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DATA STORAGE DEVICES FOR
AIR FORCE SPACE COMMAND:
A COMPARATIVE ANALYSIS

THESIS

Darryl E. Mosley, First Lieutenant, USAF

AFIT/GIR/LAL/98S-8

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AFIT/GIR/LAL/98S-8

DATA STORAGE DEVICES FOR AIR FORCE SPACE COMMAND: A COMPARATIVE ANALYSIS

THESIS

Presented to the Faculty of the Graduate School of Logistics and Acquisition Management of the Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Information Resource Management

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First Lieutenant, USAF

September 1998

Approved for public release; distribution unlimited

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Darryl E. Mosley

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Abstract

Two of Air Force Space Command's primary missions are ballistic missile warning and global navigation, accomplished by commanding and controlling Defense Support Program and Global Positioning System satellites respectively. The computerized ground control system, called the satellite command and control system (CCS) used to perform command and control of the satellites currently uses antiquated peripheral storage devices. These storage devices are critical components, but are often prone to failure, possibly resulting in adverse mission impact. The Air Force must choose an alternative storage device for use in conjunction with CCS in order to accommodate planned operations tempo increases.

This thesis compares five alternative storage devices based on seven criteria supplied by the sponsor. The comparison method used in this thesis is the Analytical Hierarchy Process model. The results of this study indicate that Amdahl's Spectris Platinum storage system will most effectively meet Air Force Space Command's needs in terms of the seven criteria each alternative was evaluated against.

DATA STORAGE DEVICES FOR AIR FORCE SPACE COMMAND: A COMPARATIVE ANALYSIS

I. Introduction

Background

Two of Air Force Space Command's current primary missions are to provide strategic and tactical missile launch detection and to provide 24 hour global navigation. As the Air Force continues its current emphasis on moving from being strictly an Air Force to becoming an Air and Space Force, the importance of these missions increases. Air Force Space Command accomplishes its missile detection and global navigation missions through command and control of Defense Support Program (DSP) satellites and Global Position System (GPS) satellites, respectively. However, Air Force Space Command's effectiveness in accomplishing these missions is potentially hampered by the inability of some of its current antiquated mission critical equipment to perform their functions.

One of the Air Force Space Command units responsible for performing these missions is the 1st Space Operations Squadron (1SOPS) located at Shriever AFB, Colorado. 1SOPS will serve as the subject organization for this thesis. The 1SOPS space operations crews establish contact with the satellite using the satellite command and control system

(CCS), the computer mainframe system within the space operations center (SOC) that issues commands to and receives and manipulates the data from the satellite. To make contact with the satellite, the space operations crew first uses CCS to establish a communication link with the remote tracking station (RTS, the large ground antenna which completes the communication link between CCS and the target satellite) closest to the satellite's orbit path. The RTS receives the commands from CCS and forwards them to the satellite. It receives the subsequent transmissions from the satellite and forwards them back to CCS.

The satellites transmit their data at such high data rates it is impossible for the space operations crews to perform their required analysis of the data in real time. Therefore, the data is processed by CCS and transferred to storage for later retrieval. Although CCS' processors are capable of matching the satellite's transmission speed, the system's storage units typically are not.

CCS is composed of a myriad of processors, controllers, storage devices, and communications channels. The main processor for the 1SOPS system is the Enterprise System/9000 Processor Complex, which contains two central processing units (CPUs). The CPUs are the brains of the system. The processor control element (PCE) monitors the performance of the processor complex through the use of various diagnostic tools. As input/output errors occur, the PCE logs them in an on-line database. Input/Output (I/O), the method of transferring data, is performed by a chain of processors and subprocessors: the main CPU, the channel, the channel controller (or control unit), and the device using the data. Each processor has a number of independent I/O paths available to it. These paths are called channels. The channels provide the connection between the device and the CPU by ensuring a common interface exists between the two. The channel controller allows one channel to handle multiple devices and converts the data into the proper format required by the device and the processor, respectively. All data flowing through the system (such as commands being issued, system requests or responses, information being received from an outside source) will reside in real memory at some point in time. Real memory is the actual physical memory installed on the mainframe and is where data is processed and instructions are executed. The 1SOPS system has a total of 256 megabytes (MB) of real memory. Real memory is used by the system to store and execute the data and instructions it needs to perform its functions. The amount of resident or real memory on a system also determines how much incoming data CCS can store and access immediately. 256 MB is an insufficient amount of real memory to allow CCS to store and manipulate any significant amount of data in addition to the required instructions and commands.

Due to this memory limitation, CCS relies heavily on auxiliary storage in the form of the direct access storage device (DASD). Through a technique called paging, dividing the data into 4 kilobyte (KB) blocks to allow continuous swapping to and from the mainframe, the DASD allows the system to manipulate an amount of information far in excess of the real memory constraint of 256MB. The DASDs consist of two main items: the Head of String (HOS) and the Head Disk Assembly (HDA). The HOS is the device controller and acts as a traffic cop; interpreting and executing commands, detecting data transfer errors, and formatting data for transfer. The HDA contains the recording media (disks) and the read/write mechanisms. The DASDs contain all the software, files, and databases necessary to perform satellite operations.

