Evaluation of Three Alternatives for Improving U. S. Navy SHF Satellite Communications Afloat

by

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EVALUATION OF THREE ALTERNATIVES FOR IMPROVING U.S. NAVY SHF SATELLITE COMMUNICATIONS AFLOAT

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(ABSTRACT)

The U.S. Navy is faced with significant, complex requirements for communications to support the effective command and control (C^2) of its forces. The satisfaction of these requirements is constrained by a number of factors including a shrinking defense budget. SHF satellite communications (SATCOM) provides the communications backbone for DoD C^2 communications. The Navy's use of SHF SATCOM to support its at-sea commanders is limited, but could be improved significantly with the implementation of three upgrades. Because of funding constraints, the implementation of these improvements may be phased over time. It is important, then, to understand the relative importance of these enhancements so that they may be implemented in their relative order of importance.

This project and report provides a systems level perspective and analysis of U.S. Navy use of SHF SATCOM to support the command and control of afloat forces and uses an analytic hierarchy process (AHP) to assess the relative merit of proposed enhancements.

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SECTION 1

INTRODUCTION

1.1 PURPOSE

This project and report provides a systems level perspective and analysis of U.S. Navy SHF satellite communications (SATCOM) requirements for the command and control (C^2) of afloat forces and uses an analytic hierarchy process (AHP), as developed by Thomas L. Saaty[1], to assess the relative merit of three proposed enhancements.

The result of this project and report is an assessment and ranking, in their relative order of merit, of three possible alternative enhancements to the Navy SHF SATCOM system. The alternative enhancements are: (1) improve SHF modem capability, (2) increase the level of control automation and, (3) use a larger shipboard antenna. These alternatives are ranked against five attributes, or goals, I wish to obtain: (1) improve satellite tracking, (2) increase information throughput as demonstrated by improved link margin, (3) improve interoperability, (4) have a low degree of technical risk and, finally, (5) have a low cost to implement. An alternative that remains, though not stated explicitly in this analysis, is to do nothing, in which case the Navy's use of SHF SATCOM remains usable for the near term, but the shortcomings described in this report remain. This is considered unacceptable alternative and, thus, is not an included in this report.

1.2 BACKGROUND

The U.S. Navy is faced with significant, complex requirements for communications to support the effective (C^2) of its forces. The satisfaction of these requirements is constrained by a number of factors including a shrinking defense budget. SHF SATCOM provides the communications backbone for DoD C^2 communications. The Navy's use of SHF SATCOM to support its at-sea communications requirements could be improved significantly by the implementation of any one, or all, of three upgrades. These particular upgrades were selected from a wide variety of candidate solutions. These included replacing the entire shipboard SHF SATCOM terminal, replacing the high powered amplifier (HPA) only, the replacement of the four foot antenna with one of several different antenna sizes, abandoning SHF SATCOM altogether and, of course, the "do nothing" alternative. Significant engineering work was done to reduce the candidates to the three that are presented here.

A similar analysis was performed to select the five attributes: tracking, throughput, interoperability, risk and cost. There are easily a dozen objectives, or attributes, for improving deficiencies in SHF SATCOM considered for this study. But, many candidates are specific to a particular installation, or are elementary remedies. The five attributes chosen appeared significant in all cases.

Other areas that constrain the utility of Navy SHF communications are not addressed in this report for two reasons. One, the sensitivity of some C^2 communications makes the material unsuitable for open publication. Second, certain solutions, such as launching new satellites or enhancing satellite transponders, require significant amounts of time and money; this report focuses on relatively near term solutions. Each alternative must be available for installation within two years of the decision to implement it. The useful life for alternatives identified in this study is five years.

1.3 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is a method of breaking down complex, unstructured situations into component parts; arranging these parts into a hierarchic order; and assigning numerical values to subjective judgements to determine which variables have the highest priority and should be acted on to influence the outcome of the situation[2]. I have found this process, and ones similar to it, useful in formulating a meaningful perspective about complex technical issues since it imposes discipline on thought processes. A direct result of the use of AHP is that it not only forces discipline upon the technical community when they describe their alternatives to a problem, but the results of this disciplined description are more easily understood by managers who may be less technical, or less familiar with the details of the subject matter. This latter group often must make decisions to select between the alternatives.

I chose to apply the AHP technique to this problem for several reasons. I have successfully used weighted hierarchical analysis to perform risk and vulnerability assessments for a major oil company and found it especially useful in forming a bridge between decision makers and the designers of alternatives. Further, a formal process, such as AHP, provides an audit trail of the decision making process. This audit trail helps later when evaluating the effectiveness of the decision process.

1.4 COMMUNICATIONS REQUIREMENTS

The need to maintain command and control of U.S. forces on a real time basis emphasizes the requirement for reliable communications systems that are rapidly available to force commanders. Requirements of communications systems that support Navy C^2 are as follows:

- interoperability with commanders around the world and throughout the chains of command
- capability of providing required throughput/connectivity even under severe environmental conditions to include hostile jamming threats
- high operational availability and reliability to ensure real-time, secure communications
- cost effectiveness relative to the mission.

The communications capability that best meet these C^2 requirements today is SHF SATCOM; for components of the Department of Defense (DoD), SHF SATCOM capabilities are provided and managed by the Defense Communications Agency through the Defense Satellite Communications System (DSCS).

1.5 SHF SATCOM DEFICIENCIES

There are a number of technical shortcomings in the performance of current Navy SHF SATCOM systems. The most significant of the technical deficiencies are related to the shipboard SHF SATCOM terminals. Deficiencies addressed by this project and report include:

- the occasional loss of tracking of the satellite beacon signal,
- lack of modem interoperability and,
- limitations on system throughput.

Technical capabilities to overcome these shortcomings are known, but a lack of available funding limits full implementation.

1.6 REPORT ORGANIZATION

This paper first presents a description of the Navy's use of SHF SATCOM and its relationship to the DSCS. This background is important since the Navy is but one of many users of the DSCS SHF SATCOM resources. Further, changes in DSCS operations will impact future Navy operations.

The next section describes three problem areas that limit the Navy's use of SHF SATCOM to support command and control afloat. The first of these problem areas is the loss of the DSCS satellite tracking beacon by the shipboard satellite terminal. When this signal is lost the antenna cannot track the satellite and communications are lost. The second problem area is the lack of interoperability of the OM-55/USC modem with the shore site modem, the AN/USC-28. While the modems are interoperable in some modes, they are not interoperable in the more robust modes. Finally, limited shipboard terminal capabilities and link budgets constrain system throughput.

The results of my AHP analysis and ranking are presented in Section 4. The attributes considered for each candidate not only include its contribution to solving deficiencies in tracking the satellite, system throughput, and interoperability; but also the negative attributes of risk and cost.

My recommendations and an AHP sensitivity analysis are presented in Section 5.

SECTION 2

SHF SATELLITE COMMUNICATIONS

2.1 NAVY SHF COMMUNICATIONS

The use of SHF communications at-sea to meet Navy command and control requirements began in the early 1980s with the installation of the AN/SSC-6 SHF satellite communications terminal aboard ship. The early terminals allowed a number of modems to provide limited data and voice connectivity between Navy command ships and U.S. and NATO command centers. This SHF satellite communications connectivity is typically limited to a ship to shore capability. Due to size (volume) and weight constraints on terminals suitable for shipboard use, ship-to-ship communications is usually impractical because of the limited radiated power and receive system sensitivity.

SHF satellite communications to support command and control is generally limited to three major networks:

1) A digital secure voice network provides secure voice access from a command ship to the Defense Communications System (DCS) automatic secure voice communications (AUTOSEVOCOM) network. The termination to the AUTOSEVOCOM network allows direct dial secure voice service between ship and shore. While this link provides high quality private and

secure communications, it also consumes a considerable amount of the shipboard terminal radiated power.

2) The World Wide Military Command and Control System (WWMCCS) network operates at 2400 bps and provides connectivity to shore command and control centers.

3) There may also be several point-to-point 75 bps Teletype circuits between the ship and shore command, control and intelligence centers. These circuits are established upon demand and are multiplexed with other circuits as link margins allow.

The first Navy shipboard SHF SATCOM terminal, the AN/SSC-6, had a single six-foot diameter antenna, an 11 kw klystron high-powered amplifier that produced an EIRP of 102 dBm and a receive system with a receive gain over noise temperature (G/T) of 10 dB/K. After the AN/SSC-6, several other prototype SHF terminals were installed aboard ships.

The current standard Navy shipboard terminal, the AN/WSC-6, utilizes one or two four-foot diameter antennas, an 8 kw water-cooled klystron high power amplifier producing a 106 dBm maximum EIRP, and a receive system with a G/T of 11 dB/K. The AN/WSC-6(V)2 is the flagship version of the terminal and uses the OM-55(V)/USC modem. The AN/WSC-6 modem, the OM-55/USC, can use time division multiple access (TDMA) or code division multiple access (CDMA) modes. This modem is built on a design similar to the shore-based AN/USC-28 modem, but interoperability between the modems is limited to the less robust, "non-mitigated"[3] CDMA mode in the DSCS ECCM network.

The AN/WSC-6(V)2 presently provides command and control communications for five Navy flagships:

- USS Belknap - Cruiser
- USS Blue Ridge
- USS Mount Whitney - Amphibious Command, Control and Communications ships
- USS Nassau - Amphibious assault ship
- USS Coronado - Auxiliary support ship

There are also approximately fourteen Surveillance Towed Array Sensor System (SURTASS) ships utilizing SHF SATCOM for relatively high speed data transfer from ship to shore, in addition to the five flagships receiving support for their command and control mission. SURTASS is the largest user of SHF SATCOM afloat, from a data volume perspective. SHF SATCOM provides communications to transfer from the Surveillance Towed Array Sensor System data aboard T-AGOS class[4] ships to shore data collection centers. The use of SHF SATCOM to support this requirement is limited to subnetworks on the DSCS. The focus of this paper is on the application of SHF SATCOM to support command and control; these other networks will not be presented in detail.

2.2 NAVAL TELECOMMUNICATIONS COMMAND

Navy SHF satellite communications provides a worldwide, jam-resistant, full-duplex capability that supports both command and control for Navy tactical forces and the relatively high capacity transfer of data for anti-submarine warfare. The Naval Computer and Telecommunications Command (NAVCOMTELCOM) is responsible for operational direction and management control of the Naval Telecommunications System which includes most of the SHF satellite communications resources. NAVCOMTELCOM also develops the planning, programming and implementation of naval telecommunications equipment, systems and facilities and is responsible to the Chief of Naval Operations (CNO) for the management and operation of U.S. Navy shore-based and sea-based communications assets[5]. In its role as manager for these facilities, NAVCOMTELCOM also responds to the needs of the Fleet Commanders-in-Chief for the operation of these assets[5]. Communications resources are allocated by the Naval Telecommunications Command and by managers within the offices of the Chief of Naval Operations, specifically Code OP-094, and the Space and Naval Warfare Systems Command, Code PD-50. Systems engineering for SHF SATCOM systems is provided by Navy laboratories such as the Naval Ocean Systems Center (NOSC); field engineering and logistics support is provided by the Naval Electronics Systems Engineering Centers and Field Activities.

Communications systems operations are partitioned into four areas of the world which approximate the areas of responsibility of the four Numbered Fleet Commands. Within each area there is one Naval Communications Area Master Stations (NAVCAMS) and several subordinate Naval Communications Station. The NAVCAMS are former Naval Communications Stations (NAVCOMSTAs) that were upgraded to DSCS communications master stations with the introduction of DSCS satellites serving ocean areas. The Navy relies on the NAVCAMS to tie Navy tactical forces to major command facilities around the world. The NAVCAMS provides the interfacing equipments and the interconnections permitting DSCS users - from the National Command Authority down through the chain of command - access to Navy commanders embarked on their Flag Ships.

The four NAVCAMS serving naval forces are:

AREA	MAJOR COMMAND	FLEET	NAVCAMS
Atlantic	CINCLANTFLT	SECOND	LANT
Pacific	CINCPACFLT	THIRD	EASTPAC
Pacific	CINCPACFLT	SEVENTH	WESTPAC
Mediterranean & Indian Ocean	CINCNAVEUR	SIXTH	MED

While the Commander of the Naval Computer Telecommunications Command is responsible for the operation, management, planning, programming, implementation and administration of the shore, fleet and strategic communications assigned by the Chief of Naval Operations, the Fleet Commanders-in-Chief exercise authoritative direction and control of the use of these communications resources[5].

2.3 THE DEFENSE SATELLITE COMMUNICATIONS SYSTEM

The Defense Satellite Communications System (DSCS) is the primary Department of Defense satellite communications resource. The use of SHF satellite communications within the U.S. Navy and throughout the

Department of Defense is growing and maturing. This growth in use of SHF satellite communications is increasing the complexity of managing and controlling the system and its networks. The Defense Communications Agency, the manager of the DSCS, is automating its control of the DSCS to improve its performance.

This section includes a description of the control systems that the DCA established to ensure the effective use of SHF resources. A major part of this control system, the DSCS Operational Control System - DOCS - is being automated. This initiative within DoD to upgrade the control of the SHF portion of the Defense Satellite Communications System will include installation of automated DOCS equipment at all the DSCS Operations Centers (DSCSOCs), including the four NAVCAMS. DOCS remote equipment will be installed at DSCS net terminals to complement the automation at the DOCS.

DOCS automation can provide a number of features that improve user throughput and interoperability by enhancing the management, human interface, and control of the DSCS SHF satellite communications networks. In addition to the installation of DOCS at the large and medium sized ground stations, Contingency DSCS Operations Control Equipment (CDOCS) will support operations and control for the smaller mobile and transportable SHF systems that are a new and growing part of DSCS SHF networks. The successful implementation of the DOCS automation requires that equipment be installed at major DSCS terminals operated as part of the DCS and also at user terminal sites.

DSCS network users must assess their requirements for such automation and plan accordingly for its implementation. A part of this assessment is understanding the current management and control responsibilities for the DSCS network.

2.3.1 Defense Communications Agency

The Defense Communications Agency Director is responsible for military satellite communications system planning and engineering, and for exercising executive management control over the acquisition and implementation of resources for the evolutionary development of the Defense Satellite Communications System (DSCS) Program[6]. The Deputy Director, Defense Communications System Organization, is the DCA executive manager for all major DSCS acquisition and control programs. The Defense Communications Engineering Center (DCEC) develops, integrates, and implements DSCS engineering functions; establishes DSCS engineering specifications and system design criteria; plans programs, submits budgets for, and manages DSCS research, development, test and evaluation; establishes DSCS technical and system performance specifications and facilities requirements; accomplishes interface analyses and establishes interface specifications; provides engineering assistance to the DSCS program manager in developing the respective program management plans, DSCS program plan, one year operating and transition plan, transition and integration plan, radio frequency plan, requirements characterization, joint systems test plan, and related test and evaluation plans; and produces the DSCS utilization concept, including loading analysis and development of system performance requirements. Within the Center for Command, Control and Communications Systems (C4S) the Deputy Director, MILSATCOM Systems Office, provides a long-range MILSATCOM Architecture and the User Requirements Data Base (URDB). The relationship of these organizations that support the DSCS is shown in figure 1.

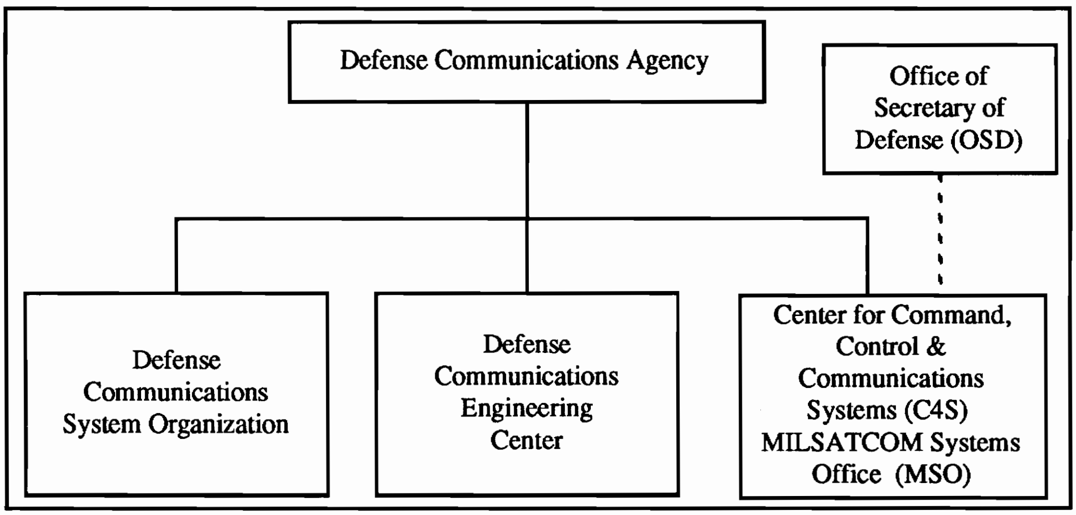

Figure 1 DSCS Organizational Support

2.3.2 DCA Responsibilities for DSCS System

The DCA exercises operational control of the DCS through the DCA Operations Control Complex. The DSCS Operations Control Complex, as the top level of the control hierarchy, resolves communications problems that cannot be resolved at lower levels of the DCS control structure.

The central control element of the DSCS Operations Control Complex is the Defense Communications Agency Operations Center at the headquarters of DCA. The primary function of the DCA Operations Center is to provide operational direction for the Defense Communications System. DCA Area Communications Operations Centers exercise operational direction over specified geographical areas in support of the DSCS Operations Center. All DCS stations within a given geographical region are under the operational direction of an Area Communications Operations Center. The DCA Operations Control Complex hierarchy provides four levels of control shown in figure 2.

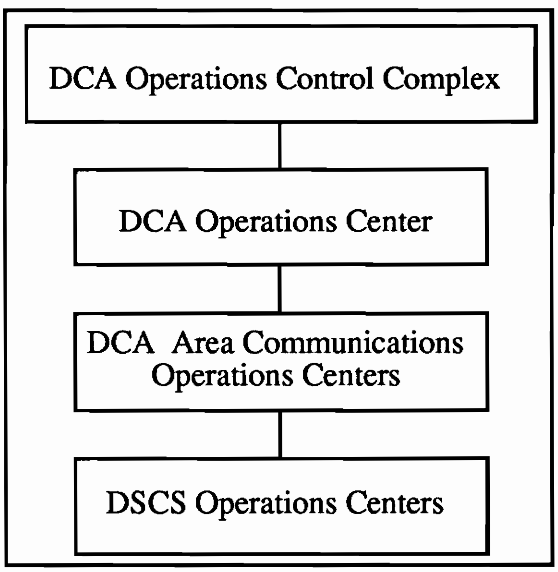

Figure 2 DSCS Control Levels

SECTION 3

PROBLEM DESCRIPTION

This section describes shortcomings in the Navy's current ability to meet SHF satellite communications requirements for command and control, and the fundamentals of AHP used to evaluate corrections to those shortcomings. Three significant shortcomings confronting the Navy's use of SHF satellite communications for C^2 at sea are:

- First, in response to either intentional or accidental jamming, the shipboard SATCOM beacon receiver and modem may lose the satellite tracking. After this occurs, the terminal quickly loses the communications signal. This requires that the terminal operator re-acquire the satellite beacon.

