and their displays that would be found on a Superset derivative is not firmly established. This could range from one to four operators.

So, the Superset point total varies from five to eight. This value will change with further definition of the ASUWCS and a selection of sensors. These point totals are summarized in Table 12.

The limitation on having a coherent surface picture throughout the combat system in Baseline 4 primarily results from the use of incompatible displays and programming languages. A single coherent surface picture is what the CO and TAO most need. This problem extends throughout the battlegroup since TWCS supports the BGDBM specification for a common force level OTH picture while C&D and ADS do not. Additionally the BGDBM design does not include the local organic surface picture. The use of a standard console and programming language should allow for the data to be easily transferred and displayed at the various levels of command. This is the primary benefit that the superset derivative offers when considering support to the Battle Organization. Therefore, the Superset DDG Derivative is the preferable design when considering support of the battle organization.

TABLE 12

SUMMARY OF POINT TOTAL FOR SUPPORT TO BATTLE ORGANIZATION

Point Assignment Criteria	Baseline 4	DDG Superset Derivative
Information available is issue EO for:		
• surface gun	0	0
• Harpoon	0	0
• TASM	1	0
ASUWC have direct access to data?	2	1
Number of subsystems that drive displays for:		
• command purposes	3	2
• weapon control	3	1
• sensor operations	2	1 to 4
Total Points	11	5 to 8

SECTION 9

CONCLUSIONS AND RECOMMENDATIONS OF FEASIBILITY STUDY

Conclusion

Table 13 highlights the conclusions drawn for each area of comparison.

At the force level, a surface combatant fleet based on the Superset concept has advantages over the structure of the present fleet. These advantages result from (1) the command and control structure which limits the multiplicity of ASUW interfaces when compared to the current number of interfaces and (2) the expanded use of common equipment which further reduces the variety and number of spares. These advantages will not be achieved until the operational and support phases of the combat system's life cycle.

At a single ship level, a Destroyer Derivative of the Superset concept is preferable to the current Baseline 4 Aegis Destroyer. The Baseline 4 design concept does not provide a focal point for both short and long range antisurface operations at the weapon control level. As a result ASUW upgrades cause changes at the command level and ASUW level training is almost equivalent to CIC team training. It is not possible to produce a single ASUW

TABLE 13

HIGHLIGHTS OF COMPARISON SUMMARIES

Force Level Comparisons		
Evaluation Criteria	Current Fleet	Superset Fleet
ASUW Command & Control Interfaces	Large variety of gun interfaces that must be supported	Reduction in maintenance efforts through less variety of interfaces
Spare Parts Requirements	Large numbers of spares required even when using standard equipment	Potential for logistics, maintenance, and training benefits for single ship & entire fleet

Single Ship Comparisons		
Evaluation Criteria	Baseline 4 DDG	Superset DDG Derivative
Combat System Upgradability	C&D impacted by almost all upgrades, training modifications required to handle upgrades that go beyond a single interface	More modular design by limiting impacts to ASUW warfighting path
Software Maintenance	Software Maintenance Plan and Software Change Control Board exist to some degree at combat system level	Potential savings due to use of common programming language and design standard
Support to Battle Organization	No consistent ASUW tactical picture, all data not available to CO	ASUW supervisor has access to all available data

tactical picture because all information cannot be easily transferred between ASUW data bases. In the Superset concept, ASUWCS provides a focal point for ASUW operations. Thus the Baseline 4 deficiencies identified above should be eliminated. Therefore the Superset's combat system upgradability and support to the battle organization is better than Baseline 4's.

For software maintenance it is not the actual design concept that makes a difference but rather how the concept is implemented and managed throughout the combat system's life cycle that matters. It can not be guaranteed at this stage of the Superset's development that software will be properly managed but the principles of the Superset concept make it more likely and therefore preferable for future software maintenance.

Recommendation

Table 14 outlines some high level pros and cons of each concept.

We recommend further investigation of the Superset concept as the combat system architecture for future surface combatants. This recommendation comes with the recognition that the following refinements need to be done before a final selection is made.