Statement of Problem

This research is directed at investigating possible hardware alternatives for data storage for the ES9000 satellite command and control system. The IBM 3380/3390 DASDs currently used have a recommended service life of 33,000 hours. At this point, the service life of these units has exceeded 40,000 hours. DASD units of this type utilize "mainframe class" disks as their storage medium.

These disks are larger and slower than some of the newer disks such as smaller, "personal computer" (PC) type disks, and offer deficient performance in comparison. Although mainframe class disk access speed on DASDs has increased roughly 4-fold during the past 10 years, processor speed has increased about 24-fold during this same period (Coyne, 1992:1). The age of the equipment and the lag in access speed has resulted in such problems as periodic hardware failure and data transfer bottlenecks, both of which may adversely impact the mission.

Research Objective

This study will research and select possible alternative storage devices and perform a comparative analysis against the IBM 3380/3390 DASDs currently being used by 1SOPS in conjunction with its IBM ES9000 processor complex to perform its command and control mission of DSP and GPS satellites. The intent of this research is to identify potential storage hardware options capable of alleviating the current problems being experienced by 1SOPS and of supporting Air Force Space Command's future information technology architecture plans by performing the following:

1. Identify constraints to which all acceptable alternative data storage devices will be subject.

2. Formulate criteria for evaluating the suitability and merits of potential data storage devices.
3. Evaluate the potential, alternative storage devices using these criteria to determine if significant advantages or disadvantages are associated with any.
4. Incorporate the evaluation results into a recommendation concerning which data storage device is most appropriate.

Thesis Overview

Chapter Two discusses literature pertinent to this research, such as background on commercial industry history and development efforts and the type of product lines those efforts will be concentrating on, as well as relevant federal, Air Force, and Major Command level requirements for information systems. Chapter Three discusses the methodology used to conduct the study and address the research objectives. It outlines the data collection plan, the method for evaluating the merits of the potential alternate storage devices, and addresses the assumptions and limitations made during this study. In Chapter Four, the analysis is conducted and the results discussed. Chapter Five makes recommendations for Air Force Space Command's plans for modifying its satellite CCS and identify some potential areas of future research.

II. Literature Review

Commercial Industry Background and Trends

The ability to communicate, manipulate, and store large quantities of data has become increasingly important to our nation's future. One major problem that must be addressed with regard to this issue is how to develop a system capable of providing this ability. Research has driven major advances in information technology over the last decade. The focus of this research has been the use and manipulation of information. Although this work has yielded astronomical increases in processor performance, we are only now realizing the need for commensurate increases in the ability to transfer, provide access to, and store the information. Processors are able to move 100 million to 1 billion bits of information per second, while current storage systems are only able to move 10 to 20 million bits per second (Coyne and Watson, 1992:626). This supports the position presented by Matick (1977). In his book, "Computer Storage Systems and Technology", he stated that the ability to utilize computers to derive solutions did not depend on processor power as much as it depends on storage capacity and speed. Storage requirements and processing speed are the bottlenecks in information system performance. Increases in the CPU or processing speeds require corresponding increases in the storage system's ability to transfer and store that same data.

The realization of the importance of the storage subsystem seems slow in coming when one considers the cost of the storage subsystem typically can approach 50% of the total system hardware cost (Gibson et al., 1996:779). Nevertheless, the development of improved storage systems is fast becoming a vital and expansive market. In 1994, storage hardware sales exceeded $40 billion. In the following years, those sales have doubled and are expected to sustain an annual growth of about 60%. This sales growth has been accompanied by a corresponding decrease in cost per byte of approximately 50% per year. In spite of the recent advances in development, the capabilities of storage systems continue to lag behind the capabilities of the available processors (Gibson et al., 1996:779).

Typical storage system components include magnetic disks, parallel disk arrays, optical disks, magnetic tape, and the software to manage the components. Of these, the majority of devices employ magnetic disks as the storage medium (as is the case with CCS). With organizations relying increasingly on the immediate availability of required information in order to sustain operations, systems must be able to store more and provide faster access to that information. In order to develop storage systems capable of fulfilling these needs, system designers must overcome problems in four predominant areas - performance, persistence and reliability, scale, and ease of use (Gibson et al., 1996:780-782).

Although progress is being made in improving overall magnetic disk performance, it is taking place at an uneven rate. Bandwidths have recently been increasing by about 40% per year, allowing faster data transmission, but that is only half of the battle. The positioning time, which is the time it takes to get the disk head and media positioned correctly for access, has seen improvements in much smaller increments because it is a primarily mechanical motion subject to physical constraints such as inertia, acceleration, and arm stiffness which are more difficult to overcome (Lee and Katz, 1993:101).