- Second, primarily due to limitations in the shipboard SATCOM terminal capabilities, information throughput is often limited to low (75 - 4800 bps) data rates.

- Third, the lack of full interoperability between the shipboard OM-55/USC modem and the shore-based AN/USC-28 limits direct interfaces between sea-based and shore-based commanders.

Three solutions to these shortcomings are presented. They include improvements in the shipboard SHF SATCOM modem, automation of network control features, and enlargement of the ship antenna. The undesirable attributes of risk and cost are considered for each alternative as are the technical benefits of improving tracking, throughput and interoperability attributes.

The likelihood that an alternative will be fielded in a timely fashion is recognized as a component of risk. Each alternative should be available for installation within two years from the date of the decision to implement an alternative. The alternatives have no value after five years from the date of first installation.

3.1 THE AHP PROCESS

The analytical hierarchy process as described by Thomas L. Saaty is used to assess the value of each alternative[1]. Each alternative is rated for its contribution to each of the five attributes that include improvements in system tracking, information throughput, interoperability, implementation risk, and installation cost. The relationships between overall Navy SHF SATCOM system improvement, the five attributes, and the three alternatives are shown in figure 3. Figure 3 shows connections between each alternative and each of the five attributes. The five attributes then come together into the overall objective - Navy SHF SATCOM Improvement. Every alternative need not contribute in a significant way to each attribute but, in the end, each alternative makes a significant contribution to the overall objective of improving Navy SHF SATCOM.

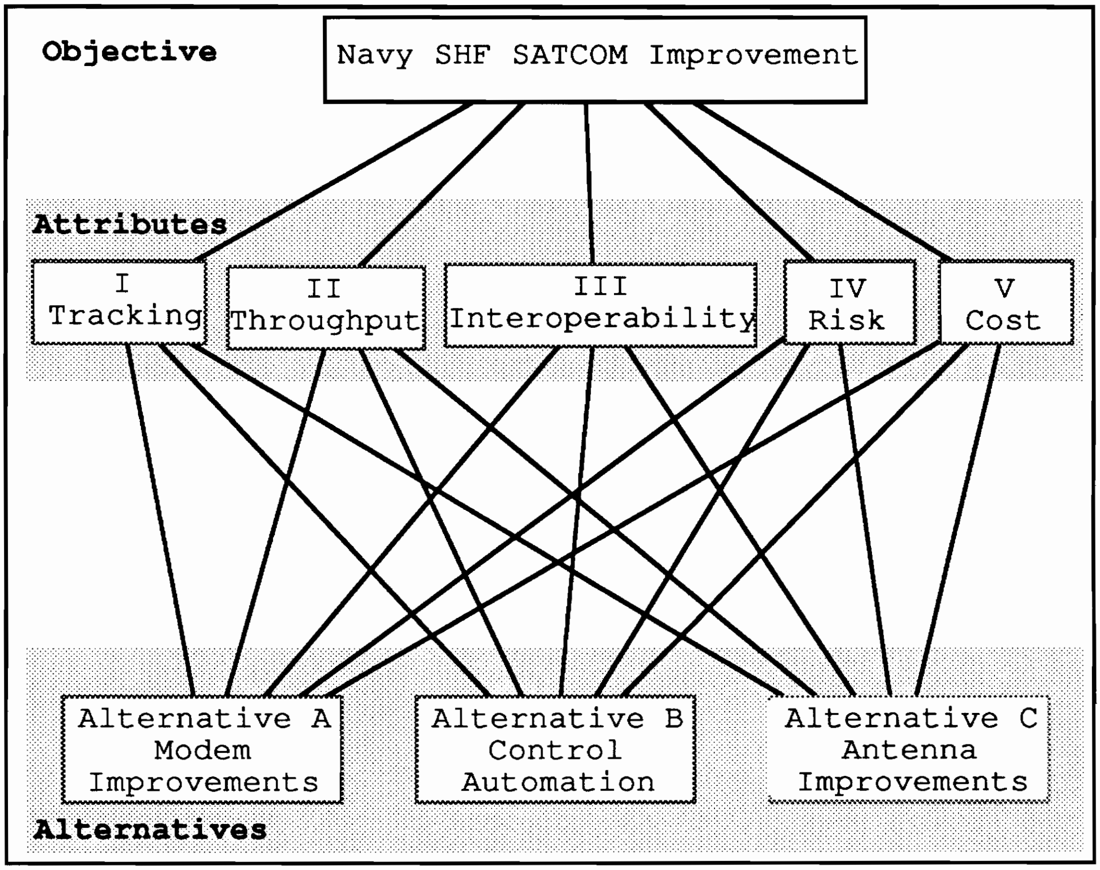

Figure 3 AHP Relationships

3.1.1 Beginning the Analytic Hierarchy Process

After each of the attributes are chosen, the relative merit of each of the attributes is determined through a paired comparison process. Each of the attributes is compared to the other four on a scale of 1 to 10. The rating values[6] are shown in table 1. Choices between values shown are permitted; for instance 6 is between strongly and very strongly more important.

Table 1 Rating Numbers

1	Equally important or preferred
3	Slightly more important or preferred
5	Strongly more important or preferred
7	Very strongly more important or preferred
9	Absolutely more important or preferred
10	Not negotiable

Figure 4 shows the beginning of the first pairwise comparison. Tracking compared to Tracking is a 1 or of equal value. Tracking is slightly more important than Throughput and is rated a 3. The reciprocal of the comparison, Throughput compared to Tracking, is given a 1/3.

	I Tracking	II Throughput	III Interoperability	IV Risk	V Cost
I Tracking	1	3			
II Throughput	1/3	1			
III Interoperability			1		
IV Risk				1	
V Cost					1

Figure 4 Beginning of Pariwise Comparisons

The actual number of comparisons that must be made is ten. The comparisons within the heavy line in figure 4 are either unity, (Tracking = Tracking = 1) or are duplicate of comparisons outside the heavy line. The process continues and Tracking compared to Interoperability is rated a 2, that is improved Tracking is absolutely more preferred than reducing Risk; and very strongly more preferred than Cost. The completed matrix is shown in figure 5.

Next, the comparison process is carried out for each alternative's contribution in each of the five attribute areas.

	I Tracking	II Throughput	III Interoperability	IV Risk	V Cost
I Tracking	1	3	2	9	7
II Throughput	1/3	1	1/2	5	3
III Interoperability	1/2	2	1	6	3
IV Risk	1/9	1/5	1/6	1	1/2
V Cost	1/7	1/3	1/3	2	1

Figure 5 Matrix of Paired Comparisons

For ease of computation, the pairwise comparisons from figure 5 are converted to decimals as shown in table 2.

Table 2 Decimal Matrix

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	3	2	9	7
II	Thru Put	0.33	1	0.5	5	3
III	Interop	0.5	2	1	6	3
IV	Risk	0.11	0.2	0.17	1	0.5
V	Cost	0.14	0.33	0.33	2	1
	SUM	2.08	6.53	4	23	14.5

3.1.2 Normalizing Comparisons

The pairwise comparisons are normalized by dividing the elements of each column by the sum of that column and then adding the elements in each resulting row and dividing this sum by the number of elements in the row. The priority weight shown at the right side of figure 6 is the relative ranking of the attribute matrix. Tracking is the most important (0.463), Interoperability is next (0.253), and Throughput is third, followed by Cost (0.071) and Risk (0.041).

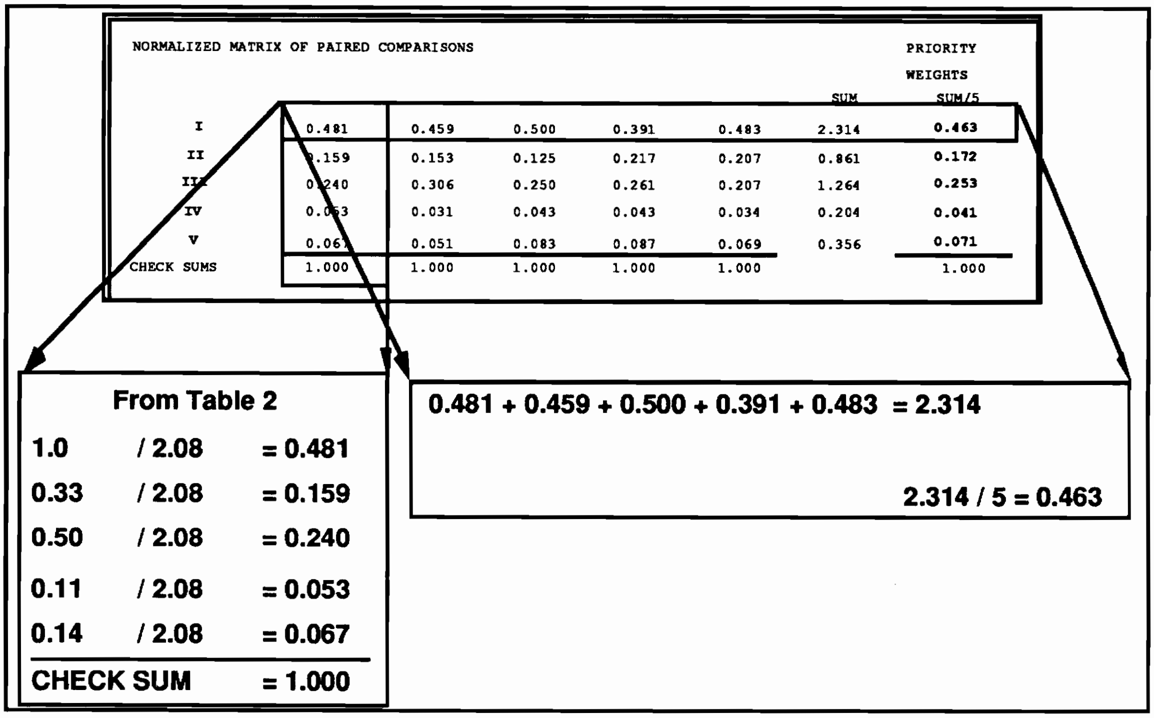

Figure 6 Normalizing the Comparisons

3.1.3 Consistency Ratio

Finally, a check referred to as the consistency ratio (CR) is made. This checks the consistency of answers obtained in the pairwise comparisons. For example, if Tracking is absolutely more important than reduced Risk and only slightly more important than Throughput, then Throughput would be more important than reduced Risk.

Verifying the consistency ratio often requires a review of the thought process which led to the pairwise comparisons. It is not unusual for people or groups to be inconsistent about derived comparisons and, without a review of this type, the inconsistencies may go unnoticed. I have found that the discussions required to resolve inconsistencies between people or groups can also resolve underlying conflicts in opinions and lead to a clearer understanding of each alternative and the overall goal.

A check of the consistency ratio is carried out in five steps. First, the matrix of paired comparisons is multiplied by the priority weights as shown in figure 7.

Results of Pairwise Comparisons — **Priority Weights**

$$\begin{bmatrix} 1 & 3 & 2 & 9 & 7 \\ 0.33 & 1 & 0.5 & 5 & 3 \\ 0.5 & 2 & 1 & 6 & 3 \\ 0.11 & 0.2 & 0.17 & 1 & 0.5 \\ 0.14 & 0.33 & 0.33 & 2 & 1 \end{bmatrix} \times \begin{bmatrix} 0.463 \\ 0.172 \\ 0.253 \\ 0.041 \\ 0.071 \end{bmatrix} = \begin{bmatrix} 2.351 \\ 0.869 \\ 1.287 \\ 0.205 \\ 0.358 \end{bmatrix}$$

Figure 7 Consistency Ratio Matrix Multiplication

Second, the results of the matrix multiplication are divided by the corresponding priority weight. Third, this result is summed and divided by N (i.e., averaged) to obtain λmax.

2.351	/	0.463	=	5.080
0.869	/	0.172	=	5.047
1.287	/	0.253	=	5.090
0.205	/	0.041	=	5.019
0.358	/	0.071	=	5.023
		Total		25.259

$$\lambda\,\text{max} = \frac{25.259}{5} = 5.052$$

Figure 8 Calculating λ max

Fourth, the Consistency Index (CI) is obtained from the formula: CI = (λmax - N) / (N - 1). The Random Indexes (RI) are available from a table calculated by Saaty[1] and are: 0.58 for N = 3, and 1.12 for N = 5.

Consistency Index (CI)

$$
\begin{aligned}
CI &= (\lambda max - N) / (N - 1) \\
&= (5.052 - 5) / (5 - 1) \\
&= 0.013
\end{aligned}
$$

The Random Index for N = 5 is 1.1

and the Consistency Ratio is

CR = Consistency Index / Random Inde

$$
\begin{aligned}
&= 0.013 / 1.12 \\
&= 0.012
\end{aligned}
$$

Figure 9 Calculating the Consistency Ratio (CR)

According to Saaty, a CR less than 0.10 is an acceptable level. As shown in figure 9, the Consistency Ratio (CR) is calculated by dividing the Consistency Index (CI) by the Random Index (RI)[7]. A Consistency Ratio less than 0.10 is considered to be acceptable.

The AHP and check of the consistency ratios are repeated for each of the attributes and alternatives. The results are shown in figures 10, and 16 through 20.

ATTRIBUTES

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	3	2	9	7
II	Thru Put	0.33	1	0.5	5	3
III	Interop	0.5	2	1	6	3
IV	Risk	0.11	0.2	0.17	1	0.5
V	Cost	0.14	0.33	0.33	2	1
	SUM	2.08	6.53	4	23	14.5

NORMALIZED MATRIX OF PAIRED COMPARISONS

						SUM	PRIORITY WEIGHTS SUM/5
I	0.481	0.459	0.500	0.391	0.483	2.314	**0.463**
II	0.159	0.153	0.125	0.217	0.207	0.861	**0.172**
III	0.240	0.306	0.250	0.261	0.207	1.264	**0.253**
IV	0.053	0.031	0.043	0.043	0.034	0.204	**0.041**
V	0.067	0.051	0.083	0.087	0.069	0.356	**0.071**
CHECK SUMS	1.000	1.000	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

	2.351	**5.080**
Results of Matrix	0.869	**5.047**
Multiplication	1.287	**5.090**
	0.205	**5.019**
	0.358	**5.023**
		25.259

$$\frac{\text{lambda max} = 25.259}{N = 5} = 5.052$$

Consistency Index = CI = 0.013

Random Index = RI = 1.120

Consistency Index = CI/RI = 0.012

Figure 10 AHP Attributes

3.2 THE MODEM

The OM-55/USC modem is an integral part of the AN/WSC-6(V)2. The shore side of the link terminates at a NAVCAMS in the flag ships' area of operation. An interface at the NAVCAMS connects the links to equipment necessary to reach destinations ashore. The interface includes secure voice over the Automatic Secure Voice Communications Network (AUTOSEVOCOM). The AUTOSEVOCOM Network provides secure voice communications to various command and intelligence centers ashore. Other NAVCAMS interfaces provide access to AUTODIN and dedicated data and Teletype circuits. Each end, the ship and the shore side, of the link is terminated through the OM-55/USC modem. The AN/WSC-6(V) is also designed for use with NATO II and III satellites, and future military SHF communications satellites.

The OM-55/USC modem and the WSC-6 system have been in use in the fleet since 1984 providing anti-jam, low probability of intercept communications in a continuous-wave narrow-band jamming environment. The SATCOM terminal is made up of several major subsystems shown in figure 11 which include an antenna group and a radio set group. There are two antenna group configurations: (1) a single antenna configuration, and (2) a dual antenna configuration. The radio group interfaces with either configuration[8].

The major components of the AN/WSC-6(V) () are listed below and are shown in figure 11.

• High Powered Amplifier	AM-7061/WSC-6
• Up Converter	CV-3592/WSC
• Modem Group	OM-55/USC
• Down Converter	CV-3594/WSC
• RF Selector Assembly	SA-2302/WSC
• Dual Tracking Converter	CV-3595/WSC
• Antenna Control Unit	C-10279/WSC
• Antenna Group	AS-3399/WSC
• Servo Electronics Unit	AM-7059/WSC
• Local Operation and Control Center	C-10808/WSC
• Remote OCC	C-10809/WSC

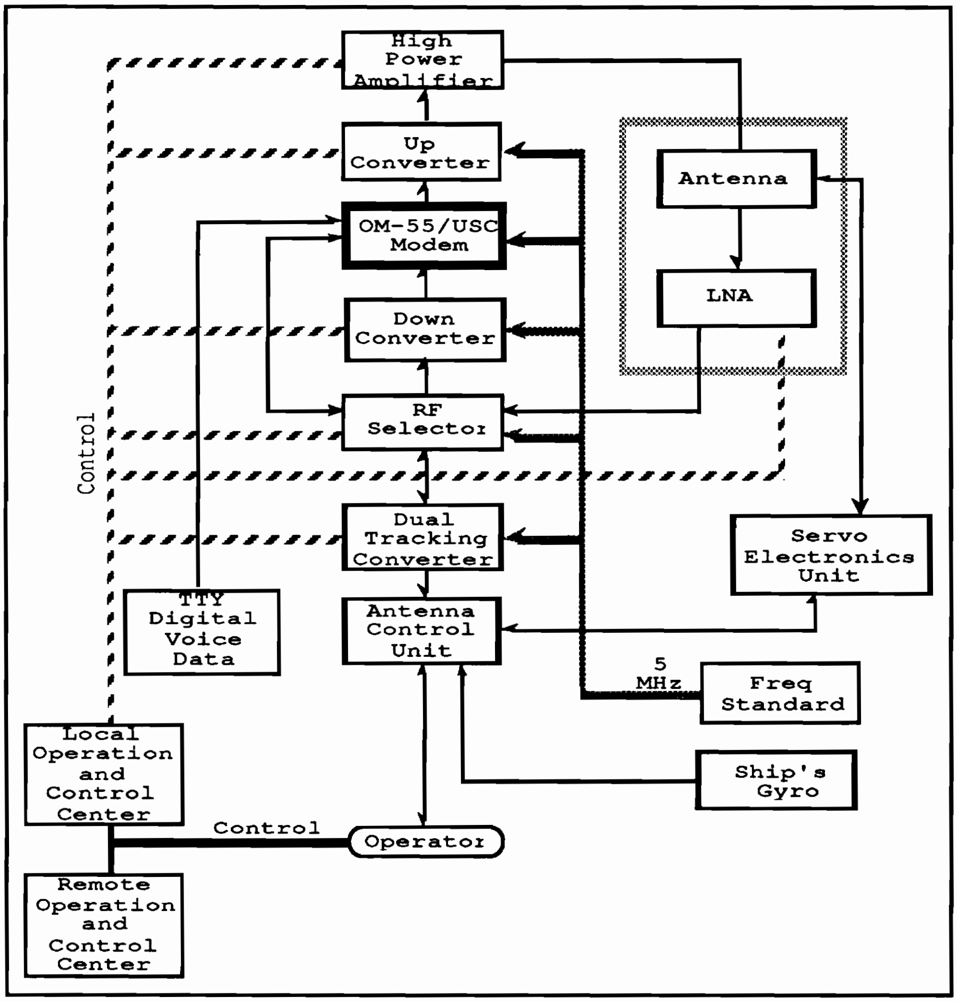

Figure 11 AN/WSC-6(V) Functional Block Diagram

The antenna is a 4-foot diameter radome-enclosed cassegrain antenna designed to provide a receive/transmit capability over the 7.25 to 8.4 GHz band. It has a corrugated feed for reducing spill-over losses, and provides hemispherical coverage with a three-axis mount.