TABLE 14

PROS AND CONS OF EACH CONCEPT

Design Concept	Pro	Con
Baseline 4	Proven design that works, able to estimate the extent of any improvements	Training is used as a workaround when design is inflexible to change, no focal point for ASUW operations
Superset	Impacts are limited to specific warfighting path, consistent tactical surface picture, potential for O&S savings at force level	Uncertainty of ASUWCS configuration - cannot estimate all impacts without more details, need more definition of the concept

(1) The study must be expanded in scope to examine the other warfare areas and how the two combat system designs support their operations. It will be important to consider not just the other warfare areas in isolation but also how they interact while performing operations in multiple warfare areas simultaneously. Considering all warfare areas interacting at once will reveal any critical differences between the two design concepts.

(2) The ultimate decision is an appropriate trade-off among many factors. Two very important factors are system effectiveness and life cycle cost. In order to address

these factors the Superset concept must be further defined.

(3) An adequate assessment of system effectiveness will require that the Superset Concept be defined in enough detail to determine data flows, data accuracy, system timing, etc. with enough fidelity to develop a meaningful assessment of performance, reliability, availability, maintainability, and other effectiveness factors. This would take the definition of the Superset concept to the next level of detail as is appropriate for the next step in an iterative development cycle. One task is to develop the various warfare area control systems, not just for ASUW but for all warfare areas, to sufficient detail to evaluate performance related factors such as reaction time and data throughput for the concept comparisons. Two examples of this for ASUW include:

a) Re-evaluating the Superset against the upgradability criteria given the complexity of the ASUW Control System's tasks and ease of modification

b) Undertaking a timing study using the actual ASUW Control System design to ensure that the time from detection to firing of ordnance is equal to, if not less than, that of today's newest surface combatant in each level of ASUW operations.

(4) Meaningful life cycle cost estimates similarly require enough design detail to estimate research, development, production, operation, maintenance, and disposal costs. A life cycle cost estimate for each design concept needs to be developed for two reasons. The first is

that one of the postulated benefits of the Superset concept is lower life cycle costs. This must be verified. The second is that with continually decreasing operating budgets the Navy needs to be concerned with lowering all costs, not just those associated with research and development.

(5) The logistic support measures for each concept which support the system maintenance concept for this new surface combatant must be investigated in more detail. Each design concept has its own method of hardware selection and computer programming techniques. This will result in unique differences in the integrated logistic support requirements for each design concept.

(6) Other combat system design concepts should be examined to determine how they compare to the two concepts considered in this project. A different concept has been proposed for the newest aircraft carrier called Integrated Interior Communications and Control $(IC)^2$. Work is also being done on the combat system configuration for the next generation of amphibious landing ships. These concepts should be evaluated to determine their potential to support the multimission needs of a surface combatant.

(7) A methodology to combine the various qualitative and quantitative evaluation criteria needs to be developed. Two techniques available to assist in this process are

Multi-attribute Utility Analysis and Adelphi consensus. These or similar formalized techniques will likely be required to provide a systematic and traceable decision process.

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APPENDIX A - FUNCTIONAL FLOW DIAGRAMS FOR ASUW

This appendix contains the functional flow diagrams for ASUW operations both within the horizon and over the horizon engagements. Figure 12 shows the basic functional flow that applies to both types of engagements. All following functional flows will be based on this basic flow. Figures 13, 14, and 15 cover the within horizon flows. Figures 16,17, and 18 cover the over horizon flows.