Persistence, which is ensuring stored information survives through system restarts, and reliability, which is the ability to maintain the stored information in the midst of a multitude of failures, are characteristics all storage systems must possess in order to be effective. The focus is on ensuring the integrity of the information or the degree to which the information is not damaged by having been stored and retrieved. These characteristics must be designed into any new storage system (Carey et al., 1994:384-385).

Scale is another area of consideration that must be managed. The term scale is meant to imply both storage capacity and bandwidth. An organization's information needs must be accurately assessed in order to determine the capacity requirements of the storage system. It generally takes large systems to store large amounts of information. Larger storage systems require more devices. Gibson et al. (1996) point out that a system with a large number of devices is typically hard to configure, monitor, and manage. Also, the information stored on these systems will be accessed by a variety of users and applications, therefore the naming conventions used to identify the various pieces of information must be standardized to allow the required access.

Bandwidth is the other half of the equation in managing scale. Simply possessing the ability to store huge amounts of information is not sufficient. That information must be transmitted quickly enough for the user to make effective use of it. Large systems have to meet enormous bandwidth requirements in order to transmit the enormous amounts of accessed information at the required speed (Coyne and Watson, 1992:627-628).

The fourth problem area that must be managed by storage system designers is ease of use. Many of the tasks that comprise the acts of accessing and storing information are of no concern to the users or the applications making the request. They simply want the information that was requested. The challenge is to design the system in such a way that allows these requests to be met while hiding the complexity of performing that function from the user or application making the request (Gibson et al., 1996:781-782).

Information technology experts argue these four issues cannot be addressed independently because they often impact one another. A great deal of the complexity in storage systems is caused by the attempts to meet the goals of one of these issues concurrently with the goals of another. The ability to effectively address these four issues simultaneously is key in determining the correct solution for meeting an organization's storage needs.

The current industry trend in developing mainframe storage is a movement towards focusing on the development of RAID, network storage, and optical media as solutions for meeting large-scale storage needs (Coyne and Watson, 1992:626-628).

RAID is an acronym standing for Redundant Array of Inexpensive Disks. Basically, the technology involves using parallelism, employing multiple disks simultaneously, to improve aggregate input/output performance, improve data access and availability, and support ease of maintenance and data protection. Rather than having just one magnetic disk per storage device, RAID storage devices have multiple disks (typically from three to nine). In this manner, data is striped, distributed transparently, across multiple disks. Disk arrays access these multiple disks in parallel, achieving both higher data transfer rates on large data accesses and higher I/O rates on small data accesses. If a disk within the array fails, the data is not lost because it is stored on more than one disk. The failed disk is merely removed and replaced. Data is copied onto the new disk and operations continue.

Network connected storage concepts use network attached storage devices to communicate directly with supercomputers and other clients while being controlled by a storage system management and control entity. By attaching the storage devices directly to the network, higher data rates can be achieved than could otherwise be supported under the traditional processor-centered storage server configurations.

Some of the leading optical media techniques being employed are optical disc changers and compact disk-read only memory (CD-ROM) network servers. They provide high capacity and long media life at a relatively low cost per byte stored. Basic optical drives read and write optical media, but require that discs be changed manually by the user. Robotic changers can be employed to manage a large number of disks, but only a few can be mounted simultaneously.

Now that different classes of potential storage device types have been identified, government and departmental policies that would affect any decision on which type of device would be employed must be considered.

Federal Information Technology Policy

In this era of diminishing availability of resources, cost management has become an increasingly significant focus for the federal government. Cost is often the main driver in the decision making process when deciding whether or not to acquire new technology. In 1996, the United States Congress passed the Information Technology Management Reform Act (ITMRA). The ITMRA covers the reformation of the acquisition process for Information Technology (IT) intended for use within the Federal Government. Under its guidelines, the heads of all executive agencies requesting the use of federal funds for the purpose of IT purchase "shall design and implement a process for maximizing the value and assessing and managing the risks of the information technology acquisitions…" This legislation illustrates the government's concern with the bottom line with specific regard to information technology.

US Air Force Information Management Policy

VISTAS is the Air Force Information Resource Management Strategic Plan, outlining the Air Force's approach to its information management of the future. The information resource management program supports the Air Force mission and vision by:

> Providing customers with reliable, timely access to information consistent with their needs. Minimizing the cost of collecting, maintaining, and using information and acquiring systems in an efficient, effective, and economic manner. Developing integrated information and technical architectures which use information resources to deliver maximum capability to the user by focusing on the information needed. (Department of the Air Force, 1998:3)

Subordinate to the higher federal policy that concentrates on cost, the Air Force's policy is to ensure its information technology will be both efficient and effective in its overall performance.

US Air Force Space Command Requirements

Air Force Space Command's focus is also system performance. Additionally, as technology advances, mission requirements will change as new capabilities are discovered. Therefore, lower level factors which impact performance must be addressed.