The radio group is configured with a frequency standard assembly, RF distribution assembly, LNA (two LNAs for the dual antenna configuration), down converter, dual beacon down converter/tracking receiver, upconverter, HPA, Local Operations and Control Center (LOCC), Remote Operations Control Center (ROCC), and prime power distribution assembly.

Each LNA includes redundant parametric amplifiers. FET line drivers provide preselection and low noise amplification of the signals. The signal is then fed via the RF distribution panel to the down converter which provides RF frequency translation to either 700 MHz or 70 MHz IFs. Beacon down conversion from 7.25 to 7.75 GHZ to 70 IF is provided by the dual conversion beacon down converter. The beacon signal is used by both the modem group and internal tracking receiver.

The transmit IF signal, either 700 MHz or 70 MHz, is fed to the up converter, which translates the signal to X-Band frequencies. The RF signal is then fed via the RF distribution panel to the Klystron HPA.

The LOCC is the principle operation and control unit for the radio group and is a central point for terminal testing and status reporting. It is also possible to perform all LOCC functions from the ROCC.

3.2.1 Tracking Concept

Tracking the satellite from the ship requires coordination between the antenna, the servo electronics unit, the antenna control unit, the dual tracking receivers, the modem, and the ship's gyro system[9]. Automatic satellite tracking is accomplished by a slow scan of the antenna reflector and use of tracking error dependent amplitude-modulated satellite beacon signals. A tracking converter accepts a Doppler-shifted satellite beacon signal from the WSC-6 antenna which is aimed at the satellite and provides the antenna control unit with a tracking error reference signal. The required correction is established and fed to the servo electronics unit which adjusts the antenna. The ship's gyro assists the process by nulling the ship's motion at the antenna platform. In addition to providing a means to track the satellite, the beacon signal also provides a means for Doppler correction within the modem. Without the beacon signal the WSC-6 antenna will lose track of the satellite and, shortly thereafter, lose communications.

Loss of the relatively low power beacon signal occurs for a number of reasons. The receive system sensitivity of the WSC-6 is modest to begin with, and at-sea conditions may worsen the reception. The high RFI environment on the ship, and land-based microwave and radar systems may interfere with reception of the beacon. Lastly, the beacon may be intentionally jammed.

A rather straightforward means for improving satellite tracking is to provide another, stronger, source of satellite location reference. This reference can be provided by a communications or net orderwire signal (NOW). The OM-55 could then utilize the relative strength of this signal to provide a reference for satellite tracking. For a number of reasons, the beacon must first be used to link up with the satellite; but once the link is established, the strength of the communications or NOW signal may be used instead of the beacon signal to track the satellite. The cost of performing the modification is included in this report.

3.2.2 Throughput

The modem is capable of data rates up to 256 kbs, which far exceeds the capability of the SHF SATCOM link. The modem is not a factor directing affecting system throughput.

3.2.3 Interoperability

The networks carried over the SHF SATCOM are under the control of the Defense Communications System and link together high level military commanders. The networks that support high level command and control commonly use the mitigated mode[3] of operation on the electronic counter-counter measure (ECCM) channels. While the OM-55/USC can operate in the ECCM channels, it is not interoperable with the AN/USC-28 in the mitigated mode. The lack of direct interoperability between the OM-55/USC and the AN/USC-28 modems can limit the near real time exchange of information between the shore-based high level commanders and those commanders embarked on the SHF-equipped flagships.

Improved interoperability would be achieved if the OM-55/USC modems were modified to provide the ECCM network mitigated mode operation. This modification requires substantial modification to the modem and also requires an increase in link margin or reduced system throughput. The additional power required for mitigated operation can be provided through use of a larger antenna.

3.2.4 Risk

Modification to the OM-55/USC to provide mitigated operation and the improved tracking capability, while extensive, is relatively straightforward and of low risk. The OM-55/USC architecture is developed from the AN/USC-28, which has these capabilities, and much of the engineering has been already performed. The upgrade is expected to be available within one year.

3.2.5 Costs for modem upgrades

An estimate for the non recurring engineering cost to perform the upgrade is $1.9 million and the cost per unit to modify 17 existing modems is approximately $4,505,000[10]. Logistics and training support plans would require updating. The modems would be retired with the introduction of the universal modem in the late 1990s. A cost estimate for the upgrade is presented in table 3.

Table 3 Modem Upgrade Cost Estimate

Reference No.	Description	Percent of equipment cost	Cost
1.1	System/Program Mgt		
1.1.1	System Engineering	5%	$320,250
1.1.2	Program Management	20%	$1,281,000
	sub-total		**$1,601,250**
1.2	Equipment Costs		
1.2.1	Non-recurring engr		$1,900,000
1.2.2	Per Unit costs	17 @ 265,000	$4,505,000
	sub-total		**$6,405,000**
1.3	Support Equipment	5%	**$320,250**
1.4	Training	15%	**$960,750**
1.5	Documentation	15%	**$960,750**
1.6	Logistics	20%	**$1,281,000**
1.7	Installation/Checkout	85%	**$5,444,250**
1.8	Spares	25%	**$1,601,250**
1	**Total Cost**		**$18,574,500**

3.3 DSCS CONTROL SYSTEM

The primary objectives for the DSCS system control are to[6]:

- Ensure critical subscriber and system connectivity
- Ensure that system control reacts quickly and effectively, with a minimum of system constraints
- Incorporate a level of control and system management consistent with the survivability of the DSCS
- Ensure sustained quality service through timely, effective testing and analysis in both normal and stressed environments
- Ensure interoperability or compatibility with the control systems associated with other communications systems such as the tactical systems used by the Navy, the ground mobile forces, and allied countries.
- Maintain control over cost in terms of funds, facilities, and personnel.

3.3.1 System Structure

The DSCS control system structure is an inherent part of the DCA Operations Control complex[6]. In general, control is first exercised at the lowest level of the control hierarchy shown in figure 2. The DSCS control system maintains and restores DSCS performance under changing traffic conditions, natural and operator induced stresses, disturbances, and equipment disruptions. Basic functions of system control include:

- Network control, which includes network configuration control, reconstitution, restoral, extension, supervision, and satellite configuration
- Performance assessment and status monitoring, which provides subscriber, equipment, transmission and network data to determine DSCS performance over time
- Technical control and patch and test, which includes quality assurance and monitoring, coordinating, restoring, and reporting functions necessary for executive technical supervision and control over trunks and circuits traversing or terminating in both DCA and non-DCA facilities.

The DCA Satellite Operations Division, Code B440, is the operations manager of the DSCS within the DCA Defense Communications System Organization, as shown in figure 12. One of the responsibilities of Code B440 is to develop and manage a control system that ensures that the DSCS mission and operational objectives are met.

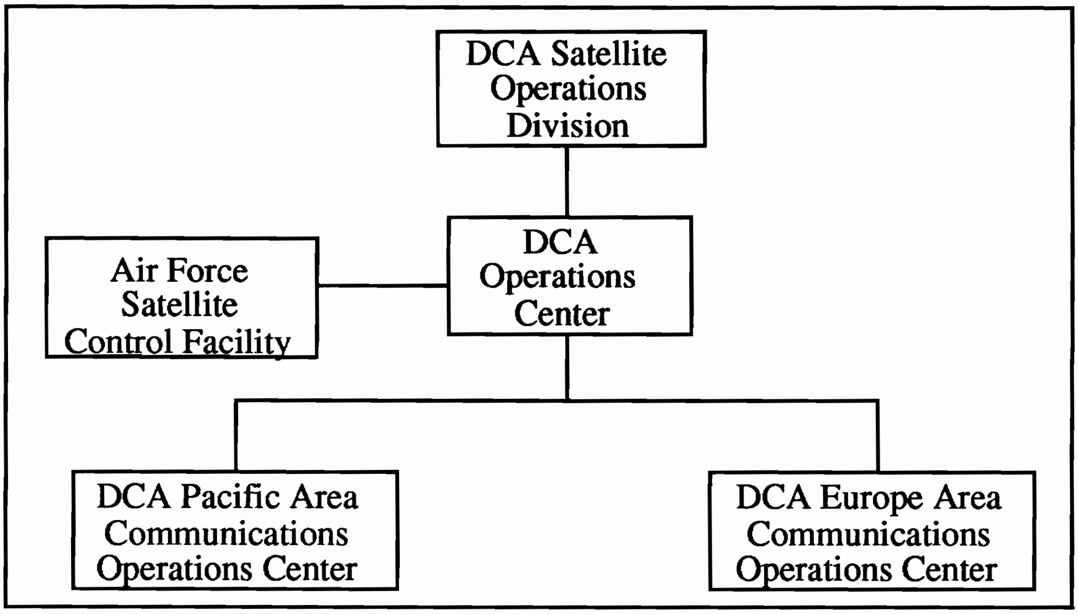

Figure 12 DCA Area Communications Operations Centers

3.3.1.1 Categories of DSCS Control

There are three major categories of control within DSCS[6]:

- Spacecraft Control
- Satellite Communications Payload Control
- Satellite Communications Network Control.

Spacecraft Control

Spacecraft control is the process of keeping the satellites in their assigned position in the orbital path, maintaining the desired spacecraft orientation relative to the earth (attitude control), and supporting the housekeeping functions needed to ensure optimum operation of the spacecraft. The position of each satellite is tracked by one or more remote stations, and information is relayed to the Air Force Satellite Control Facility. Any necessary corrections are effected by commands sent to the satellite via the Control Link, and the subsequent adjustments are made by the thruster motors attached to the body of the spacecraft.

The Air Force Satellite Control Facility performs all satellite control functions for DSCS satellites from its Satellite Test Center. The Air Force Satellite Control Facility has numerous remote tracking stations around the world to assist in these functions. The Air Force Satellite Control Facility continues to support satellite health and orbit maintenance functions as DOCS automation is implemented for DSCS III satellites. Communications payload control is accomplished by the DCA through the DSCS Operations Centers. The Air Force Satellite Control Facility retains a backup capability to control the communications payload, and the DSCS Operations Centers provide backup spacecraft control for the Air Force Satellite Control Facility.

Communications Payload Control

There is a much greater need for dynamic, near-real-time SATCOM link-margin control when supporting mobile and transportable systems than is required for fixed terrestrial systems. In a terrestrial system, transmission paths are fixed and are engineered to meet relatively static requirements. There are a large number of varying link parameters in the satellite system which arise from such factors as earth coverage capability, the multiplicity of uplink interfering signals, and the very low levels of down-link received signals. Further, there is the problem in networks using FDMA techniques of high level intermodulation products. Power output requirements necessitate the operation of the transponders in a non-linear mode, but the extent of transponder nonlinearity must be traded-off against the number of carriers, their relative power levels, and the type of modulation on each carrier. In addition, there is the need to reconfigure the satellite assets (such as antenna selection, antenna pointing, antenna nulling, selection of redundant equipment units, and selection of the gain state of the transponders). Since all of these requirements vary from time to time, a dynamic payload control system is almost a necessity.

The communications payload control subsystems will permit day-to-day optimization of the total system in an unstressed environment by reducing channel margins to the level necessary to just meet required performance standards for the existing system loading. A major control function in a jamming environment is to reconfigure DSCS assets in response to the jamming threat and minimize the disruption to communications. The goal of the DOCS is first to rapidly and unambiguously detect the location, frequency and power level of a jammer. Then DOCS must rapidly reconfigure the DSCS II and III satellites' communications elements - especially the nulling capability of the uplink multiple beam antenna (MBA) and spread spectrum modulation equipment - to overcome the effect of the jammer on essential circuits.

Satellite Communications Network Control

Network control has more to do with support to the user networks provided by each of the SATCOM ground terminals than it does with systems aboard the satellites. The links using the satellite are normally monitored by personnel at network control terminals (NCTs) and the satellite communications (SATCOM) Network Controller. The SATCOM network controller responds to changes in users' needs for connectivity.

3.3.1.2 Critical Control Circuits

The DCA Operations Control Center (DCAOCC) provides direction to DSCS stations through the use of critical control circuits (CCCs). CCCs are voice and data communications circuits used by the DSCS Operations Control Center for exchanging status and control information. A DSCS Net Control Terminal (NCT) within each satellite footprint and user network is responsible for maintaining control of the network and the CCC. Each Net Terminal (NT) is a member of the CCC and responds to requests and commands from the NCT.

The CCC is used to:

- Provide user-to-user communications support within the DSCS network

- Provide DSCS status information in a useful form that permits the users to perform their missions and reduce duplication of efforts
- Coordinate the operating elements, users, operations and maintenance agencies, military services, and other government agencies to quickly identify communications problems
- Maintain the DSCS under normal, adverse, and catastrophic conditions.

Specifically, the critical control circuit provides a means for exercising the operational direction necessary to exploit the full capability of the DSCS in providing user-to-user communications support.

The AN/USC-28 is the primary SHF modem in use at the DSCS earth terminals and the AN/USC-28 Critical Control Circuit (CCC) is the primary means of controlling the DSCS networks on the DSCS II and DSCS III satellites. The AN/USC-28 orderwire is compatible with the Navy OM-55/USC shipboard modem.

The ECCM CCC is a jam-resistant orderwire which provides continuous Network Control Terminal (NCT) or Alternate Network Control Terminal (ANCT) broadcast transmission. The ECCM CCC enables users having critical command and control requirements to enter the ECCM network for communications during normal and stressed conditions. Each terminal equipped with the AN/USC-28 spread spectrum modem is capable of receiving broadcast messages addressed to that terminal. The ECCM CCC is also the primary means of providing precise time and timing for the network.

3.3.1.3 Current Control System Management

The DSCS control segment is achieved through the implementation of policies, guidance documents and procedures which the personnel supporting network participants use to guide the operation, control and monitoring of DSCS equipment. DSCS control authority starts with the DCA Satellite Operations Division, Code B440, and continues through the control hierarchy of the DCA Operations Centers, the Area Communications Operations Centers, the DSCS Operations Centers down to the earth terminals. The control segment consists of personnel supported by hardware that is distributed between the control centers, the satellites, and the earth terminals. It also consists of a distributed software driven capability which is used to evaluate status and to determine appropriate operator actions. It is the function of the control element to ensure that, in accordance with mission requirements, the DSCS is flexibly and responsively configured to meet changing system requirements in both an unstressed environment and during military hostilities. Adapting to stressed conditions must be made on a near real time basis and will be largely concerned with the preservation of priority circuits in the presence of jamming signals, and the alternate routing of circuits as system resources and capabilities deteriorates.

The DCA Area Communications Operations Centers (ACOC) exercise day-to-day network control of the DSCS as directed by the the Defense Communications Agency Operations Center (DCAOC). The DCA Pacific (DCAPAC) Area Communications Operations Center is responsible for the East Pacific (EASTPAC) and West Pacific (WESTPAC) networks. DCA Europe (DCAEUR) Area Communications Operations Center is responsible for the control and management of all earth terminals' accesses to the DSCS II satellites. The Air Force Satellite Control Facility performs necessary spacecraft telemetry, tracking and access command functions for the DSCS satellites, including communications payload allocation functions directed by the DSCS Operations Center.

3.3.1.4 Automated DSCS Operational Control System

More demanding requirements for operational responsiveness and survivability in support of command and control and contingency operations, as well as a general expansion of user requirements and types of service, have necessitated significant changes in the DSCS ground and space segments to lower system response times, expand system capacity, and improve communications.

A significant upgrade of the DSCS control segment is being undertaken through the evolutionary implementation of automated DSCS operational control which will be a subsystem of the DCA Operational Control Complex. DSCS control relies on prior engineering and planning to allocate the available transponder capacity on a baseline basis to meet anticipated user needs. The baseline includes parameters such as frequency, occupied bandwidth, and the power required to provide a desired downlink signal level with adequate margin and acceptable intermodulation. A major disadvantage of this pre-assignment of operating margins is that transponder power must be allocated on a worst case basis. In practice, this means allowing maximum link fading and signal jamming. As an example, the margin at each site may vary from zero to 6 db. Allowing a 4 db rain margin would result in inefficient use of the transponder capability if, indeed, it is not presently raining. As the automated DOCS becomes operational, it will implement a near-real-time control system on a largely computer automated basis. DOCS will continuously monitor link performance at each terminal and at the satellite, to establish a baseline status for the system. This information will be stored in computer memory at the DSCS Operations Center and will provide the basis for developing corrective action to alleviate system degradation, and actions required will accommodate changing user requirements. Status and control signals will be exchanged between the DSCS Net Terminals and the Network Control Terminals associated with the DSCS Operations Center, via a common communications circuit.

3.3.1.5 Contingency DSCS Operational Control Systems

The most pertinent aspect of DOCS automation for the Navy is represented by the Contingency DSCS Operational Control System - CDOCS.

CDOCS, when fully implemented, will provide many automated planning and some control features to the less capable transportable users.

The potential impact of DSCS automation on the Navy's use of SHF to support its ships is significant. This automation affects the network throughput, operational availability, reliability and interoperability of the DSCS SHF satellite communications network.

Network throughput and operational availability may be improved by automated planning and control tools that support the near real time management of satellite link margins. Reliability, the probability that the system will perform in a satisfactory manner for a given period of time when used under specified operating conditions, is improved through the accurate reporting of system failures, analysis of the causes of the failures, and the introduction of system wide corrective measures.[11] Interoperability is added through the management of the User Requirement Data Bases (URDB) and network parameters that allow users to quickly obtain information necessary to establish networks.

The Navy in the past has had limited integration into the DSCS. Its use of DSCS to support five of its flagships was limited as a subnetwork of the DSCS. In 1989 these Navy flagships terminated their subnetwork status and became part of the DCA DSCS network. While the Navy is becoming "full fledged" members of the DSCS SHF community, the Navy shipboard equipment used to provide SHF connectivity may limit future compatibility with a more automated DSCS. This may be to the detriment of both the Navy and the DSCS.

The Navy should consider the capabilities and improvements that DOCS automation can provide as it plans the expansion of SHF SATCOM for aircraft carrier battle groups and additional flagships.

The Contingency Defense Satellite Communications System Operations Control System (CDOCS) is made up of three major subsystems as shown in figure 13.