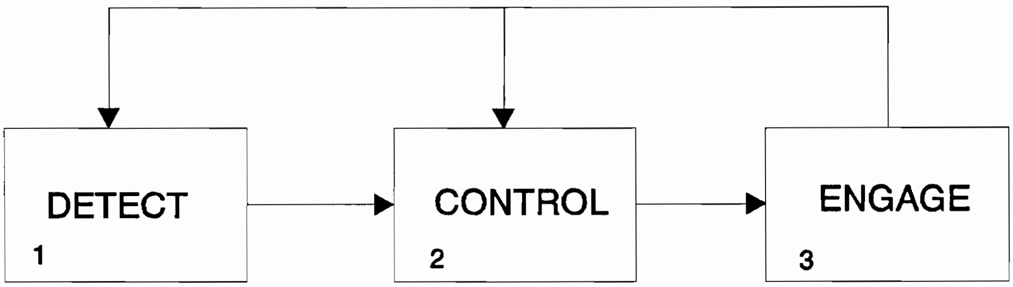

FIGURE (12): BASIC FUNCTIONAL FLOW FOR ASUW

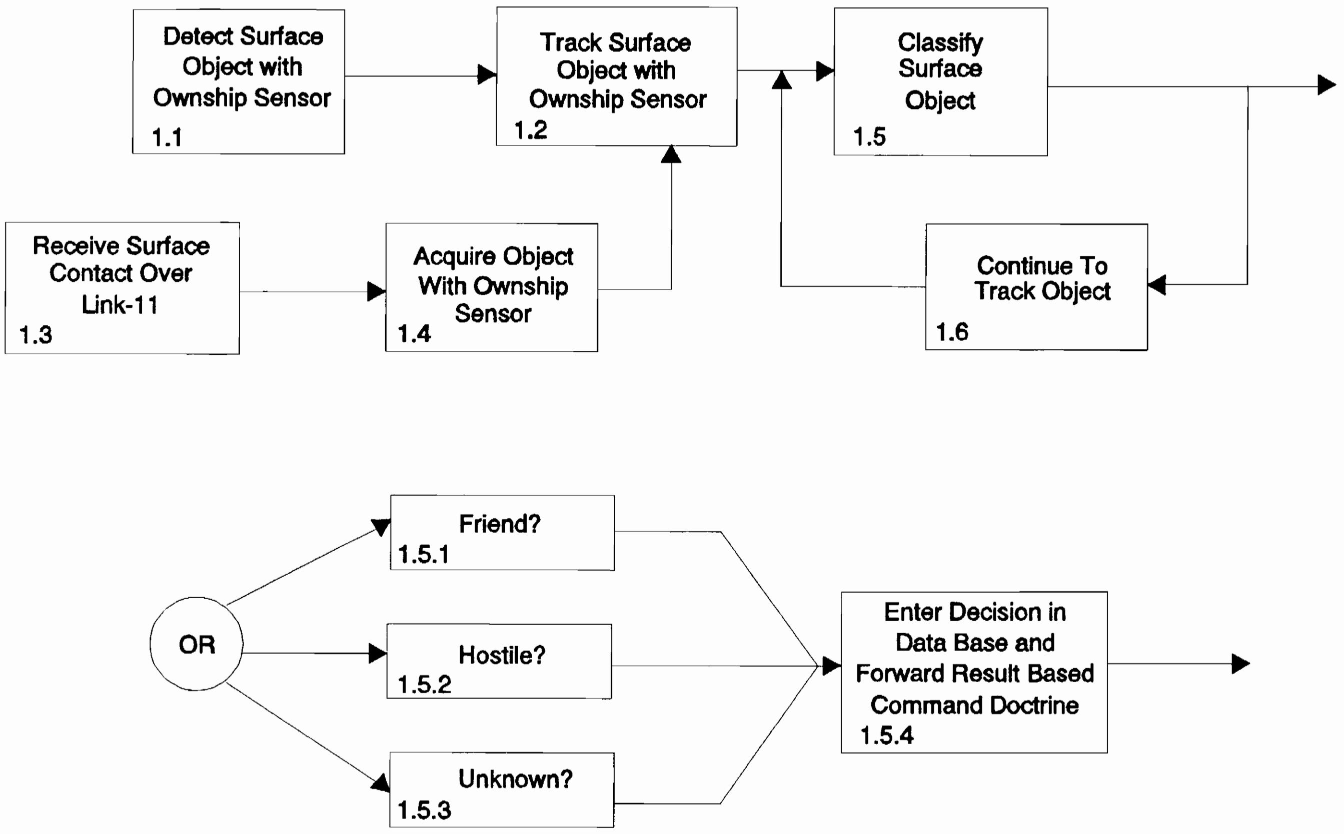