The Operational Requirements Document for Satellite Control, AFSPC ORD 002-94-I/II, Para. 1.3, mandates that the satellite command and control system will be fault tolerant with no single point of failure. Any changes and upgrades will be implemented with the intent to "reduce the overall cost of conducting O&M with a goal of improving current levels of security, reliability, dependability, and mission effectiveness" (Department of the Air Force, 1995:1-2). Although the ORD does not attempt to identify a specific design for the next evolution of the satellite command and control system (CCS), it does stipulate that the next system will be a distributed, open system architecture. Additionally, it mandates that any proposed, new capability will "permit increased expandability to accommodate new mission requirements, interoperability, and interface with Department of Defense (DoD) and other satellite command and control capabilities" (Department of the Air Force, 1995:1-8). The ORD states the preferred approach to improving capabilities is by incrementally upgrading select portions of the system in order to minimize risk to current operations. Air Force Space Command's policy on information technology acquisition emphasizes minimizing cost, improving flexibility and interoperability, and avoiding interruption of mission accomplishment.

Federal Contracting Competition Guidelines

The Competition in Contracting Act of 1984 (CICA) mandated that "full and open competition" be practiced in all federal acquisitions. This mandate is achieved primarily through the use of two basic methods of procurement: 1) Sealed Bidding and 2) Competitive Proposals. According to CICA, sealed bidding will be used provided a) time permits, b) price and other price-related factors will be the basis of the contract award, c) there is no need to discuss the bids with the responding sources, and d) receipt of more than one sealed bid can be reasonably expected. One of the main objectives of the sealed bidding process is to ensure all interested parties have a reasonable opportunity to enter into a business relationship with the government. The basic process is as follows. The government publishes its requirement, usually in the periodical, The Commerce Business Daily, then solicits invitations for bids. The bids are received, reviewed and, if necessary, corrected. Selection is then made. CICA directs that, if the contract is awarded at all, it must be awarded to the bidder with the lowest responsive bid (Arnavas and Ruberry, 1994:4-3).

In the event that any of the four conditions requiring use of the sealed bid process are not present, the contracting officer needs only to provide written explanation citing which of the four has not been met and then may use any combination of competitive procedures. Typically, the procurement will be conducted using competitive negotiations. This approach allows the contracting officer to be considerably more subjective in determining which contractor will win the award. Under this approach, the contracting officer is allowed to consider such factors as the offeror's experience, the offeror's technical and management capability, and contract type the offeror is willing to accept. This may actually result in the contract being awarded to an offeror other than the one submitting the lowest cost bid.

Another point which may prove to be of special interest in this study are the exemptions Congress has granted to two types of purchases. In 1994, Congress established an exemption from the requirement for full and open competition for "micro-purchases" of $2500 or less. Since the information technology being researched in this study will have a cost far in excess of this micro-purchase threshold, this particular exemption is not a factor in this study. However, Congress also established an exemption for procurements not exceeding $100,000 using electronic commerce methods. Given the global nature of business and economies, it is highly probable that the vendors capable of being deemed responsive in any procurement action that could possibly result from this study would possess the required electronic commerce capability (Arnavas and Ruberry, 1994:2-19).

Comparison Methods

One can argue that performing a comparative analysis is equivalent to the decision making or problem solving processes involving multiple alternatives. For the purposes of this study, that argument will be accepted as valid. The study of decision making has yielded a variety of very effective models, both qualitative and quantitative. The decision making process and a couple of the more prominent decision making models will be briefly discussed below.

Systems Analysis Approach. In his book, The Decision-Makers Handbook, Alexander Cornell states the systems analysis approach is the foundation upon which all decision models are based. This approach is characterized by five phases: 1) Formulation, 2) Search, 3) Evaluation, 4) Interpretation, and 5) Verification (Cornell, 1980:28-36).

The Formulation phase involves defining the system to be studied or the subject about which a decision is to be made. The situation in which the decision is to take place must be understood as well. This is the environment and the conditions present in which the decision will take place. The objective to be achieved must be clearly stated and understood and any relevant assumptions must be identified.

The Search phase involves identifying alternatives and measuring the costs of each alternative. In addition, the level of effectiveness of each alternative must be measured as well.

In the Evaluation phase, the decision-maker evaluates the alternatives. The criteria for evaluation are determined and applied to each alternative.

The Interpretation phase is the act of making a choice. This act of choosing may be in the form of a recommendation to a higher authority. Typically, it consists of implementation. This can be another series of steps, such as the acquisition process within the Department of Defense. Usually, however, this means the commitment of resources in support of the alternative selected.

The final phase is verification of results. This is the actual go or no go decision. At this point, the primary and secondary effects of the decision are reevaluated for a final time (Cornell, 1980:28-36).

Decision Trees. Decision trees are a popular decision-making tool many decision-makers use to help make complex decisions with multiple variables. The decision tree can be extremely effective in clarifying the different choices, risks, payoffs, and effects of the various alternatives for the decision-maker. The decision tree is made up of a series of branches and nodes. Each node is a choice or alternative called a chance event. Following each node is a series of branches representing and alternative course of action or decision. Following each alternative course out to completion, the decision tree provides the decision-maker with an associated payoff for following that course of action (Greenwood, 1969:83-92).