- Contingency DSCS Electronic Counter-Counter-Measures Control System (CDECS),
- Contingency DSCS Operational Support Subsystem (CDOSS),
- Man-Machine Interface (MMI).

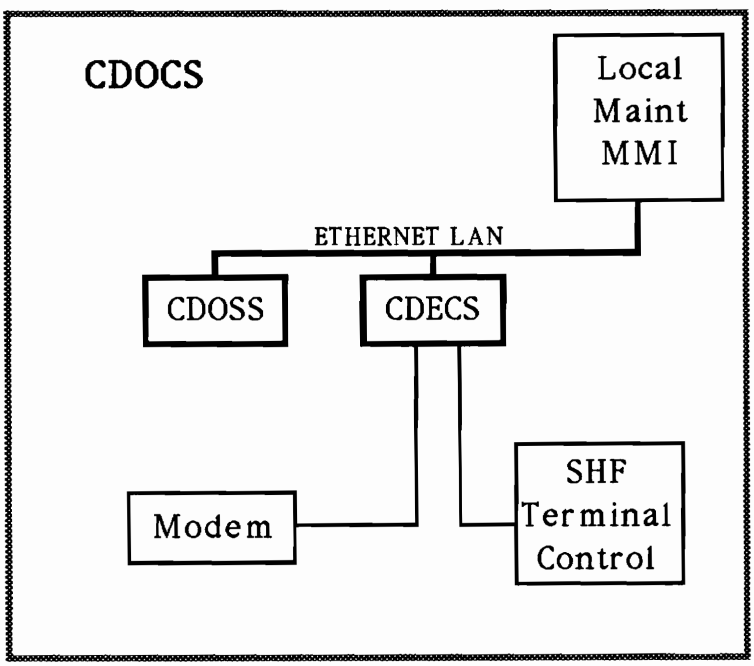

Figure 13 CDOCS Functional Block Diagram

Contingency DSCS ECCM Control System

The Contingency DSCS ECCM Control System (CDECS), figure 14, provides both Net Control Terminals and Net Terminals with automated tools to manage their participation in the ECCM network. The CDECS automation of functions such as ECCM network polling, status monitoring and acknowledgement, and limited performance monitoring provides the user terminal with a rapid, effective, response to network irregularities, such as out of tolerance operation, equipment failures and jamming.

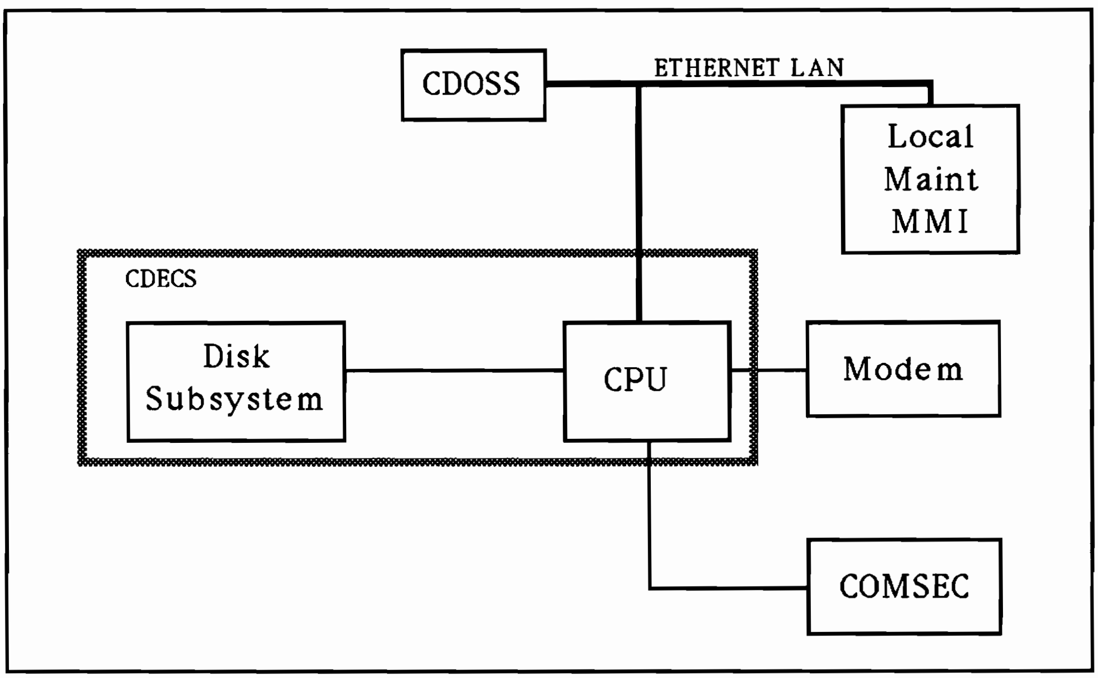

Figure 14 CDECS Functional Block Diagram

Contingency DSCS Operational Support System (CDOSS)

The Contingency DSCS Operational Support System (CDOSS), figure 15, will provide features similar to the DOSS described in Appendix A. In the near term, CDOSS capabilities will be limited, and features such as FDMA Control, automated spectrum analysis, terrestrial CCC (TCCC), and GMF control will not be available. Near term capabilities include:

- Network planning,
- Link reconfiguration assistance,
- Network status.

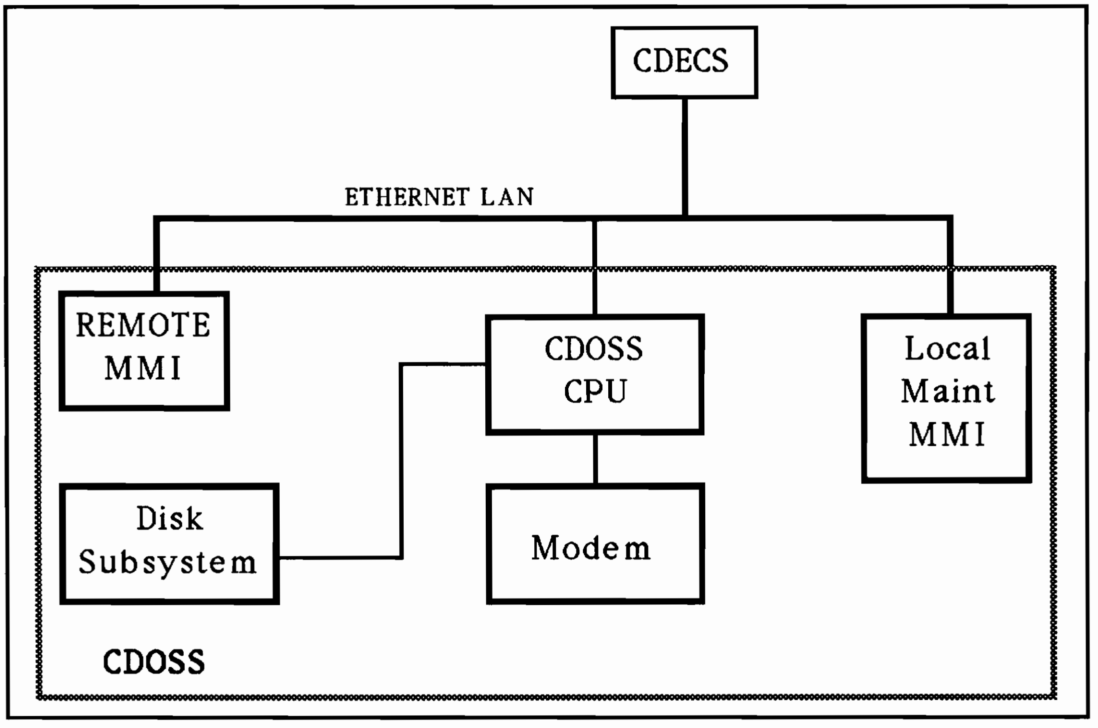

Figure 15 CDOSS Functional Block Diagram

3.3.1.6 Benefits Of DOCS Automation

DOCS automation is expected to improve the services for several types of SHF satellite communications. Improvements include:

- Reliable, effective connectivity for mobile and special user terminals,
- Rapid configuration of the DSCS ECCM Network in both normal and contingency situations,
- Extended service capability to users.

The DSCS operations centers will have access to the satellites for spectrum monitoring, satellite telemetry and command, and for over-the-satellite control circuits. They will be able to reconfigure the DSCS assets in response to jamming of critical circuits. In addition to satellite communications payload control, the DSCS operations centers will also be capable of performing spacecraft telemetry and command functions for the DSCS III spacecraft under emergency conditions, as directed by the Air Force Satellite Control Facility. A description of each of the subsystems within the automated DOCS is contained in Appendix B.

3.3.2 Tracking

The contingency DSCS control system does not directly provide improvements to the shipboard terminal satellite tracking. The control system can, however, provide support which helps to identify intentional and accidental jamming and provide assistance in reducing the effects of jamming.

3.3.3 Throughput

As discussed above, the DSCS control can be a significant aid in improving system throughput. This is done by optimizing user link margins and near real time control of terminal operating parameters.

3.3.4 Interoperability

Interoperability is improved by providing users with automated tools that allow users to quickly access the users' requirements data base which provides critical information on network operating parameters.

3.3.5 Risk

The risk in implementing CDOCS is moderate due to the considerable amount of software that must be written and tested. Because of this, there is some concern that the control equipment may not be available within a two-year period. There is also a smaller risk that if control automation is not adopted, communications between the DSCS Operations Centers and non-automated Navy ships will be adversely affected. Thus, a decision to do nothing could cause the eventual deterioration of SHF SATCOM service.

3.3.6 Cost

Representative costs to improve the SHF control segment aboard the five Navy flagships are shown in table 4[10].

Table 4 Control Cost Estimate

Reference No.	Description	Percent of equipment cost	Cost
1.1	System/Program Mgt		
1.1.1	System Engineering	25%	$1,687,500
1.1.2	Program Management	15%	$1,012,500
	sub-total		**$2,700,000**
1.2	Equipment Costs		
1.2.1	Non-recurring engr		$4,500,000
1.2.2	Per Unit costs	5 @ 450,000	$2,250,000
	sub-total		**$6,750,000**
1.3	Support Equipment	10%	**$675,000**
1.4	Training	15%	**$1,012,500**
1.5	Documentation	15%	**$1,012,500**
1.6	Logistics	20%	**$1,350,000**
1.7	Installation/Checkout	65%	**$4,387,500**
1.8	Spares	25%	**$1,687,500**
1	**Acquisition Costs**		**$19,575,500**

3.4 ANTENNA

The capabilities of the shipboard terminal can be enhanced by replacing the four-foot antenna with a seven-foot one. This raises the EIRP to over 76 dbW and improves the G/T to 21 db/kt. The seven foot antenna requires more resources, to include installation funds, structural support and open space. The link analysis below will show the relative merits of the increase in antenna size.

3.4.1 Tracking

Improving the G/T of the antenna system will improve reception of the satellite beacon, but it may also provide the same "improvement" to interfering signals. Coupled with the modem track-on-communications capability the antenna will aide in keeping the WSC-6 locked on the satellite.

3.4.2 Throughput

The impact on throughput of changing to a seven-foot antenna from a four-foot one can be seen in the following calculations.

3.4.2.1 Link Analysis

Ship System Parameters - 4 ft.Antenna

$G_t = (4pA_e)/l^2 = 5814.6$ or 37.6 db

$G_r = (4pA_e)/l^2$ 5104.6 or 37.1 db

where $(4pA_e) = 87.8$ sq ft

$A_e = A * eff = 12.7 * 0.55 = 6.985$

A (4-foot diameter) = 12.7 sq ft

e = efficiency = 55%

l^2 (up) $= (c / f1)^2 = (0.1228)^2 = 0.0151$

f1 = 8 GHz

l^2 (down) $= (c / f2)^2 = (0.1311)^2 = 0.0172$

f2 = 7.5 GHz

c = free space speed of light = 9.833 E8 ft/sec

Path Loss

$L_p = 20 \log (4pR)/l$

= 202.5 up, 202 down

Ship System Parameters - 7 ft.Antenna

$G_t = (4pA_e)/l^2 = 17617.89$ or 42.46 db

$G_r = (4pA_e)/l^2$ 15466.86 or 41.89 db

where $(4pA_e) = 266.03$ sq ft

$A_e = A * eff = 38.49 * 0.55 = 21.17$

A (7-foot diameter) = 38.49 sq ft

e = efficiency = 55%

l^2 (up) $= (c / f1)^2 = (0.1228)^2 = 0.0151$

f1 = 8 GHz

l^2 (down) $= (c / f2)^2 = (0.1311)^2 = 0.0172$

f2 = 7.5 GHz

c = free space speed of light = 9.833 E8 ft/sec

System Noise Temperature T_s

$T_s = T_{LNA} + T_{in} = 256 + 130.8 = 386.8 \quad = 25.8$ db (4-foot)

$T_s = T_{LNA} + T_{in} = 60 + 130.8 = 190.8 \quad = 22.8$ db (7-foot)

T_s = system noise temperature

T_{LNA} = LNA noise temperature = 256 K for the 4 foot antenna

T_{LNA} = LNA noise temperature = 90 K for the 7 foot antenna

$T_{in} = T_A * G_l + T_L * (1 - G_l)$

$= 60 * 0.692 + 290 * (1 - 0.692) = 130.8$

T_A = Antenna noise temperature = 60 K

$G_l = 1/ L_l$

L_l = Transmission line losses (ANT to LNA) = 1.6 db = 1.445

T_L = Ambient noise temperature of transmission line 290 K

Comparison of Ship G/Ts

Based on the preceding, the AN/WSC-6 receive figures of merit, G/Ts, for the four-foot antenna is equal to:

$G/T = G_r - T_s = 37.1 - 25.8 = 11.3$

And the seven-foot antenna is:

$G/T = G_r - T_s = 41.9 - 22.8 = 19.1$

Thus, the seven foot antenna using state of the art LNAs shows an improvement of 7.8 db over the four foot antenna.

Link Transmit Parameters

Transmit freq, T_f (RHC)	8 GHz	
Transmit HPA power, $P_{t\ max}$	8 kw	39 db
Transmit HPA power, $P_{t\ nominal}$	5.6 kw	37.5 db
EIRP (4-foot ant) = $P_t + G_t$ = 37.5 + 37.6		75.1 db
EIRP (7-foot ant) = 37.5 + 42.5		80.0 db
Losses L (2.85 db nominal)		
Line losses, 150 ft max, L_{lm}		4.5 db
Line losses nominal L_{ln}		0.6 db
Antenna coupling loss L_c		1 db
Rainfall loss, typical, L_{rn} (Each end)		0.5 db
Pointing loss, L_{tp}		0.5 db
Radome loss, L_{tr}		0.25 db
Margin, M		2 db

The figure of merit, C/kT, for the nominal ship uplink to a DSCS II satellite is:

$$C/kT = P_t + G_t + (G_r/T_s) - L - M - k$$

$$= 37.5 + 37.6 - 16 - 202.5 - 2.9 - 2.0 + 228.6$$

$$= 80.3 \text{ dbw/Hz}$$

DSCS II Satellite Parameters[12]

Pt max	40w	16.0 dbw
Pt Nominal	20w	13.0 dbw
G		18 db
G_r/T_s		-16 db/k
EIRP		31 db
L, satellite losses		0.2 db
Margin		2 db

DSCS III Satellite Parameters[13]

EIRP Ch 1 MBA/Earth beam	29 dbw
EIRP Ch 1 MBA/Narrow beam	40 dbw
G/T MBA/Earth beam	-18.5 db/k
G/T MBA/Narrow beam	-3.5 db/k

DSCS II Downlink to ship

Assume the satellite transponder devotes 1/10 of 20 watts (3 db) for the link to the ship. The C/kT for the DSCS II downlink to the ship with a four-foot antenna is:

$$C/kT = P_t + G_t + (G_r/T_r) - L_p - L - M - k$$

$$C/kT = 3 + 18 + 11 - 202 - 3.1 - .2 + 228.6 = 53.5 \text{ dbw/Hz.}$$

If the four-foot antenna is replaced with a seven-foot antenna the C/kT becomes:

$$C/kT = 3 + 18 + 19.2 - 202 - 3.1 - .2 + 228.6 = 63.5 \text{ dbw/Hz.}$$

Typical DSCS Earth Terminal

Antenna Gain, G_t min		61 db
Transmit HPA power, P_t max	5 kw	37.0 dbw
Transmit HPA power, P_t nominal	4. kw	36.0 dbw
EIRP		97 dbw
G_r/T_s		39 db/K
Losses L (3 db nominal)		
Line losses nominal L_{ln}		1.5 db
Antenna coupling loss L_c		1 db
Rainfall loss, typical, L_{rn} (Each end)		0.5 db

Assume 1/20 of the terminal nominal power (0.05 * 4 kw) is used for the link. The C/kT for an earth station uplink to a DSCS II Satellite is:

$$C/kT = P_t + G_t + G_r - T_s - L_{fs} - L - k$$

$$= 23.0 + 61 + 18 - 36 - 202 - 3 + 228.6 = 89.6 \text{ dbw/Hz.}$$

3.4.3 Interoperability

A seven-foot antenna improves interoperability by providing a stronger signal to the satellite receiver and a more sensitive receive system for the satellite transmitter. This can accommodate the greater margins required for communications ship-to-ship, or ship-to-shore as shown in the following table.

Table 5 Antenna Performance Comparisons

	Antenna Size		Margin
	4 foot	7 foot	Improvement
Gr	37.1 db	41.9 db	4.8 db
Gt	37.6 db	42.5 db	4.9 db
EIRP	72.3 dbw	77.2 dbw	4.9 dbw
G/T	11.3 db/kt	19.1 db/kt	7.8 db/kt

A second factor limiting interoperability is the limited power output of the AN/WSC-6 terminal. The lack of power often requires the distant end terminal to provide the ship with a retransmitted local loop signal. This is referred to as long loop operation. The WSC-6 provides two net timing sources to the OM-55 modem. One is the orderwire receiver which receives net orderwire information from the distant net control terminal (NCT). The other receiver provides a loopback signal transmitted through the satellite. This loopback signal may be a local loop - transmitted through the satellite and directly back to the WSC-6; or it may be a long loop - transmitted by the WSC-6 through the satellite to a shore site and then retransmitted through the satellite to the ship. These signals are used to establish satellite range, Doppler correction, and code-division multiple access phase timing and synchronization.

The WSC-6 frequently does not have sufficient margin to close its own local loop with the satellite. This is overcome by having the shore station receive and retransmit the WSC-6's timing loop signal. This limits interoperability by requiring the distant terminal to support the shipboard with both additional equipment and transmitted power.

There are two means identified to overcome the need for a long loop. One is to increase the EIRP from the satellite, the second is to increase the G/T of the shipboard receive system. The seven-foot antenna with low noise LNAs improves the G/T significantly and allows the shipboard terminal to close its own local loop.