FIGURE (13): FUNCTIONAL FLOW FOR WITHIN HORIZON ENGAGEMEMENT - DETECT

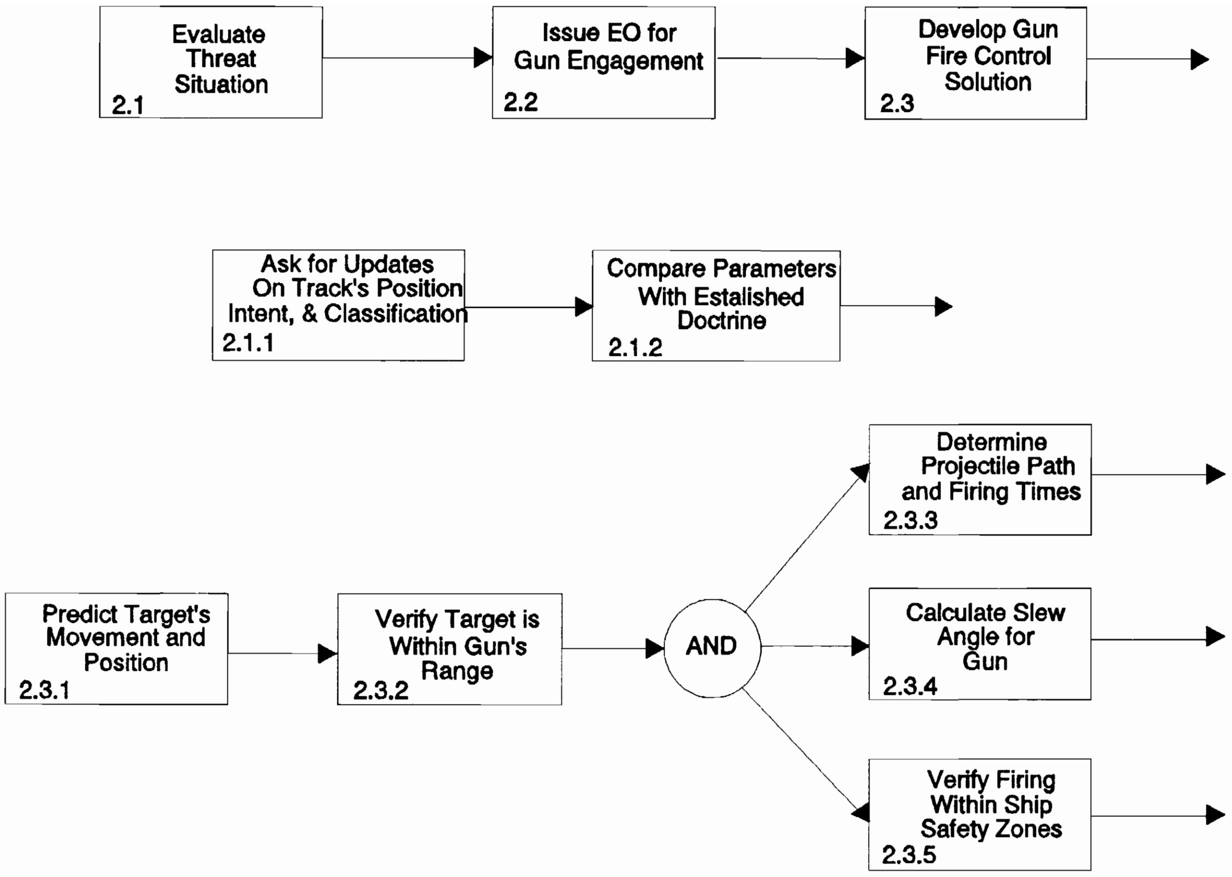

FIGURE (14): FUNCTIONAL FLOW FOR WIHTIN HORIZON