Additive Preference. The additive preference approach is an effective means of assisting the decision-maker in selecting among alternatives with conflicting objectives. This approach is useful when the decision-maker must also consider various trade-offs in the utility offered by those alternatives. The additive utility function is one of the specific models used in this type of approach. This model allows the decision-maker to "calculate a utility score for each objective and then add the scores, weighting them appropriately according to the relative importance of the various objectives."

According to the model, there are individual utility functions ($U_m(x_m)$ for m different attributes x_m. Each utility function is valued between 0 and 1, from worst to best, for that particular objective. Weights, denoted as k_I, are assigned to each attribute to denote the relative importance of each as compared to the other attributes. All of the weights are positive and add up to 1. Finally, an attribute's utility is calculated by summing $k_I U_I x_I$ for each attribute, where I = 1. The alternative with the best utility function score will be selected (Clemen, 1996:536-540).

Analytical Hierarchy Process (AHP). The Analytical Hierarchy Process was developed by Thomas L. Saaty in an effort "to include and measure all important tangible and intangible, quantitatively measurable, and qualitative factors" (Saaty, 1980:1). According to Saaty, a hierarchy represents the "analysis of the most important elements in the situation" (Saaty, 1980: 17).

To summarize the AHP process, a problem is solved by following these four subsequent steps:

(1) First, Sum the elements in each row and normalize by dividing each sum by the total of all the sums, with the resulting sums now adding up to unity. The first entry of the resulting vector is the priority of the first element; the second entry is the priority of the second element and so on.

(2) Take the sum of the elements in each column and form the reciprocals of these sums. To normalize so that these numbers also add to unity, divide each reciprocal by the sum of the reciprocals.

(3) Divide the elements of each column by the sum of that column or, in other words, normalize the column. Then, add the elements in each resulting row and divide this sum by the number of elements in the row.

(4) Multiply the *n* elements in each row and take the *n*th root. Normalize the resulting numbers.

The element with the highest score is the best alternative (Saaty, 1980:17-19).

III. Methodology

Chapter Overview

This chapter describes the constraints provided by Air Force Space Command against which the selection of all acceptable alternative storage devices would be subject to, and the identification of those acceptable alternative storage devices. This chapter will also describe the data collection plan, the design methodology, and discuss the assumptions and limitations of this study.

Constraints

In order to conduct a more accurate comparison of data storage devices and to ensure this study addresses the proper concerns, the sponsor was asked to identify those factors most important in the selection of potential, replacement data storage devices. The most important factor was cost. In this era of ever shrinking budget dollars, the sponsor's main concern is minimizing the acquisition and lifecycle costs of follow-on systems.

The physical size of the unit is another serious concern. The space operations squadrons (SOPS) at Falcon Air Force Base are housed within secured vaults or modules of limited size. All equipment rests on raised floors able to support only a limited amount of weight per square foot.

Under the current circumstances, there is no possibility of expanding the areas within the modules where the information systems hardware is stored, therefore the height, width, and weight of all equipment is a concern. Under the present module configurations, the sponsor has noted the weight limit of the raised floor on which the storage units will rest can be increased from its current level of 1000 pounds per square foot to 1500 pounds per square foot. In addition to weight restrictions, any device selected will be subject to height and width constraints. Specifically, any storage device utilized must be no more than 281 square feet in size.

The third and final constraint identified by the sponsor was storage capacity, the amount of data the device is capable of storing. Any storage unit selected must possess a minimum total storage capacity of 25.2 gigabytes of data per unit. Although 1SOPS currently employs multiple devices to achieve this minimum level of storage capacity, the intent, as dictated by the sponsor, is to identify individual devices capable of meeting this minimum constraint.

Identification of Feasible Alternatives. The first step in identifying feasible alternatives was determining the type(s) of data storage device and technique that would be used. As mentioned earlier in chapter two, some of the leading techniques currently being concentrated on and developed by the commercial industry are RAID, network storage, and the use of optical media. In order to conform to Air Force Space Command's intent to modernize and improve the efficiency of its operations, the selected alternative will more than likely come from one of these newer leading edge techniques.

A review of the specifications of the current satellite command and control system was conducted in order to identify which of the leading data storage techniques being considered would be the most compatible. Based on the library research and vendor data gathered from manufacturers of the types of data storage devices compatible with the satellite command and control system of the subject organization, a list of feasible alternative devices was assembled.