3.4.4 Risk

The seven-foot antenna design is based on the four-foot design to reduce risk and to keep incremental costs at a minimum. While the antenna has not been fully certified for shipboard use, it is close to acceptance. No major problems are expected. There is little risk that the antenna will not be available when needed.

3.4.5 Cost

The cost estimate to convert to the seven-foot antenna is shown in table 6[10].

Table 6 Antenna Upgrade Cost Estimate

Reference No.	Description	Percent of equipment cost	Cost
1.1	System/Program Mgt		
1.1.1	System Engineering	25%	$656,250
1.1.2	Program Management	20%	$525,000
	sub-total		**$1,181,250**
1.2	Equipment Costs	per system	**$2,625,000**
1.3	Support Equipment	5%	**$131,250**
1.4	Training	15%	**$393,750**
1.5	Documentation	15%	**$393,750**
1.6	Logistics	20%	**$525,000**
1.7	Installation/Checkout	85%	**$2,231,250**
1.8	Spares	25%	**$656,250**
1	**7 ft Antenna Total Costs**		**$8,135,500**

SECTION 4

AHP ANALYSIS

The following figures show the results of the AHP evaluation of the three alternatives' contribution to the five attributes. The results are shown in bold type under the "CALCULATION OF PRIORITY WEIGHTS" column.

4.1 TRACKING IMPROVEMENT ATTRIBUTES

Figure 16 presents the alternatives' contribution to tracking improvement. The scores show the relative preference for each of the three alternatives: enhance the modem; improve control capabilities; and install a seven foot antenna in place of a four foot one. For tracking improvement, the modem upgrade provides the greatest contribution. This is followed by the antenna and then the CDOCS. The distance between the scores indicates the degree of preference. There is significant value to the modem improvements and almost no value to the CDOCS relative to their contribution to improved tracking of the satellite by the AN/WSC-6 system.

ALTERNATIVES

I TRACKING IMPROVEMENT

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	8.000	3.000
B	CONTROL	0.125	1.000	0.167
C	ANTENNA	0.333	6.000	1.000
	SUMS	1.458	15.000	4.167

NORMALIZED MATRIX OF PAIRED COMPARISONS

				SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.686	0.533	0.720	1.939	**0.646**
B	0.086	0.067	0.040	0.192	**0.064**
C	0.228	0.400	0.240	0.868	**0.289**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication		
	2.028	**3.138**
	0.193	**3.013**
	0.890	**3.074**
		9.224

$$\frac{\text{LAMBDA MAX} = 9.224}{N = 3} = 3.0746$$

Consistency Index = CI = 0.0373

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.0643

Figure 16 Tracking Improvement Attributes

4.2 SYSTEM THROUGHPUT

The antenna improvements provide the greatest contribution to system throughput as shown in figure 17. The margin is two-to-one compared to the CDOCS and nine-to-one over the modem. The control improvements contribute over four times the score of the modem.

II THROUGHPUT

MATRIX OF PAIRED COMPARISONS

	A	B	C
A MODEM	1.000	0.200	0.111
B CONTROL	5.000	1.000	0.500
C ANTENNA	9.000	2.000	1.000
Sums	15.000	3.200	1.611

NORMALIZED MATRIX OF PAIRED COMPARISONS

	A	B	C	SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.067	0.063	0.069	0.198	**0.066**
B	0.333	0.313	0.310	0.956	**0.319**
C	0.600	0.625	0.621	1.846	**0.615**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication		
	0.198	**3.000**
	0.956	**3.001**
	1.847	**3.002**
		9.003

$$\frac{\text{LAMBDA MAX} = 9.003}{N = 3} = 3.001$$

Consistency Index = CI = 0.00044425

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.0008

Figure 17 Throughput Attributes

4.3 INTEROPERABILITY IMPROVEMENTS

As shown in figure 18 the preferred choice for improving interoperability is the modem upgrade. It has twice the score of the CDOCS and over eight times the score of the antenna upgrade.

III INTEROPERABILITY

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	2.000	8.000
B	CONTROL	0.500	1.000	5.000
C	ANTENNA	0.124	0.200	1.000
	SUMS	1.624	3.200	14.000

NORMALIZED MATRIX OF PAIRED COMPARISONS

	A	B	C	SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.616	0.625	0.571	1.812	**0.604**
B	0.308	0.313	0.357	0.978	**0.326**
C	0.076	0.063	0.071	0.210	**0.070**
	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

MATRIX MULTIPLICATION		
	1.817	**3.007**
	0.978	**3.003**
	0.210	**2.998**
		9.008

$$\frac{\text{LAMBDA MAX} = 9.008}{N = 3} = 3.00266$$

Consistency Index = CI = 0.001332
Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.002

Figure 18 Interoperability Attributes

4.4 RISK COMPARISON

Figure 19 shows the results of the risk analysis comparison for the three alternatives. The antenna is by far the superior alternative. It is followed by the modem and the control system improvements.

IV RISK

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	3.000	0.500
B	CONTROL	0.333	1.000	0.125
C	ANTENNA	2.000	8.000	1.000
	SUMS	3.333	12.000	1.625

NORMALIZED MATRIX OF PAIRED COMPARISONS

	A	B	C	SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.300	0.250	0.308	0.858	**0.286**
B	0.100	0.083	0.077	0.260	**0.087**
C	0.600	0.667	0.615	1.882	**0.627**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication		
	0.860	**3.007**
	0.260	**3.002**
	1.893	**3.017**
		9.027

$$\frac{\text{LAMBDA MAX} = 9.027}{N = 3} = 3.009$$

Consistency Index = CI = 0.004424

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.00762

Figure 19 Risk Attributes

4.5 COST COMPARISONS

The results of the cost factors evaluation are presented in figure 20. The antenna enlargement has the lowest total cost and, therefore, received the best AHP score. The modem enhancement was next and the control improvement was last. The approximate total costs and cost-per-system for each of the alternatives are summarized in table 7.

Table 7 Alternatives Cost Summary

Alternative	Cost of Alternative	No. Sys	Cost-per-system
A. MODEM	$18,574,500	17	$1,092,618
B. CONTROL	$19,575,500	5	$3,915,100
C. ANTENNA	$8,135,500	7	$1,162,214

The cost for Alternative A involves the conversion of 17 OM-55/USC modems at a cost of $18,574,500. The most desirable alternative, the antenna upgrade is $8,135,500. The cost of both alternative A and C is approximately $26,710,000. This would upgrade both ship-based and shore-based OM-55/USC modems and, subject to ship specific engineering studies, replace the seven existing four-foot shipboard antennas with seven-foot antennas. These two alternatives account for almost 80% of the priority weights for all alternatives. Achieving the remaining 20% requires an additional $19,575,500; 42% of $46,285,500 total; making the implementation of the control upgrade appear relatively costly.

V COST

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	2.000	0.200
B	CONTROL	0.500	1.000	0.160
C	ANTENNA	5.000	6.000	1.000
	SUMS	6.500	9.000	1.360

NORMALIZED MATRIX OF PAIRED COMPARISONS / CALCULATION OF PRIORITY WEIGHTS

	A	B	C	SUM	SUM/N
A	0.154	0.222	0.147	0.523	**0.174**
B	0.077	0.111	0.118	0.306	**0.102**
C	0.769	0.667	0.735	2.171	**0.724**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication		
	0.523	**2.999**
	0.305	**2.992**
	2.207	**3.049**
		9.040

$$\frac{\text{LAMBDA MAX} = 9.040}{N = 3} = 3.013$$

Consistency Index = CI = 0.0067

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.0012

Figure 20 Cost Attributes

SECTION 5

CONCLUSION

The results of the AHP analysis presented in figure 21 show the modem improvements to be the preferred alternative. The antenna is next and the control system improvements are last.

	I Tracking 0.463	II Thru Put 0.172	III Interop 0.253	IV Risk 0.041	V Cost 0.071	Weighted Evaluations
A Modem	0.646	0.066	0.604	0.286	0.174	**0.487**
C Antenna	0.289	0.615	0.070	0.627	0.724	**0.335**
B Control	0.064	0.319	0.326	0.087	0.102	**0.178**
Check Sums	1.000	1.000	1.000	1.000	1.000	1.000

SUMMARY OF PRIORITY WEIGHTS, EVALUATION RATINGS AND WEIGHTED EVALUATIONS In Order of Preference

Figure 21 AHP Summary

The contribution of each alternative to each attribute, and each attribute to the overall objective are taken from the results shown in figure 21 and are presented in their relative positions in the AHP hierarchy in figure 22.

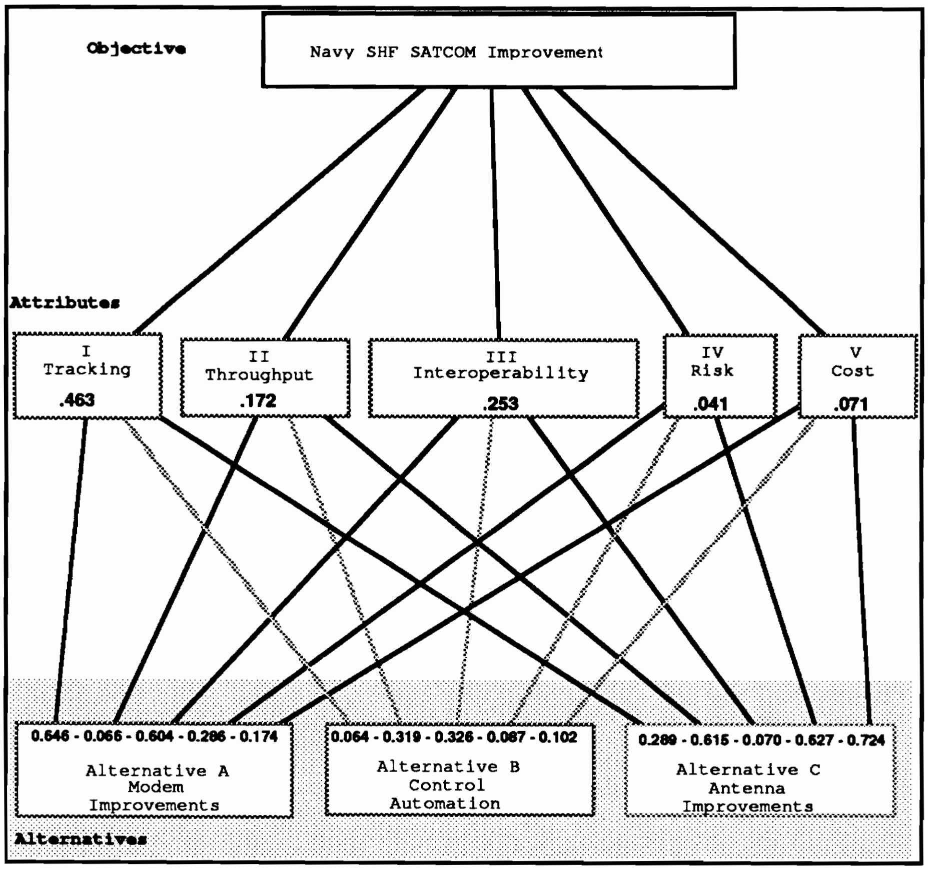

Figure 22 AHP Hierarchy

5.1 FURTHER ANALYSIS

Changing circumstances and conditions, differing opinions and new requirements may cause changes in the relative merit of the alternatives. New factors, and changes in existing factors may be inserted into the AHP method and new results determined. Also, attributes may be separated into cost and benefit groups for further analysis.

5.1.1 Sensitivity Analysis

A sensitivity analysis was performed to determine the impact of the attribute weighting factors shown in figure 5. MicroSoft EXCEL was used to perform the calculations the results of which are summarized in table 8. The full results of the analyses are in Appendix C.

The sensitivity analysis was conducted by assigning each of the attributes a value that made it very strongly preferred over each of the other attributes in the pairwise comparisons. Other values were left as they were. This caused some inconsistency, as can be seen in the consistency index, but not enough to invalidate the sensitivity analysis.

Table 8 Results of Sensitivity Analysis

	Tracking	Thruput	Interop	Risk	Cost
Modem	**.513**	.281	**.515**	.366	.310
Control	.149	.241	.240	.127	.140
Antenna	.388	**.477**	.245	**.507**	**.550**

The modem is the first choice when improved tracking, or better interoperability are very strongly preferred. If improved throughput, reduced risk or lowest cost are rated very strongly preferred then the seven-foot antenna is the first choice. Control enhancements are third choice in every case.

The sensitivity analysis could be enlarged to extend the range between attributes and can also be applied to each of the alternatives. The results of this analysis show a close choice between the modem improvements and the larger antenna.

5.1.2 Cost-Benefit Analysis

An alternative approach to the one just presented is to develope a cost versus benefit analysis by separating Tracking, Throughput and, Interoperability into one group - BENEFITS; and Risk and Cost into another group - COSTS. This process identifies the alternative with the best cost-benefit ratio, as opposed to the best overall score originally presented. The pairwise comparison and weighting factor process is similar to that presented earlier.

The results, presented in appendix D, show that the antenna is the preferred alternative from a cost-benefit perspective. This reflects the original results that show the antenna enlargement with the highest scores (best cases) for both Risk and Cost, a high score in Throughput, and moderate scores in Tracking and Interoperability.

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[1]Saaty, Thomas L., 1988, *Decision Making for Leaders,* Pittsburgh, PA: RWS Publications, Chapters 1-5.

[2]Saaty, p.5.

[3] The mitigated mode refers to modem processing techniques that reduce the effects of atmospheric scintillation due to nuclear weapons detonations.

[4] A T-AGOS class of ship is a large tug boat with a huge cable reel mounted astern. The reel tows a several thousand foot long acoustic sensor for detecting submarines.

[5] Department of the Navy, November 1982, *NWP2, Organization of the NAVY,* Office of the Chief of Naval Operations, Washington, D.C.

[6] Defense Communications Agency, April 1986, *Operation and Control of the Defense Satellite Communications System (DSCS)*, DSCS-800-70-1, DCS, Washington, D.C.

[7] Canada, John R., W.G. Sullivan, *Economic and Multi-attribute Evaluation of Advanced Manufacturing Systems,* Englewood Cliffs, New Jersey: Prentice-Hall, Inc., chapter 10.

[8]Space and Naval Warfare Systems Command, 8 January, 1988, *Communications Set, SHF Satellite, AN/WSC-6 (V),* SPAWAR-C-453C, Department of the Navy, Washington, D.C.

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[9] Space and Naval Warfare Systems Command, 8 January, 1988, *Modem Group, OM-55(V)/USC,Satellite Communications,* SPAWAR-C-458-1B, Department of the Navy, Washington, D.C.

[10] Cost figures are meant to be representative of actual costs estimates, but do not to represent any official or proprietary information.

[11] Benjamin S. Blanchard and Wolter J. Fabrycky, Systems Engineering and Analysis, Englewood Cliffs, NJ, Prentice-Hall, p. 323

[12] Defense Communications Agency, 28 August 1984, *Satellite Communications Reference Data Handbook,* DCA Circular 800 70-1 Supplement 2, Defense Communications Agency, Washington, D.C.

[13] Defense Communications Agency, 28 August 1984, *Satellite Communications Reference Data Handbook,* DCA Circular 800 70-1 Supplement 1, Defense Communications Agency, Washington, D.C.

APPENDICES

APPENDIX A

DSCS RESPONSIBILITIES FOR SYSTEM CONTROL

In accomplishing the assigned mission regarding DSCS system control, the Director, DCA is responsible for[1]:

- Exercising operational direction over the functional areas of the DSCS system control and delegating control authority as appropriate,
- Exercising management control over military departments, Unified and Specified commands, and other DoD agencies' research and development planning, engineering and programming activities that support the establishment and improvement of the functional area of the DSCS system control,
- Developing policy, concepts, and operating procedures in coordination with the military departments for DSCS facilities, and developing general guidelines for system control training curriculum,
- Performing operational evaluation of DSCS facilities,
- Providing guidance and assistance in developing the criteria for the design and layout of DSCS system control facilities in coordination with the military departments,
- Obtaining data on the operational status of DSCS satellite earth terminals and networks directly from the DSCS stations or DSCS facilities, and providing that information to DSCS users and operating elements,

- Developing, reviewing and approving the critical control communications networks for interconnecting the DSCS control facilities,
- Providing planning, programming, engineering, R&D, and standardization guidance for DSCS system control facilities to ensure compatibility in the development, acquisition, and operation of DSCS facilities,
- Developing the design engineering, operation, and maintenance standards for the DSCS system control facilities and the technical design standards for equipment and facilities and also for prescribing operational standards for the interface of non-DSCS equipment and facilities to the DSCS,
- Reviewing and approving facilities implementation and installation plans, subsystem and project plans, and management engineering plans for compliance with DSCS standards and criteria.

The accomplishment of the DCA mission requires close cooperation and coordination between the DCA and the military departments and users of DSCS. While accomplishing operational direction and management control of the DSCS in the general areas of system control DSCS the DCA will:

- Coordinate actions affecting operational control of the DSCS with the Joint Chiefs of Staff, the military departments, other DoD components, and government agencies having collateral or related functions,

- Maintain an active liaison for exchanging system control and operations and maintenance information and advice with all components of the DoD, other government agencies, and the DSCS users,
- Maintain security controls over the DSCS system,
- Direct system control actions to meet user requirements by establishing, disconnecting, changing, or testing DSCS user services.

The military departments, as part of the DCS, have a number of responsibilities that support the Defense Communications System. These responsibilities include:

- Providing full support and assistance to DCA in the operational direction and management control of the DSCS,
- Ensuring responsiveness of DSCS elements to the operational direction of the DCA,
- Providing personnel, facilities, equipment, and other support required to operate and maintain system control facilities within the DSCS for which a military department has responsibility.

Lastly, all DSCS users have the responsibilities and corresponding authority to:

- Communicate directly with the designated DSCS control facility,

- Respond to requests from system control facilities for assistance on service restoration problems and actions,
- Communicate directly with the appropriate circuit validating office concerning establishment of new service and changing or terminating existing DSCS services.

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[1] Defense Communications Agency, April 1986, *Operation and Control of the Defense Satellite Communications System (DSCS)*, DSCS-800-70-1, DCS, Washington, D.C.

APPENDIX B

DOCS AUTOMATION

DOCS is implemented via an acquisition strategy which is phased over a period of several years. The upgrading of the DSCS Control Segment began in 1978 when the Department of Defense directed that the Pilot Control System (PCS) and a subsequent upgrade called the PCS extension (PCS-X) be used to provide more efficient Atlantic DSCS II satellite network operation until DOCS becomes operational. DOCS now includes the DSCS FDMA Control Subsystem (DFCS), formally called the Pilot Control System Extension (PCS-X), which is enhanced by the DOCS program[1]. The DOCS upgrade program facilitates the transition of the DSCS control segment from a manual to a highly automated system. The DFCS together with the DOSS/DASA and SCCE equipment constitute the initial DOCS for the DSCS. Major DOCS subsystems shown in figure B1 are the:

- Satellite Configuration Control Element (SCCE),
- Control Secure Voice Link (CSVL)
- DSCS ECCM Operational Control Subsystem (DECS),
- DSCS Automatic Spectrum Analyzer (DASA),
- DSCS Operational Support System (DOSS),
- Ground Mobile Force (GMF) Control Link (DGCL),
- DSCS FDMA Control Subsystem (DFCS),
- AN/USC-28 modem (Critical Control Circuit),
- RF-IS Interface Subsystem (RFIS).