ENGAGEMENT - CONTROL

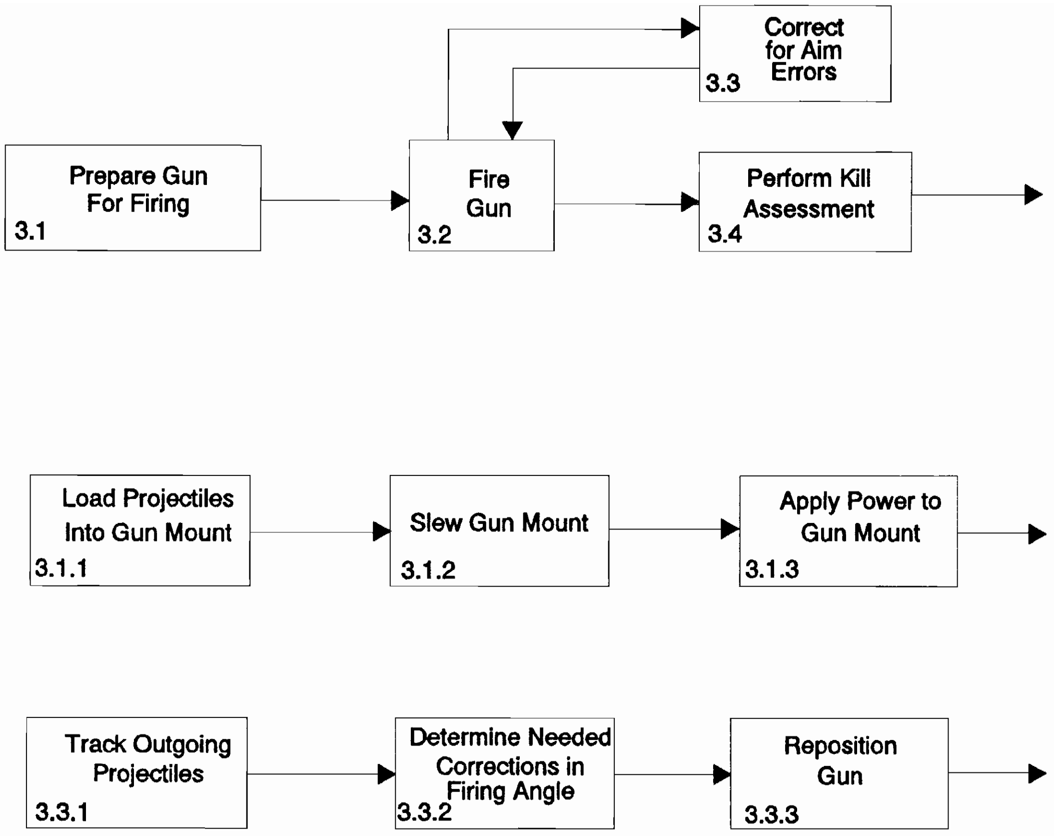

FIGURE (15): FUNCTIONAL FLOW FOR WITHIN HORIZON ENGAGEMENT- ENGAGE