Data Collection Plan

Information on the data storage devices under study and the evaluation criteria used to establish their relative merits were obtained from four sources:

1. Federal and Department of Defense reports and publications;
2. Business, industry, and professional association reports, pamphlets, brochures, standards, and correspondence;

3. Books and periodicals; and

4. Personal and telephone interviews.

To become familiar with the current system, its purpose, performance requirements, and performance shortfalls, a series of conference telephone interviews with officials from the Air Force 50th Space Wing (50SW/XP), 1st Space Operations Squadron (1SOPS/MA), and 50th Logistics Support Squadron (50LSS/SCO) were conducted. In addition to these telephone conference interviews, 10 subsequent individual telephone interviews were conducted with the 1SOPS/MA representative and 5 subsequent individual telephone interviews were conducted with the 50LSS/SCO representative in order to receive further clarification on the aforementioned issues. Each of the individuals within the 50SW, 1SOPS, and 50LSS contacted performed a key role in the establishment of system requirements, the operation of the system, and the maintenance of the system. In addition to the information and knowledge derived from these interviews, secondary data in the form of standards, regulations, reports, and intra-organizational correspondence was furnished on an on-going basis.

Following the initiation of the interview process, the next step in the data collection process was library research of appropriate books and periodicals. The results of this research formed the basis for the development of the initial bibliography and subsequent data retrieval and accumulation.

In conjunction with the library research, industry product data was gathered from leading manufacturers and retailers of mainframe data storage devices. This was accomplished through telephone interviews and electronic correspondence. Great care was taken to ensure each manufacturing and retail representative contacted received essentially the same information and request. The relevant purpose of the research effort was explained and the type of performance and cost data desired was clearly outlined. Initial responses by vendor representatives were used to establish the benchmark levels of performance and cost, with subsequent vendor responses used to validate those levels.

Consistency with other references was the main criteria used to subjectively assess the validity of each source; however, personal or employer related prejudice and the purpose of the information transmission (to advertise, educate, or investigate) was also considered.

Analysis Design

In order to evaluate and compare potential alternate data storage devices, criteria were developed and formulated in cooperation with the sponsor that incorporated compliance with the legal, policy, performance, and resource constraints in effect at the time of this research and that accounted for the needs of the Air Force and system users.

Selected Criteria. Seven factors were selected as measurement devices against which to compare the merits of potential alternatives. They are, in decreasing order of importance:

1. Purchase Price. How much will it cost to initially purchase the device?
2. Capacity. How much data is the device capable of storing?
3. Size. What are the unit's physical dimensions (height, width, depth)?
4. Weight. How much does it weigh?
5. Mean Time to Failure. What is the expected service life of the device? How many hours of consecutive operation will the device be capable of?
6. Maintenance Costs. How available is the required expertise, and how much does it cost to ensure the required expertise is available?
7. Power. How much power, measured in either Kilowatts (kWhs) or British Thermal Units (BTUs), will this device require to function?

Systems Evaluation

The Analytic Hierarchy Process Model (AHP) developed by Thomas L. Saaty and described by Cliff T. Ragsdale (Ragsdale, 1997) will be used to evaluate the alternative devices according to the seven criteria listed in this study. Using this model, a pairwise comparison matrix for each alternative on each criterion is created using a scale, such as the one below, to rate them (Ragsdale, 1997:717-718).

Table 1. Scale for Pairwise Comparisons in AHP

Value	Preference
1	Equally Preferred
2	Equally to Moderately Preferred
3	Moderately Preferred
4	Moderately to Strongly Preferred
5	Strongly Preferred
6	Strongly to Very Strongly Preferred
7	Very Strongly Preferred
8	Very Strongly to Extremely Preferred
9	Extremely Preferred

In constructing the matrix, each alternative is compared to and rated against each of the other alternatives. The matrix will show all alternatives listed along both the rows and columns of the matrix. An alternative along the row compared to itself along the column will receive a score of 1 or equally preferred. That same alternative along the row compared to the next alternative along the column will receive a score indicative of the decision-maker's degree of preference of the first alternative over the next. Once the decision-maker's preference between the first alternative and the second is determined, the preference rating between the second preference and the first can be derived by taking the reciprocal score of the first and the second alternative's comparison. In this manner, the entire pairwise comparison matrix for each criterion can be completed. The final row of the comparison matrix will be the sum of each of the columns.

After the pairwise comparisons are performed, they must be normalized. In order to construct a normalized matrix, each entry in the matrix is divided by its corresponding column sum from the pairwise comparison matrix. The average of each row in the normalized matrix is then used as the score for each alternative on the respective criterion being considered. This final score is used to determine which alternative is more attractive with regard to the criterion it is being evaluated against.

The next issue is to ensure the consistency of the original pairwise comparison matrix preferences. The consistency measure for each alternative is calculated by summing the product of each alternative's normalized matrix score and the associated row's individual pairwise matrix scores, then dividing that figure by the alternative's normalized matrix score. The goal is that each alternative's consistency measure will equal the number of alternatives being considered, implying the decision-maker was consistent in stating his preferences. However, some amount of inconsistency is not unusual and the stated preferences will still be considered reasonable, provided the amount of inconsistency is not excessive.