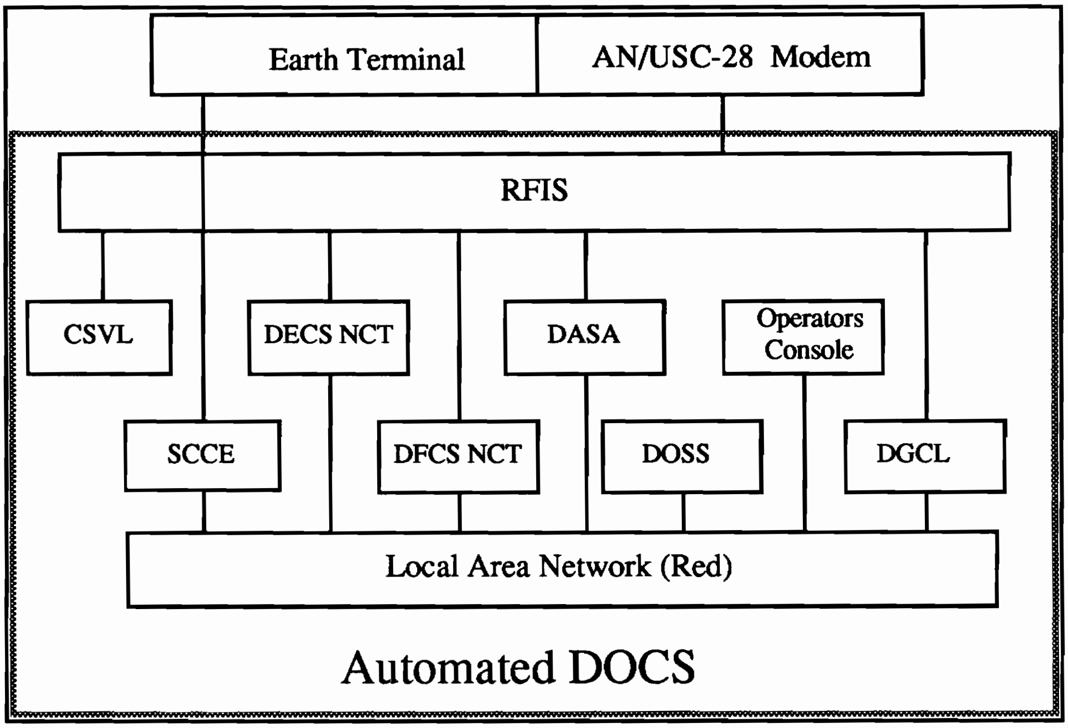

Figure B1 DOCS Functional Block Diagram

B.1 Satellite Configuration Control Element (SCCE)

The Satellite Configuration Control Element is installed at the DSCS Operations Center to provide telemetry reception and command transmission functions for the control of critical satellite payload functions such as the configuration of the multi-beam antenna and the gimbaled dish antenna (GDA), the control of satellite transponder gain state and the detection of malfunctions. The SCCE interfaces with the DOSS equipment at the DSCS Operations Centers and provides the following operational capabilities[1]:

- Derives commands and command sequences for any two of three satellites, one satellite at a time, based on tasking requirements and coverage files received from the DOSS,

- Processes and dispatches commands via the collocated SATCOM earth terminal for transmission to the satellite,
- Acquires telemetry data via the collocated earth terminal for processing, recording, and display,
- Performs full processing and display of the real-time or playback telemetry data stream from any two of three predetermined satellites.

The SCCE is comprised of three major subsystems that combine to perform control and display of data and information from the SCCE. These functional block diagram for these subsystems are shown in figure B2.

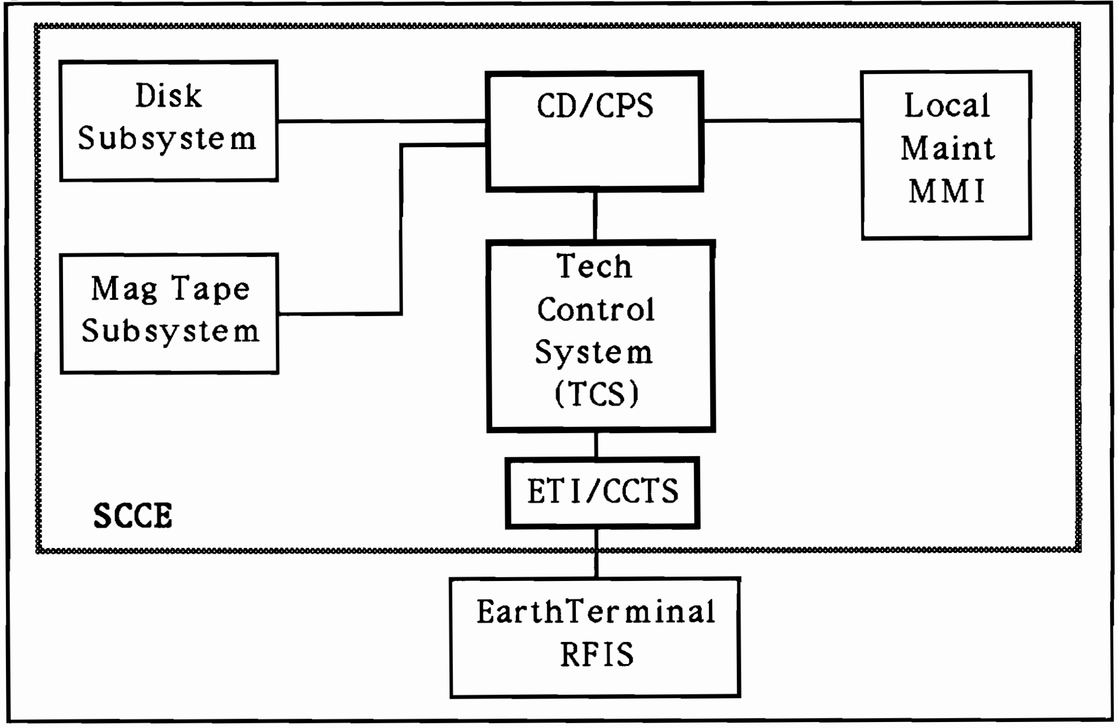

Figure B2 SCCE Functional Block Diagram

The control and display, computer and peripheral subsystem (CD/CPS) provides command generation, telemetry, telemetry processing and display, satellite reconfiguration, and the man-machine interface.

The telemetry and command subsystem (TCS) that enables processing of DSCS III telemetry and command data, provides an interface with the earth terminal via the interface and checkout-calibration and test subsystem, and provides operation under control of the control and display, computer and peripheral subsystem (CD/CPS). The TCS computer transmits and verifies execution of authorized command sequences generated by a communications configuration control program and it sends the data for the display of this information to the CD/CPS.

The earth terminal interface, checkout-calibration and test subsystem (ETI/CCTS) provides signal conversion and translation and a functional checkout and diagnostic testing of the SCCE.

B.2 Control Secure Voice Terminal (CSVT)

The Control Secure Voice Terminal (CSVT) provides the capability for FDMA secure communications over the satellite network between the DSCS Operations Centers and their respective earth terminals. The functional block diagram for the CVST is shown in figure B3. The CSVT will provide the communications and data needed by the DSCS SATCOM Network Controller to rapidly allocate and maintain DSCS satellite and earth terminal resources during non-stressed conditions. This interface can be provided either through a PBX landline connection to the remote FDMA terminal or via the RFIS to the earth terminal.

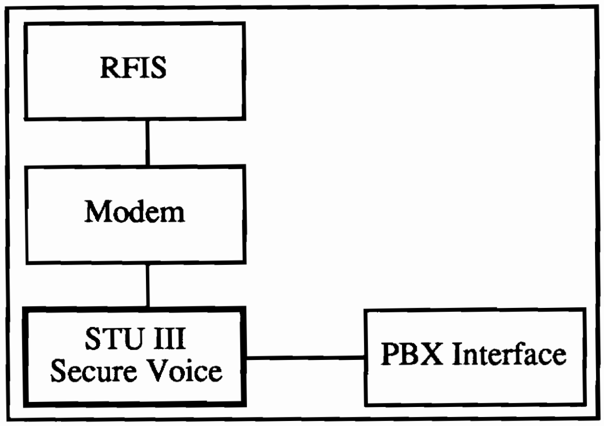

Figure B3 CSVT Functional Block Diagram

B.3 DSCS ECCM Control Subsystem (DECS)[2]

The DSCS ECCM Control System (DECS) assists in the configuration control, status reporting and performance monitoring of the equipment resources and communications signals of the DSCS ECCM network. The DECS subsystem automates the functions of ECCM network polling, status collection and evaluation, and provides an automatic performance monitoring capability. The automation of these functions allows a more rapid and precise response to jammming and equipment malfunctions; thus improving system availability, and reducing operator workload. The DECS is provided in two configurations - one for Net Control Terminals (NCTs) and one for Net Terminals (NTs).

B.4 DECS Net Control Terminal (NCT) Operation

The DECS NCT functional block diagram in figure B4 consists of the DECS, a central processor and man-machine interface (MMI), a polling controller, a spread power monitor (SPM), a satellite communications modem, the AN/USC-28(V), teletypewriters and associated COMSEC equipment. The AN/USC-28 modem is dedicated to the DSCS Operational Control System (DOCS) and is not used for user communications.

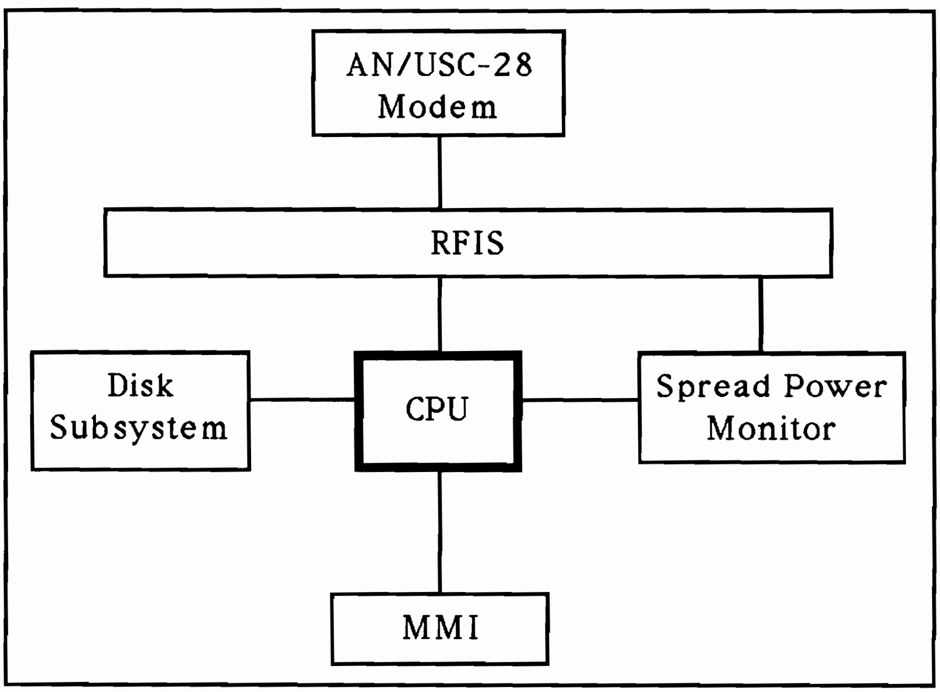

Figure B4 DECS NCT Functional Block Diagram

The DECS NCT supports the following functions:

- ECCM network polling
- Monitoring link performance

  - Link Quality
  - Jamming Detection
  - Terminal response
- Directing DSCS terminal configuration
- DECS status monitoring.

The DECS NCT subsystem continually monitors - via the spread power monitor - the quality of all links in an ECCM network, to include jamming detection, and sends the results of the monitoring to the DSCS Operational Support System (DOSS) and MMI. As an adjunct to the detection of jamming, this function also recommends either the response to jamming on the margin-to-threshold status of each link, or required increase in link power to maintain specified margin-to-threshold values on each link. Any out of tolerance condition of link quality detected is signaled to the ECCM Network Controller.

All DECS functions are controlled from the DSCS Operational Support System (DOSS) or from the DECS man-machine interface (MMI). Control of the DECS by the DOSS is accomplished through an interface with the local area network (LAN). The MMI interfaces directly with the DECS and has the capability of overriding the DOSS control or to interrupt the automated mode operations to change modes and to perform all DECS functions.

The DECS NCT has the capability to direct the configuration of ECCM equipment located at DSCS terminals. This capability includes the input of configuration data from the DOSS in the automated mode, or from the ECCM network controller via the MMI manual mode. Transmission of this configuration data is via the ECCM CCC. The DECS NCT has the capability to store configuration data for five complete configurations. The data required to specify a single configuration at one DSCS terminal includes:

- DSCS terminal settings
- AN/USC-28 attenuation values
- CSU Army and Navy sequence
- User channel schedule displays
- Multiplex plans.

The DECS NCT performs ECCM polling by accepting polling schedules from the DOSS or the MMI, polling in accordance with a schedule, and by processing received messages and sending them to the DOSS and MMI. Alarm conditions for parameters to be monitored are included in the polling schedule format. These parameters are monitored and the results sent back via the polling response - pollback - message and compared with expected DSCS terminal responses. Abnormal conditions generate an alarm condition that is forwarded to the DOSS and MMI.

The DECS monitor function provides status information on DECS equipment to the DOSS via the LAN and to the ECCM Network Controller via the Man Machine Interface. The status information includes:

- Status of the dedicated AN/USC-28 at the DSCS Operations Center
- Status of the DECS NCT equipment
- Status of the AN/USC-28 equipment at the DSCS terminals

- Status of other DSCS terminal ECCM communications equipment

DECS NCT equipment will be located at the following DSCS sites:

- Ft. Detrick, MD
- Camp Roberts, CA
- Landstuhl, FRG
- Clark AFB,Philippines
- Northwest, VA
- Ft. Buckner
- Ft. Monmouth Test Facility, NJ
- USASIGCEN, GA

B.5 DECS Net Terminal (NT) Operation

The DECS Net Terminal (NT), figure B5, configures the ECCM communications equipment in response to direction from the DECS NCT. DSCS terminal configuration data is received via the ECCM Critical Control Circuit (ECCC) and stored by the DECS NT. The DECS NT is capable of storing ten configurations. The description of the active configuration is based on data received via the ECCC, or by the selection of the DSCS terminal operator. Selection by the DSCS terminal operator will be at the direction of the DSCS Operations Center and will not be an independent selection. The DECS NT configuration shares the AN/USC-28 modem interfaces with the with the user communications for purposes of configuration control, status and performance monitoring. The DECS NT equipment also interfaces with the Low Rate Multiplexers

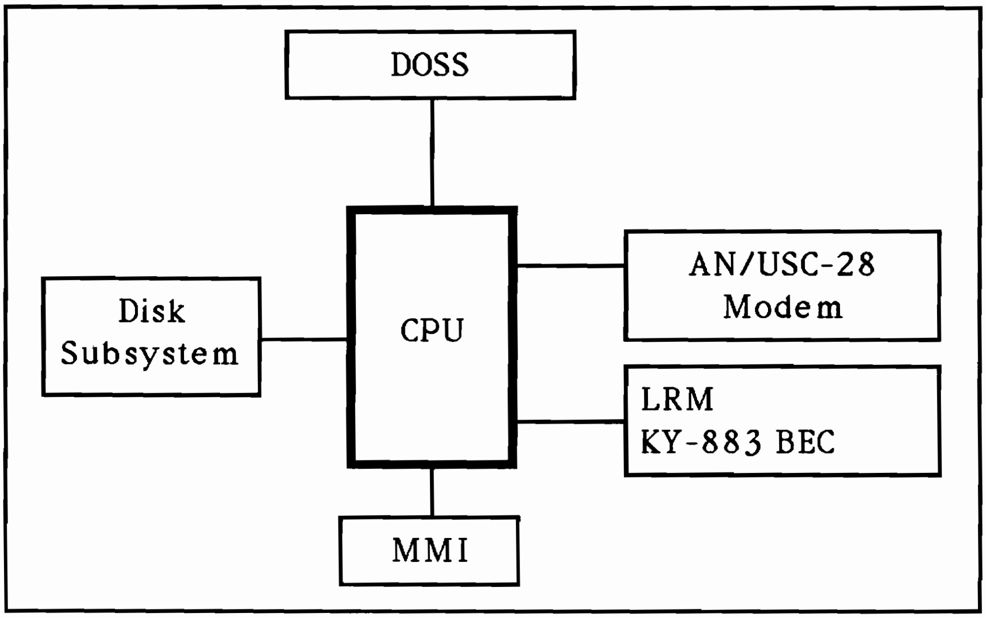

Figure B5 DECS NT Functional Block Diagram

(LRMs) and associated KY-883, Burst Error Correction Coder. The data required to specify a single configuration includes is the same as for the NCT.

The DECS NT includes status information in its pollback message to include:

- Status of the AN/USC-28 elements
- Status of the DSCS terminal ECCM communications equipment
- Status of the DECS NT
- Status of the Low Rate Multiplexers
- Status of the KY-883s

The DECS NT will also respond to requests from and provide status parameters to the Secure Conferencing Program Digital Conference Director.

B.6 DSCS Automatic Spectrum Analyzer (DASA)[3]

The DSCS Automatic Spectrum Analyzer (DASA), figure B6, provides a spectrum monitor and analysis capability for use with the DOSS. Its primary function is to monitor signals transmitted by the DSCS satellite, compare measured signals parameters with expected values, and provide the SATCOM network controller with the data required to verify proper DSCS network operations. The DASA is valuable for the management of FDMA channels where power balancing among terminals is important.