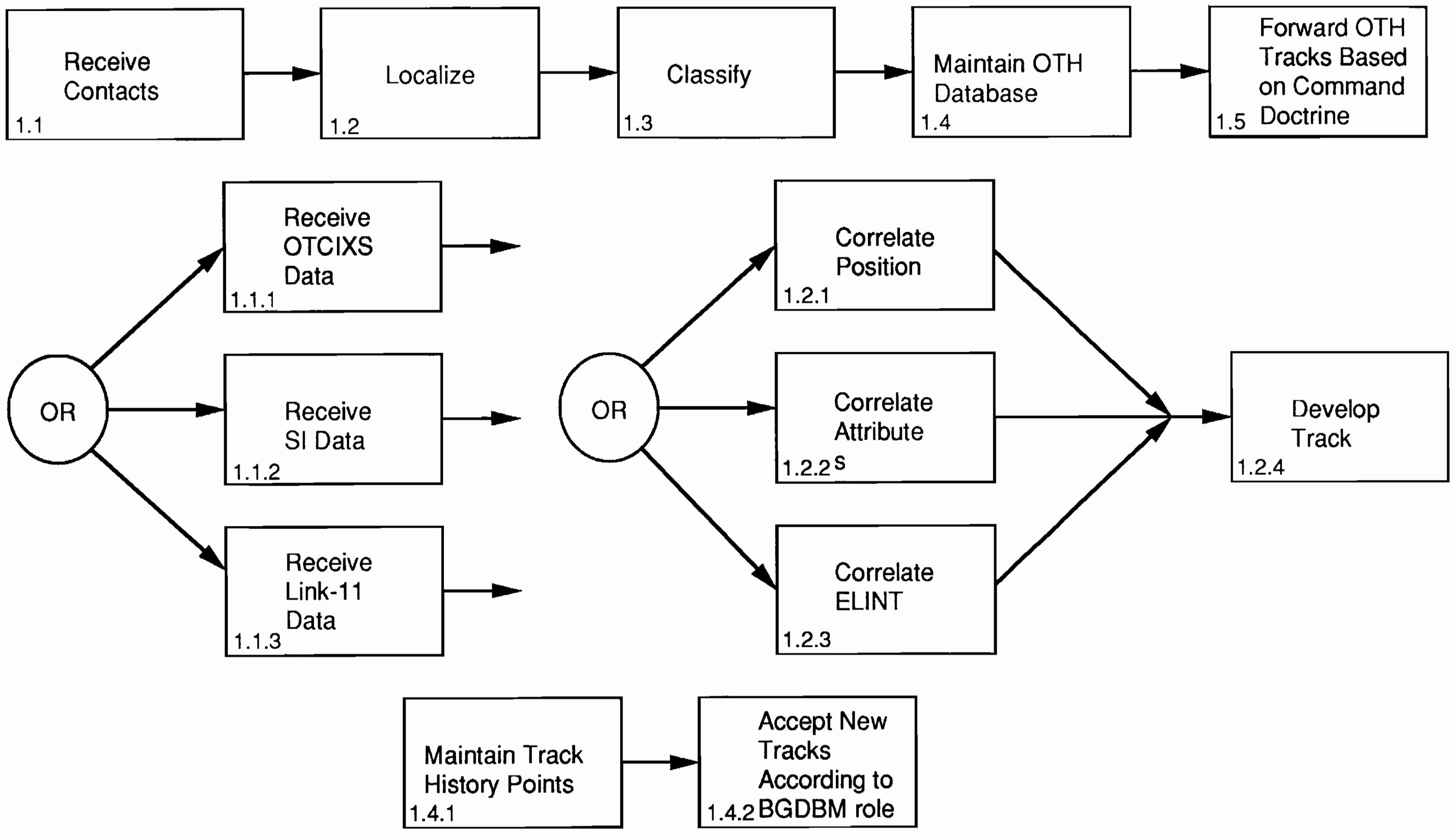

FIGURE (16): FUNCTIONAL FLOW FOR OTH ENGAGEMENT - DETECT

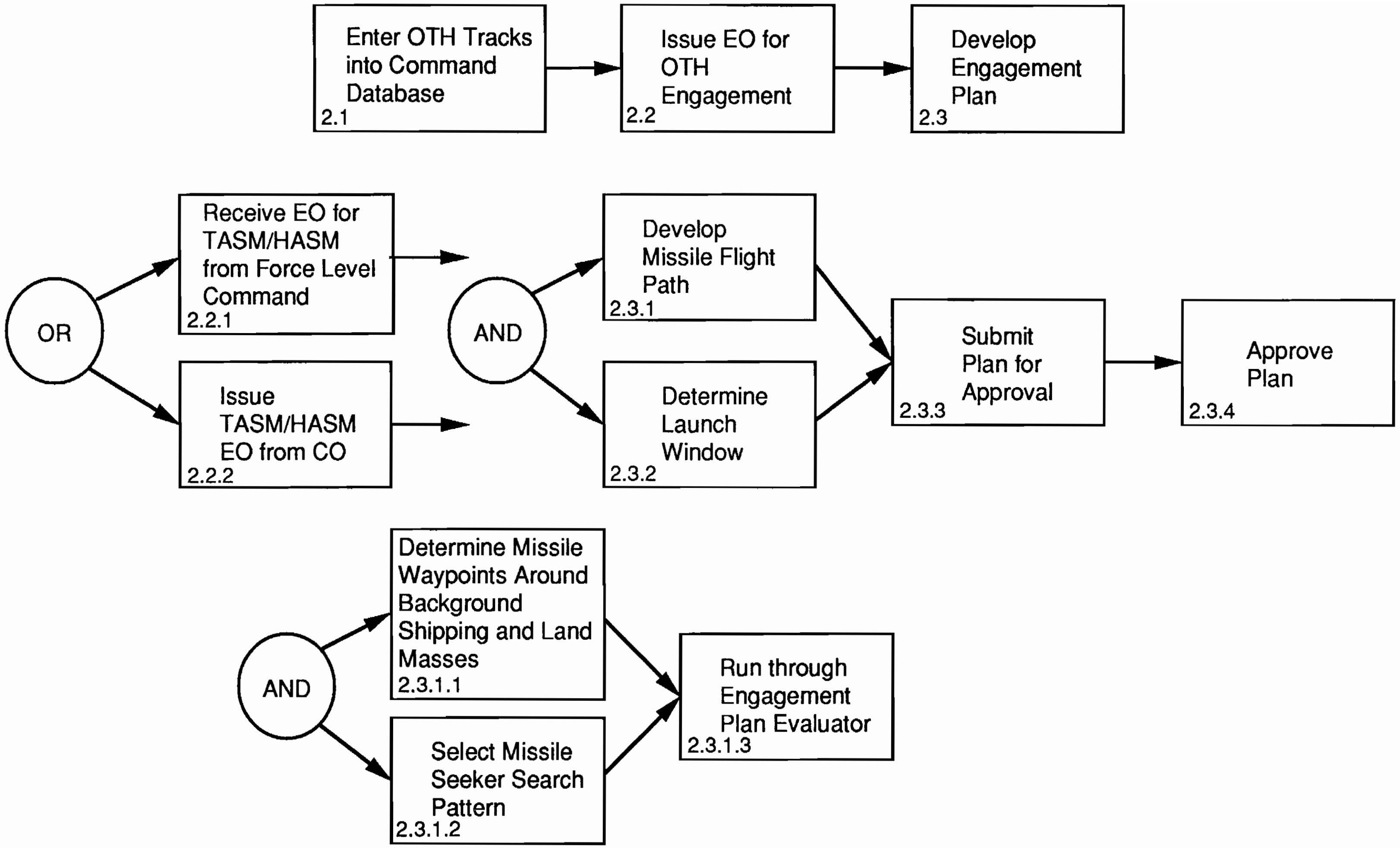