To determine the level of inconsistency, consistency indexes and consistency ratios are computed as follows:

Where:

λ = The average consistency measure for all alternatives

n = The number of alternatives

RI = The appropriate random index as derived from the table below (Ragsdale, 1997)

Table 2. Values of RI For Use in AHP

N	RI
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41

The consistency index (CI) equals λ minus n divided by n minus 1. The consistency ratio (CR) equals CI divided by RI. If the CR is less than or equal to 0.10, the degree of consistency in the pairwise comparison matrix is satisfactory.

Next, the criterion weights must be determined in order to indicate the relative importance of each of the criteria to the decision-maker. The same pairwise comparison process used to generate scores the alternative on each criteria is also used to generate criterion weights.

The final step is to calculate the weighted average scores for each decision alternative. All weighted average scores for each alternative are summed. The alternative with the highest weighted average score is the option that should be selected (Ragsdale, 1997:717-724).

Assumptions and Limitations

Assumptions. This research assumes all constraints and criteria identified at the outset of this effort will remain constant for the entirety of this research process. The current properties and configuration of the command and control system (CCS) being used by the subject organization to conduct satellite operations will remain the same. Even though preliminary discussions covering the design of the next generation of CCS are taking place, there is no definite word on which direction those discussions are heading. Any new requirements for CCS design and configuration which could result from these discussions, such as moving to a totally distributed architecture, could possibly affect the accuracy and the results of this study. Any improvements or enhancements will take place in a modular fashion in accordance with the current CCS ORD.

Limitations. This research effort related strictly to the satellite command and control system being utilized by the 50th Space Wing's 1st Space Operations Squadron. Other space operations squadrons use slightly different configurations or computer systems altogether, depending upon what type of satellites they are responsible for commanding. The differences in system design and configuration, and mission requirements result in different stress levels being placed on the respective systems. These differences are the reason for the exclusion of the other space operations squadrons from this study. The reason the 1st Space Operations Squadron was selected as the subject organization was its current system and configuration is similar to the 3rd and 5th Space Operations Squadrons and its mission is similar to the 2nd Space Operations Squadron's.

Additionally, when attempting to identify and evaluate the feasibility of potential alternate storage units, only those vendors rated in the top five in the industry were considered. Admittedly, there is a large possibility that other vendors could supply products that would fit the parameters of this study and meet the mission needs of the subject organization. However, the decision to restrict inclusion to only those companies who enjoy the largest market share was made in an effort to ensure that an acceptable level of quality, performance, and support would be received from their product. In addition, this course of action minimizes any concerns about the solvency of the companies involved and their ability to remain going concerns. It would pointless to conduct a study and determine that the better alternative is a product marketed by a company that will potentially go bankrupt in the near future.

IV. Results and Analysis

Identification of Sources of Alternative Storage Devices

As stated earlier, the three storage techniques examined are RAID, network storage, and Optical storage. After a review of the specifications of the current satellite command and control system, which took into account the type of system connectivity, demographics of system and data users, and location of system and data users, the three architectures were evaluated.

Network storage is not a viable option at this time due to limitations of the current system. 1SOPS's satellite command and control system is governed by a single IBM ES9000 mainframe and is not part of a network architecture.

The use of optical media and some of its accompanying configuration techniques is also unacceptable under these circumstances. Although they possess high storage capacity, optical disc changers are ideally suited for organizations that generate large amounts of data locally that is required by relatively few users at a time. Therefore, of the three leading storage techniques and architectures, RAID is the technique that will best meet the needs of the subject organization.

The Competition in Contracting Act of 1984 mandated that all government contracts be awarded competitively. During the course of the award process, all potential contractors must be considered responsive and responsible. In order to be responsive, a contractor's bid must conform to and meet the material terms of the government's invitation for bid. In order to be considered responsible, the government must be convinced the contractor is able to perform the contracted tasks properly.

Due to the time constraints to which this study is subject to, it was not realistically possible to identify all potential sources of storage devices capable of meeting Air Force Space Command's needs. Therefore, in the interest of brevity and to ensure the responsibleness of the sources being used in this study, the top five vendors, in terms of market share, were used. They were IBM, EMC, Hitachi data Systems, Storage Technology (StorageTek), and Amdahl. The devices evaluated during this study were IBM's RAMAC, EMC's Symmetrix 5100-9M04, Hitachi's HDS 7700, StorageTek's Iceberg, and Amdahl's Spectris Platinum.

Comparison Results

The data detailing the attributes of the five alternatives being evaluated was supplied by each vendor's representative and is illustrated in Table 3. Each of the seven criteria will be further discussed in the following paragraphs. The initial scores of each alternative with regard to each of the criteria will be discussed, followed by the consistency ratings of those scores. The weighted average of each criterion will then be discussed, representing the relative importance of the criteria to the decision-maker. Finally, the composite score, denoting the best choice as determined by the AHP model, will be illustrated. All rating values were provided by the 1 SOPS/MA representative, who served as the coordinating point of contact for this study.