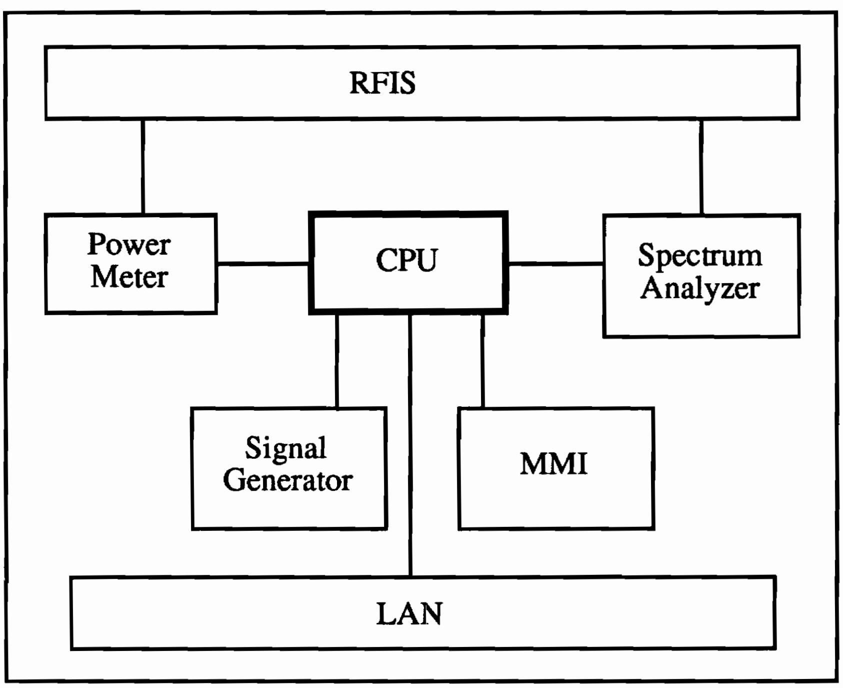

Figure B6 DASA Functional Block Diagram

The DASA, located at the DSCS Operations Centers, is integrated with the DOSS hardware and software. It is also capable of stand alone operation as a signal analyzer for test and calibration of receive circuit equipment. The DASA accepts signal monitoring data from the spectrum analyzer, computes various signal parameters based on the current operational traffic configuration in the DOSS data base, and compares the measured values with the expected values generated by the DOSS central processing unit. The DASA provides continuous monitoring of the entire downlink spectrum to include:

- Percentage of satellite channel power used by each link,
- Received carrier-to-noise density (C/kT) of each link,
- Received power level (dBm) and noise density (dBm/Hz),
- Percentage of total power radiated by each satellite transponder,
- Frequency and power of unauthorized signals detected within the downlink frequency band.

The SATCOM Network Controller uses the DASA information to verify proper DSCS network operations. The DASA equipment will be installed at each of the DSCS Operations Centers.

The primary function of the DASA is to monitor downlink signals transmitted by the DSCS satellites, compute various signal parameters based on the current operational traffic configuration in the DOSS data base, and compare the measured values with expected values. The DASA can be operated in the Monitor mode, Carrier mode, or the Single Scan mode. The monitor mode allows the DASA to monitor the entire downlink spectrum (7250 - 7750 MHz) and measure all the downlink parameters. The carrier mode provides the operator with the capability to request detailed analysis of a single carrier link. The single scan mode allows the operator to obtain a detailed analysis of a particular frequency band. The DASA generates reports which include variances between measured and expected values, link status, satellite channel status, link and satellite channel history, and alarm history.

The DASA consists of the following major components which are located the the DSCS Operations Centers:

- Spectrum analyzer (HP 8566),
- Signal generator (HP 8672),
- Power meter,
- Central processing unit and software,
- Man-machine Interface.

B.7 DSCS Operational Support Subsystem (DOSS)

The DSCS Operational Support System (DOSS) provides computational support for the SATCOM Network Controller. The DOSS is equipped with software to provide for DSCS Network Planning and interfaces with the DSCS Automatic Spectrum Analyzer (DASA). The DOSS and the DASA work together to provide the SATCOM Network Controller the capability to: operate an efficient communications network; continuously monitor the network; and perform long term planning functions.

The DOSS processing equipment is located in the DSCS Operations Centers. The DOSS planning and monitoring capabilities are also available to DOSS remote sites located at the DCA headquarters, the DCA Operations Center, and the Area Communications Operations Centers (ACOCs). The DCS Operations Center will eventually have four remote terminals connected to DSCS Operations Centers in the EASTPAC, WESTPAC, Indian Ocean, and Atlantic satellite operating areas. The DSCS Operations Centers can then assist the Area Communications Operating Centers and DSCS Operating Centers in the planning and monitoring of the DSCS network.

The DOSS provides computational support for the SATCOM Network Controller to calculate DSCS reconfiguration parameters in rapid response to changes in: user requirements; network status; or environmental conditions. The operational capabilities provided by the DOSS are:

- Network resource allocation analysis including ECCM adaptation analysis
- Generation of spacecraft communications payload tasking data for transmission to the Satellite Configuration Control Element (SCCE)
- Receipt, storage and evaluation of spacecraft, earth terminal and control subsystem status data.

The central processing unit shown in figure B7 is the hub of the DOSS network. Peripheral equipment includes the communications interface, data storage devices and a printer/terminal, and control consoles. display/monitor, graphics terminals, and printers. The DOSS Remote Controller is functionally identical to the DOSS Local Controller.

The DOSS Local Controller is the primary Man-Machine-Interface and consists of its own CPU, storage devices, large screen display.

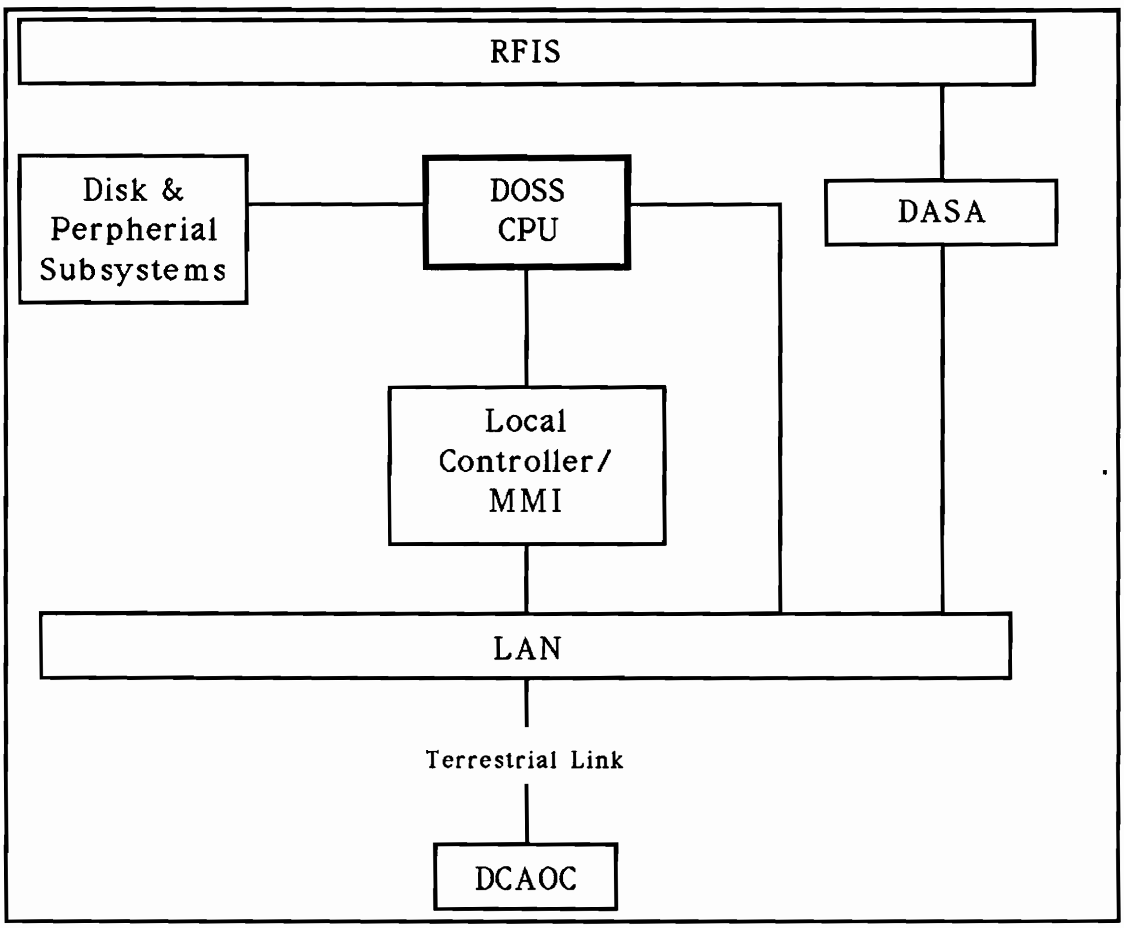

Figure B7 DOSS Functional Interface

B.8 DSCS Ground Mobile Forces Control Link (DGCL)

Full DGCL equipment will be installed at the Ft. Detrick, Camp Roberts, and Landstuhl DSCSOCs. The DGCL will be a subnet of the DSCS and will provide GMF satellite communication control orderwire service between the DSCS SATCOM Network Controller and the GMF controller. The principal components of the DGCL will be identical to those in the AN/MSQ-114 which is used in the GMF for network control. A limited DGCL control capability - primarily for GMF modems - will also be provided at the other DSCS Operations Centers.

B.9 RF Interface Subsystem (RFIS)

The DSCS Operations Centers will interface with RFIS for the purpose of controlling the transmission and reception of SHF signals to and from the DSCS III satellites and the DSCS earth terminals. Controlled interfaces will be X-band (RF) and 70 or 700 MHz (IF). The DSCS Operations Centers have a status and control interface to the RFIS subsystem which is capable of handling full-duplex control and data codes on an asynchronous basis. The DSCS Operations Centers also have the capability of sending status commands and inquiries to the RFIS, and receive responses. The Network Terminals (NTs) will also interface with RFIS.

B.10 DSCS FDMA Control Subsystem (DFCS)[4]

The primary function of the DFCS is to provide control and performance monitoring of the FDMA links. The DFCS will be installed at all heavy and medium earth terminals in the Atlantic area where some elements of the Pilot Control System Extension equipment has been in use for some time. DFCS equipment will be installed outside the Atlantic area at heavy and medium earth terminals at a later time. DFCS Net Control Terminal (NCT) equipment, the AN/FSC-96, will be installed in the DSCS Operations Centers; DFCS Net Terminal (NT) equipment, AN/GSC-51, will be installed at DSCS terminals capable of FDMA operation. The DFCS will help establish the FDMA link, manage network power and monitor network status. The DFCS NT equipment will allow the NT to provide data to the NCT regarding status and performance and to respond to NCT commands automatically. The NCT receives and processes the performance and status data sent by the NTs and, when necessary, the NCT sends out signals to reconfigure the NT equipment on the link. FDMA carrier performance will be measured at the 70 MHz IF connection as well as the baseband interface of the terminal equipment.

B.11 DSCS Terrestrial Critical Control Circuit

The DSCS terrestrial hubbed orderwire is encrypted and provides a means to plan, establish and re-establish, as necessary, the DSCS satellite networks. All DSCS earth terminals are equipped with teletypewriters and KG-84 COMSEC equipments which enable them to interface with their respective DSCS Operations Centers. The (Terrestrial Critical Control Circuit) TCCC is considered the primary critical control circuit for the DSCS.

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[1] Defense Communications Agency, April 1986, *Operation and Control of the Defense Satellite Communications System (DSCS)*, DSCS-800-70-1, DCS, Washington, D.C.

[2] Defense Communications Agency, June 1985, *DSCS ECCM Control Subsystem (DECS) Information Pamphlet*, DCA, Washington, D.C.

[3] Defense Communications Agency, June 1985, *DSCS Automatic Spectrum Analyzer (DASA Information Pamphlet*, DCA, Washington, D.C.

[4] Defense Communications Agency, June 1985, *DSCS Frequency Division Multiple Access Control System (DFCS) Information Pamphlet*, Defense Communications Agency, Washington, D.C.

APPENDIX C

SENSITIVITY ANALYSIS

ATTRIBUTES

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	**7**	**7**	**7**	**7**
II	Thru Put	**0.143**	1	0.5	5	3
III	Interop	**0.143**	2	1	6	3
IV	Risk	**0.143**	0.2	0.17	1	0.5
V	Cost	**0.143**	0.33	0.33	2	1
	SUM	1.572	10.53	9	21	14.5

NOMALIZED MATRIX OF PAIRED COMPARISIONS

						SUM	**PRIORITY WEIGHTS SUM/5**
I	0.636	0.665	0.778	0.333	0.483	2.895	**0.579**
II	0.091	0.095	0.056	0.238	0.207	0.686	**0.137**
III	0.091	0.190	0.111	0.286	0.207	0.885	**0.177**
IV	0.091	0.019	0.019	0.048	0.034	0.211	**0.042**
V	0.091	0.031	0.037	0.095	0.069	0.323	**0.065**
CHECK SUMS	1.000	1.000	1.000	1.000	1.000		**1.000**

CHECK OF CONSISTANCY RATIO

N = 5

MATRIX MULTIPLICATION		
	3.526	6.091
	0.713	5.196
	0.981	5.547
	0.215	5.092
	0.335	5.191

lambda max = 27.116 divide by N = 5.423

Consistancy Index = CI = 0.106
Random Index = RI = 1.120 for N=5

Consistancy Index = CI/RI 0.094

Figure C1 Attributes
Tracking Improvements Very Strongly Preferred

ALTERNATIVES

I TRACKING IMPROVEMENT

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	8.000	3.000
B	CONTROL	0.125	1.000	0.167
C	ANTENNA	0.333	6.000	1.000
	SUMS	1.458	15.000	4.167

NORMALIZED MATRIX OF PAIRED COMPARISONS

				SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.686	0.533	0.720	1.939	**0.646**
B	0.086	0.067	0.040	0.192	**0.064**
C	0.228	0.400	0.240	0.868	**0.289**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication		
	2.028	**3.138**
	0.193	**3.013**
	0.890	**3.074**
		9.224

$$\frac{\text{LAMBDA MAX} = 9.224}{N = 3} = 3.0746$$

Consistency Index = CI = 0.0373

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.0643

Figure C2 Tracking
Tracking Improvements Very Strongly Preferred

Note: The alternative priority weights have not changed as a result of the sensitivity analyses, but are repeated here for ease of reference.

II THROUGHPUT

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	0.200	0.111
B	CONTROL	5.000	1.000	0.500
C	ANTENNA	9.000	2.000	1.000
	Sums	15.000	3.200	1.611

NORMALIZED MATRIX OF PAIRED COMPARISONS

	A	B	C	SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.067	0.063	0.069	0.198	**0.066**
B	0.333	0.313	0.310	0.956	**0.319**
C	0.600	0.625	0.621	1.846	**0.615**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication	0.198	**3.000**
	0.956	**3.001**
	1.847	**3.002**
		9.003

$$\frac{\text{LAMBDA MAX}= 9.003}{N = 3} = 3.001$$

Consistency Index = CI = 0.00044425

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.0008

Figure C3 Throughput
Tracking Improvements Very Strongly Preferred

III INTEROPERABILITY

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	2.000	8.000
B	CONTROL	0.500	1.000	5.000
C	ANTENNA	0.124	0.200	1.000
	SUMS	1.624	3.200	14.000

NORMALIZED MATRIX OF PAIRED COMPARISONS

CALCULATION OF PRIORITY WEIGHTS

	A	B	C	SUM	SUM/N
A	0.616	0.625	0.571	1.812	**0.604**
B	0.308	0.313	0.357	0.978	**0.326**
C	0.076	0.063	0.071	0.210	**0.070**
	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

MATRIX MULTIPLICATION	1.817	**3.007**
	0.978	**3.003**
	0.210	**2.998**
		9.008

$$\frac{\text{LAMBDA MAX} = 9.008}{N = 3} = 3.00266$$

Consistency Index = CI = 0.001332
Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.002

Figure C4 Interoperability
Tracking Improvements Very Strongly Preferred

IV RISK

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	3.000	0.500
B	CONTROL	0.333	1.000	0.125
C	ANTENNA	2.000	8.000	1.000
	SUMS	3.333	12.000	1.625

NORMALIZED MATRIX OF PAIRED COMPARISONS

	A	B	C	SUM	CALCULATION OF PRIORITY WEIGHTS SUM/N
A	0.300	0.250	0.308	0.858	**0.286**
B	0.100	0.083	0.077	0.260	**0.087**
C	0.600	0.667	0.615	1.882	**0.627**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication		
	0.860	**3.007**
	0.260	**3.002**
	1.893	**3.017**
		9.027

$$\frac{\text{LAMBDA MAX} = 9.027}{N = 3} = 3.009$$

Consistency Index = CI = 0.004424

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.00762

Figure C5 Risk
Tracking Improvements Very Strongly Preferred

V COST

MATRIX OF PAIRED COMPARISONS

		A	B	C
A	MODEM	1.000	2.000	0.200
B	CONTROL	0.500	1.000	0.160
C	ANTENNA	5.000	6.000	1.000
	SUMS	6.500	9.000	1.360

NORMALIZED MATRIX OF PAIRED COMPARISONS — CALCULATION OF PRIORITY WEIGHTS

	A	B	C	SUM	SUM/N
A	0.154	0.222	0.147	0.523	**0.174**
B	0.077	0.111	0.118	0.306	**0.102**
C	0.769	0.667	0.735	2.171	**0.724**
Check Sums	1.000	1.000	1.000		1.000

CHECK OF CONSISTENCY RATIO

Results of Matrix Multiplication	
0.523	**2.999**
0.305	**2.992**
2.207	**3.049**
	9.040

$$\frac{\text{LAMBDA MAX} = 9.040}{N = 3} = 3.013$$

Consistency Index = CI = 0.0067

Random Index = RI = 0.58

Consistency Ratio = CI/RI = 0.0012

Figure C6 Cost
Tracking Improvements Very Strongly Preferred

Summary of weighted evaluations

SUMMARY OF PRIORITY WEIGHTS, EVALUATION
RATINGS AND WEIGHTED EVALUATIONS

	I	II	III	IV	V
	Trackinc	Thru Put	Interop	Risk	Cost
	0.579	0.137	0.177	0.042	0.065
A - Modem	0.646	0.066	0.604	0.286	0.174
B - Control	0.064	0.319	0.326	0.087	0.102
C - Antenna	0.289	0.615	0.070	0.627	0.724
CHECK SUMS	1.000	1.000	1.000	1.000	1.000

Weighted Evaluations	
A - Modem	0.513
B - Control	0.149
C - Antenna	0.338
CHECK SUM	1.000

Figure C7 Summary of Weighted Evaluations
Tracking Improvements Very Strongly Preferred

ATTRIBUTES

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	0.143	2	9	7
II	Thru Put	7	1	7	7	7
III	Interop	0.5	0.143	1	6	3
IV	Risk	0.11	0.143	0.17	1	0.5
V	Cost	0.14	0.143	0.33	2	1
	SUM	8.75	1.572	10.5	25	18.5

NOMALIZED MATRIX OF PAIRED COMPARISIONS

						SUM	PRIORITY WEIGHTS SUM/5
I	0.114	0.091	0.190	0.360	0.378	1.134	0.227
II	0.800	0.636	0.667	0.280	0.378	2.761	0.552
III	0.057	0.091	0.095	0.240	0.162	0.646	0.129
IV	0.013	0.091	0.016	0.040	0.027	0.187	0.037
V	0.016	0.091	0.031	0.080	0.054	0.272	0.054
CHECK SUMS	1.000	1.000	1.000	1.000	1.000		1.000