FIGURE (17): FUNCTIONAL FLOW FOR OTH ENGAGEMENT - CONTROL

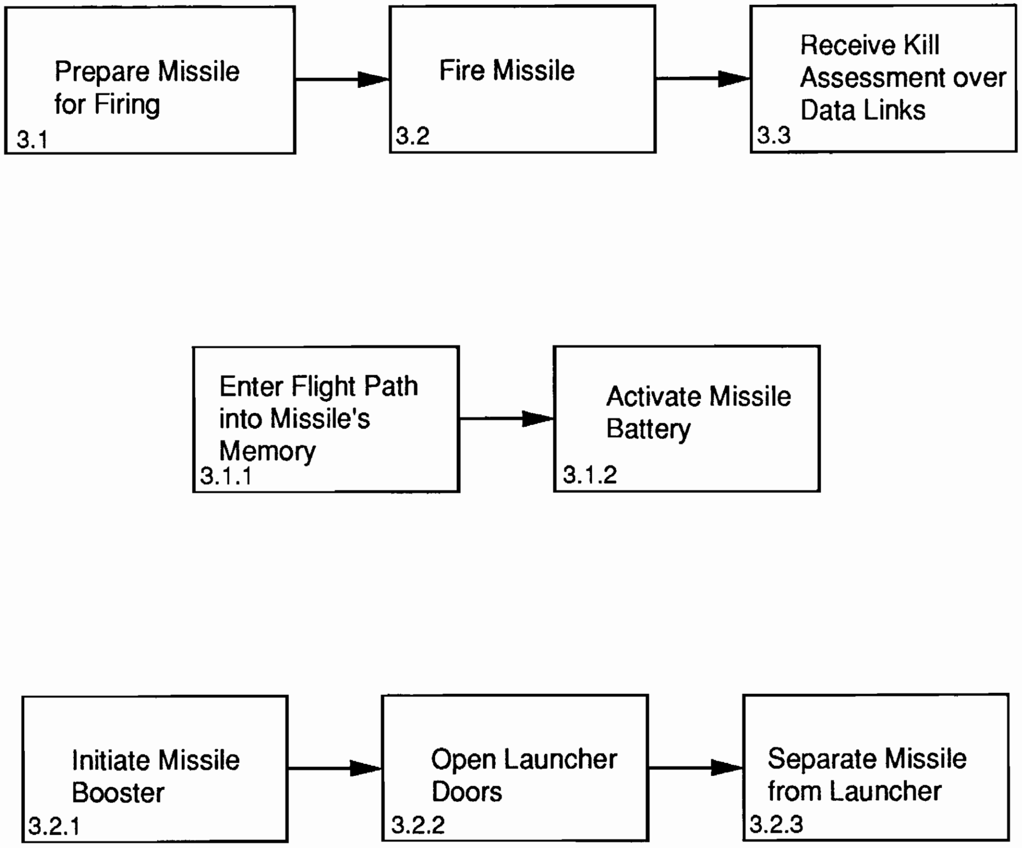

FIGURE (18): FUNCTIONAL FLOW FOR OTH ENGAGEMENT - ENGAGE