CHECK OF CONSISTANCY RATIO

MATRIX MULTIPLICATION		
	1.282	5.650
	3.687	6.676
	0.709	5.492
	0.190	5.099
	0.283	5.185

N = 5

lambda max = 28.1022737 divide by N = 5.620

Consistancy Index = CI = 0.155

Random Index = RI = 1.120

Consistancy Index = CI/RI = 0.138

Figure C8 Attributes
Tracking Improvements Very Strongly Preferred

SUMMARY OF PRIORITY WEIGHTS, EVALUATION RATINGS
AND WEIGHTED EVALUATIONS

	I Tracking	II Thru Put	III Interop	IV Risk	V Cost
	0.227	0.552	0.129	0.037	0.054
A - Modem	0.646	0.066	0.604	0.286	0.174
B - Control	0.064	0.319	0.326	0.087	0.120
C - Antenna	0.289	0.615	0.070	0.627	0.724
CHECK SUMS	1.000	1.000	1.000	1.000	1.000

	Weighted Evaluations
A - Modem	0.282
B - Control	0.241
C - Antenna	0.477
Check sum	1.000

Figure C9 Summary of Weighted Evaluations
Tracking Improvements Very Strongly Preferred

ATTRIBUTES

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	3	0.143	9	7
II	Thru Put	0.33	1	0.143	5	3
III	Interop	7	7	1	7	7
IV	Risk	0.11	0.2	0.143	1	0.5
V	Cost	0.14	0.33	0.143	2	1
	SUM	8.58	11.53	1.572	24	18.5

NOMALIZED MATRIX OF PAIRED COMPARISIONS

						SUM	PRIORITY WEIGHTS SUM/5
I	0.117	0.260	0.091	0.375	0.378	1.221	0.244
II	0.038	0.087	0.091	0.208	0.162	0.587	0.117
III	0.816	0.607	0.636	0.292	0.378	2.729	0.546
IV	0.013	0.017	0.091	0.042	0.027	0.190	0.038
V	0.016	0.029	0.091	0.083	0.054	0.273	0.055
CHECK SUMS	1.000	1.000	1.000	1.000	1.000		1.000

CHECK OF CONSISTANCY RATIO

MATRIX MULTIPLICATION		
1.399	5.727	
0.630	5.368	
3.725	6.825	for N=5
0.194	5.101	
0.282	5.151	

lambda max = 28.1713608 divide by N = 5.634

Consistancy Index = CI = 0.159

Random Index = RI = 1.120

Consistancy Index = CI/RI = 0.142

Figure C10 Attributes
Interoperability Improvements Very Strongly Preferred

SUMMARY OF PRIORITY WEIGHTS, EVALUATION RATINGS AND WEIGHTED EVALUATIONS

	I Tracking	II Thru Put	III Interop	IV Risk	V Cost
	0.244	0.117	0.546	0.038	0.055
A - Modem	0.646	0.066	0.604	0.286	0.174
B - Control	0.064	0.319	0.326	0.087	0.102
C - Antenna	0.289	0.615	0.070	0.627	0.724
CHECK SUMS	1.000	1.000	1.000	1.000	1.000

Weighted Evaluations	
A - Modem	0.516
B - Control	0.240
C - Antenna	0.244
Check sum	1.000

Figure C11 Summary of Weighted Evaluations
Interoperability Improvements Very Strongly Preferred

ATTRIBUTES

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	3	2	0.143	7
II	Thru Put	0.33	1	0.5	0.143	3
III	Interop	0.5	2	1	0.143	3
IV	Risk	7	7	7	1	7
V	Cost	0.14	0.33	0.33	0.143	1
	SUM	8.97	13.33	10.83	1.572	21

NOMALIZED MATRIX OF PAIRED COMPARISIONS

						SUM	PRIORITY WEIGHTS SUM/5
I	0.111	0.225	0.185	0.091	0.333	0.946	0.189
II	0.037	0.075	0.046	0.091	0.143	0.392	0.078
III	0.056	0.150	0.092	0.091	0.143	0.532	0.106
IV	0.780	0.525	0.646	0.636	0.333	2.921	0.584
V	0.016	0.025	0.030	0.091	0.048	0.209	0.042
CHECK SUMS	1.000	1.000	1.000	1.000	1.000		1.000

CHECK OF CONSISTANCY RATIO

MATRIX MULTIPLICATION			
	1.014	5.361	
	0.403	5.145	for N=5
	0.567	5.328	
	3.494	5.981	
	0.213	5.082	

lambda max = 26.8971 divide by N = 5.379

Consistancy Index = CI = 0.095

Random Index = RI = 1.120

Consistancy Index = CI/RI = 0.085

Figure C12 Attributes
Minimum Risk Very Strongly Preferred

SUMMARY OF PRIORITY WEIGHTS, EVALUATION RATINGS
AND WEIGHTED EVALUATIONS

	I Tracking	II Thru Put	III Interop	IV Risk	V Cost	
	0.189	0.078	0.106	0.584	0.042	1.000
A - Modem	0.646	0.066	0.604	0.286	0.590	
B - Control	0.064	0.319	0.326	0.087	0.085	
C - Antenna	0.289	0.615	0.070	0.627	0.325	
CHECK SUMS	1.000	1.000	1.000	1.000	1.000	

Weighted Evaluations

A - Modem	0.383
B - Control	0.126
C - Antenna	0.491
Check sum	1.000

Figure C13 Summary of Weighted Evaluations
Minimum Risk Very Strongly Preferred

ATTRIBUTES

MATRIX OF PAIRED COMPARISONS

		I	II	III	IV	V
I	Tracking	1	3	2	9	0.143
II	Thru Put	0.33	1	0.5	5	0.143
III	Interop	0.5	2	1	6	0.143
IV	Risk	0.11	0.2	0.17	1	0.143
V	Cost	7	7	7	7	1
	SUM	8.94	13.2	10.67	28	1.572

NOMALIZED MATRIX OF PAIRED COMPARISIONS

						SUM	PRIORITY WEIGHTS SUM/5
I	0.112	0.227	0.187	0.321	0.091	0.939	0.188
II	0.037	0.076	0.047	0.179	0.091	0.429	0.086
III	0.056	0.152	0.094	0.214	0.091	0.606	0.121
IV	0.012	0.015	0.016	0.036	0.091	0.170	0.034
V	0.783	0.530	0.656	0.250	0.636	2.855	0.571
CHECK SUMS	1.000	1.000	1.000	1.000	1.000		1.000

CHECK OF CONSISTANCY RATIO

MATRIX MULTIPLICATION			
	1.076	5.728	
	0.460	5.362	
	0.673	5.545	for N=5
	0.174	5.119	
	3.573	6.257	

lambda max = 28.0114 divide by N = 5.602

Consistancy Index = CI = 0.151

Random Index = RI = 1.120

Consistancy Index = CI/RI = 0.134

Figure C14 Attributes
Minimum Cost Very Strongly Preferred

SUMMARY OF PRIORITY WEIGHTS, EVALUATION RATINGS AND WEIGHTED EVALUATIONS

	I Tracking	II Thru Put	III Interop	IV Risk	V Cost
	0.188	0.086	0.121	0.034	0.571
A - Modem	0.646	0.066	0.604	0.286	0.174
B - Control	0.064	0.319	0.326	0.087	0.102
C - Antenna	0.289	0.615	0.070	0.627	0.724
CHECK SUMS	1.000	1.000	1.000	1.000	1.000

	Weighted Evaluations
A - Modem	0.310
B - Control	0.140
C - Antenna	0.550
Check sum	1.000

Figure C15 Summary of Weighted Evaluations
Minimum Cost Very Strongly Preferred

APPENDIX D

ALTERNATE COST BENEFIT APPROACH

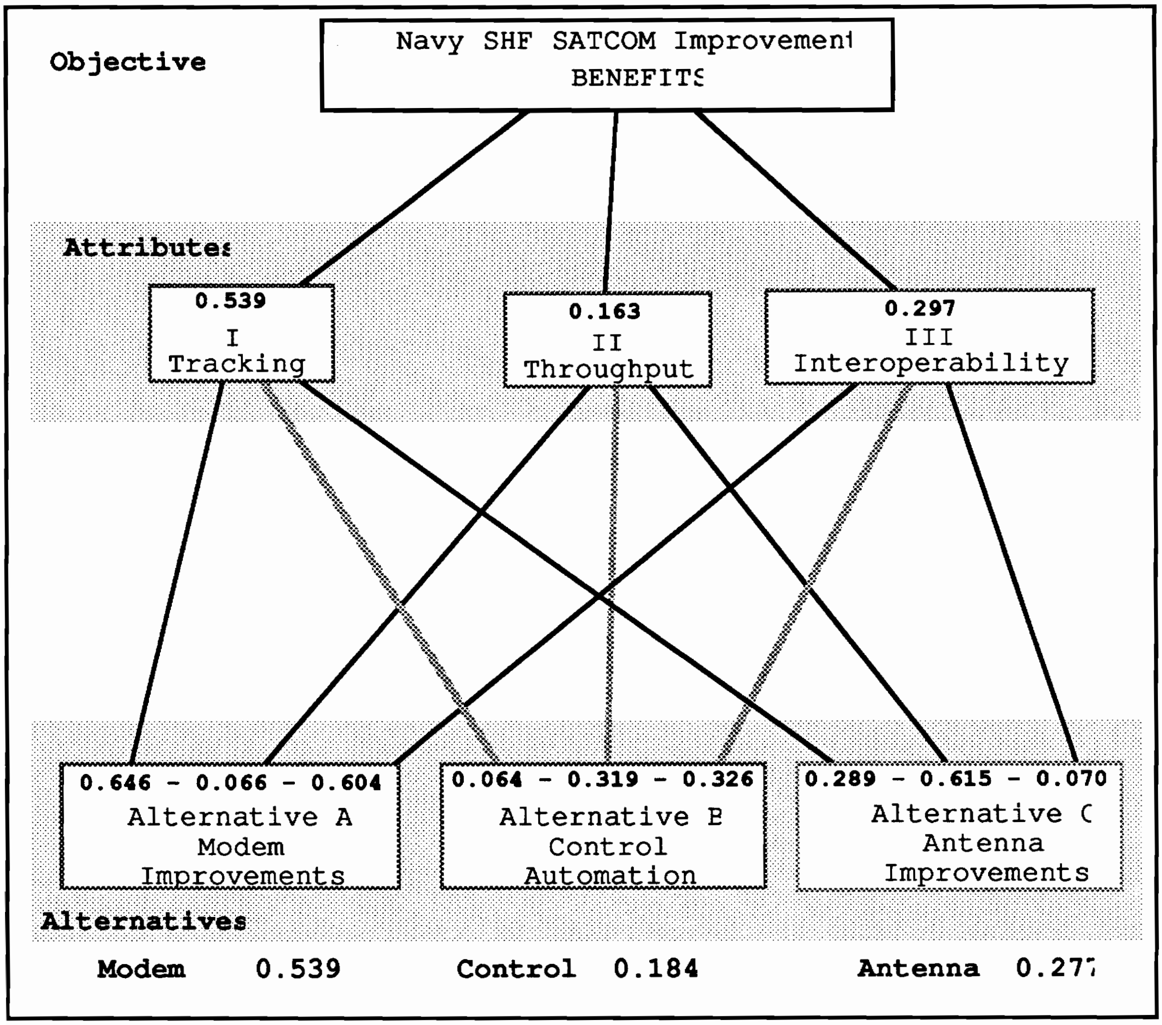

Figure D1 Benefits Hierarchy

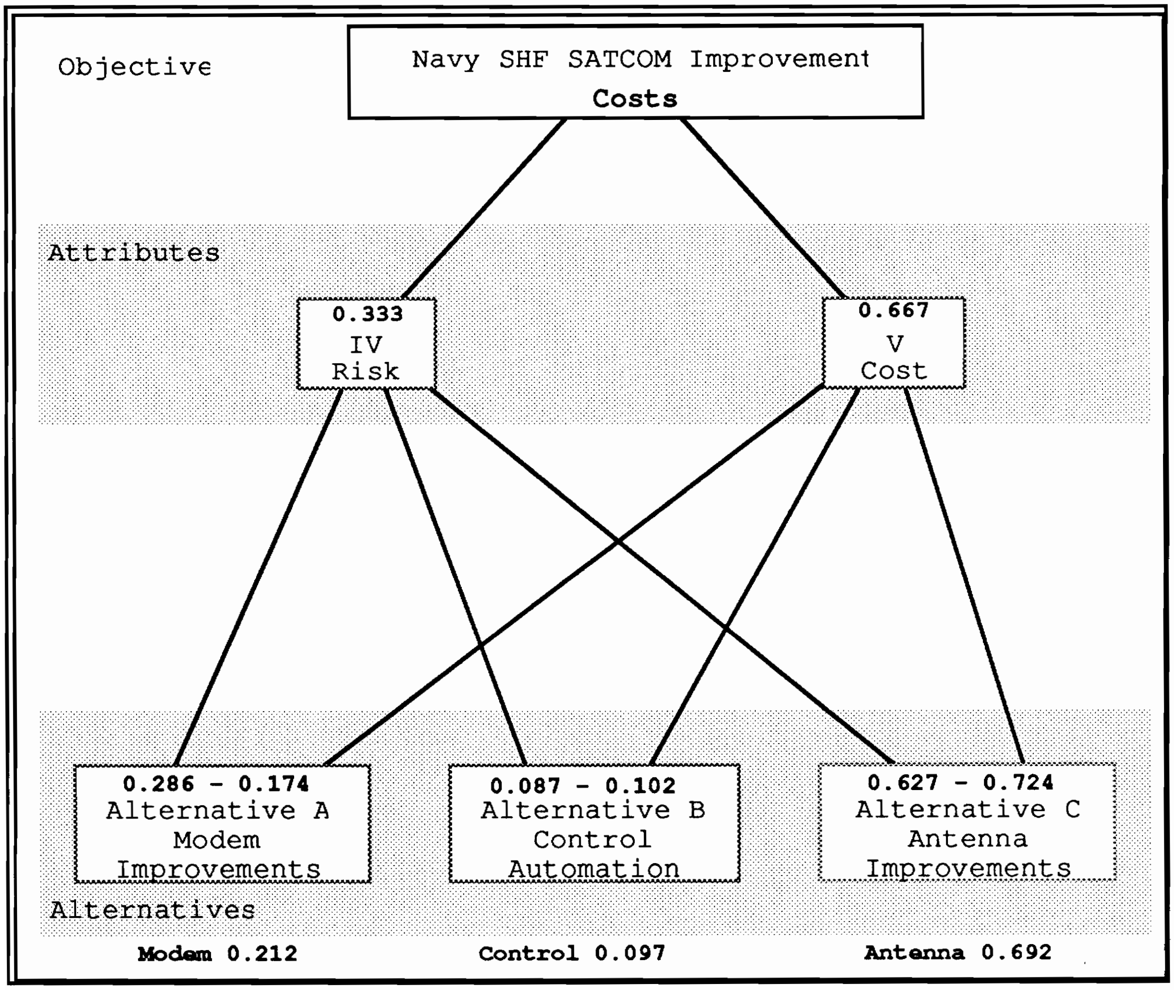

Figure D2 Costs Hierarchy

Table D1 Costs/Benefit Comparison

	Benefits		Costs		Weighted Scores
Modem	**0.539**	X	**0.212**	=	**0.353**
Control	**0.184**	X	**0.097**	=	**0.055**
Antenna	**0.277**	X	**0.692**	=	**0.592**

APPENDIX E

GLOSSARY

ACOC	Area communications operations center
AFSAT	Air Force satellite
AHP	Analytic Hierarchy Process
AJ	Antijam
AUTODIN	Automatic digital network
B	Bandwidth
BER	Bit error rate
bps	Bits per second
BPSK	Binary phase shift keying
BW	Bandwidth
C/kT	Carrier-to-noise density ratio
C/N	Carrier-to-noise ratio
C^2	Command and control
C4S	Center for Communications Command and Control Systems
CCC	Critical control circuit
CD/CPS	Control and display/computer and peripheral subsystem
CDASA	Contingency DSCS automatic Spectrum Analyzer
CDECS	Contingency DSCS ECCM Control Subsystem
CDFCS	Contingency DSCS FDMA control system
CDMA	Code division multiple access

CDOCS	Contingency DSCS operations support system
CDOSS	Contingency DSCS Operational Support System
CINC	Commander in Chief
CINCLANTFLT	Commander in Chief Atlantic Fleet
CINCPACFLT	Commander in Chief Pacific Fleet
CINCUSNAVEUR	Commander in Chief U.S. Naval Forces Europe
Code B 440	DCA Satellite Operations Division
CPU	Central processing unit
CSVL	Control Secure Voice Link
CSVT	Control Secure Voice Terminal
DASA	DSCS Automatic Spectrum Analyzer
db	decibel
dbm	decibel milliwatts
dbW	decibel watts
DCA	Defense Communications Agency
DCAOCC	DCA Operations Control enter
DCEC	Defense Communications Engineering Center
DCS	Defense Communications System
DECS	DSCS ECCM Control Subsystem
DFCS	DSCS FDMA Control Subsystem
DGCL	DSCS Ground Mobile Force Control Link
DOCC	DCA Operations Control Complex
DOCS	DSCS Operations Control Complex
DoD	Department of Defense
DOSS	DSCS Operational Support System

DSCS	Defense Satellite Communications System
DSCSOC	DSCS Operations Center
EASTLANT	Eastern Atlantic
EASTPAC	Eastern Pacific
EC	Earth coverage
ECCM	Electronic counter-counter measures
EIRP	Effective isotopic radiated power
ETI/CCTS	Earth terminal interface / checkout,calibration and test subsystem
FDMA	Frequency division multiple access
FLTCINC	Fleet Commander in Chief
G/T	Gain divided by thermal noise
GDA	Gimballed dish antenna
GMF	Ground Mobile Force
GHz	Giga (10^9) Hertz
Hz	Hertz
IO	Indian Ocean
LAN	Local area network
LANT	Atlantic
LRM	Low rate multiplexer
MED	Mediterranean
MHz	MEGAHERTZ
MMI	Man machine interface
NAVCAMS	Naval Area Communications Station
NAVCOMTELCOM	Naval Computer and Telecommunications Command

NCT	Network control terminal
NOSC	Naval Ocean Systems Center
NT	Network terminal
OCC	Operator Control Console
PAC	Pacific
PBX	Private Branch Exchange
PCS	Pilot Control System
RFIS	Radio Frequency Interface Subsystem
SATCOM	Satellite Communications
SCCE	Satellite Configuration Control Element
SPM	Spread power monitor
STU III	Secure Telephone Unit III
SURTASS	Surveillance towed array sensor system
TCCC	Terrestrial critical control circuit
TCS	Telemetry control subsystem
TDMA	Time division multiple access
URDB	User requirements data base
WESTLANT	Western Atlantic
WESTPAC	Western Pacific