Table 3. Alternatives and Criterion

	IBM RAMAC	EMC Symmetrix	Hitachi HDS 7700	StorageTek Iceberg	Amdahl Spectris
Price	$555,893.00	$115,273.00	$126,327.00	$87,000.00	$45,000.00
Capacity	160 GB	34.1 GB	55.92 GB	200 GB	100 GB
Height	32 IN	74.9 IN	141 IN	72 IN	70.9 IN
Width	47.5 IN	68.7 IN	51.2 IN	114.9 IN	33.5 IN
Depth	32 IN	36.4 IN	63 IN	32 IN	31.0 IN
Total Square Feet	28.15 SqFt	108.39 SqFt	263.20 SqFt	153.20 SqFt	42.61 SqFt
Weight	1629 lbs.	4000 lbs.	1953 lbs.	1629 lbs.	1387 lbs.
Mean Time To Failure	1,000,000 Hrs	1,000,000 Hrs	2,000,000 Hrs	1,000,000 Hrs	1,000,000 Hrs
Maintenance Costs	$1,759.55	$474.00	$1,111.00	$2,388.00	$1,500.00
Power Consumption	5.10 kVa	1.40 kVa	4.10 kVa	12.10 kVa	1.00 kVa

Price Comparison Results. Table 4 below shows the results of the comparisons of the alternatives based on the criteria of purchase price.

Table 4. Pairwise Price Comparison

Price Criteria	IBM	EMC	Hitachi	StorageTek	Amdahl
IBM	1.0000	0.3333	0.2500	0.1667	0.1111
EMC	3.0000	1.0000	2.0000	0.3333	0.2000
Hitachi	4.0000	0.5000	1.0000	0.2500	0.1667
StorageTek	6.0000	3.0000	4.0000	1.0000	0.3333
Amdahl	9.0000	5.0000	6.0000	3.0000	1.0000
SUM	23.0000	9.8333	13.2500	4.7500	**1.8111**

The AHP model shows that the Amdahl Spectris Platinum storage unit is the least expensive and, therefore, most preferable option with regard to price. The next best choice with regard to price is StorageTek's Iceberg unit, followed by EMC's Symmetrix and then Hitachi's HDS 7700. The IBM RAMAC is the least preferable option based on price.

Capacity Comparison Results. Table 5 below shows the results of the comparison of alternatives based on storage capacity. The results of the AHP model process show that with regard to capacity, StorageTek is the most preferable option followed by IBM's RAMAC. Amdahl's Spectris is the next preferable option, followed by Hitachi's HDS 7700 and then EMC's Symmetrix.

Table 5. Pairwise Capacity Comparison

Capacity Criteria	IBM	EMC	Hitachi	StorageTek	Amdahl
IBM	1.0000	7.0000	6.0000	0.5000	2.0000
EMC	0.1429	1.0000	0.5000	0.1250	0.2000
Hitachi	0.1667	2.0000	1.0000	0.1429	0.2500
StorageTek	2.0000	8.0000	7.0000	1.0000	4.0000
Amdahl	0.5000	5.0000	4.0000	0.2500	1.0000
SUM	3.8095	23.0000	18.5000	**2.0179**	7.4500

Size Comparison Results. In Table 6 below, the alternatives are rated according to physical size. IBM's product is the most preferable choice followed closely by Amdahl's, both of which are significantly preferable to the next choice which is EMC's system. Next is StorageTek's product, followed finally by Hitachi's.

Table 6. Pairwise Size Comparison

Size Criteria	IBM	EMC	Hitachi	StorageTek	Amdahl
IBM	1.0000	6.0000	8.0000	7.0000	2.0000
EMC	0.1667	1.0000	4.0000	2.0000	0.2000
Hitachi	0.1250	0.2500	1.0000	0.3333	0.1429
StorageTek	0.1429	0.5000	3.0000	1.0000	0.1667
Amdahl	0.5000	5.0000	7.0000	6.0000	1.0000
SUM	**1.9345**	12.7500	23.0000	16.3333	3.5095

Weight Comparison Results. Each of the alternatives is compared with regard to weight in Table 7. The AHP Model shows Amdahl is the more desirable choice with regard to weight, followed by both IBM and StorageTek. Next is Hitachi, with the least desirable choice being EMC.

Table 7. Pairwise Weight Comparison

Weight Criteria	IBM	EMC	Hitachi	StorageTek	Amdahl
IBM	1.0000	8.0000	3.0000	1.0000	0.5000
EMC	0.1250	1.0000	0.1429	0.1250	0.1111
Hitachi	0.3333	7.0000	1.0000	0.3333	0.3333
StorageTek	1.0000	8.0000	3.0000	1.0000	0.5000
Amdahl	2.0000	9.0000	3.0000	2.0000	1.0000
SUM	4.4583	33.0000	10.1429	4.4583	**2.4444**

Mean Time to Failure Comparison Results. In Table 8, the alternatives are compared according to mean time to failure. With the exception of the Hitachi product, which is twice as long, all of the devices have an equal mean time to failure rating.

Table 8. Pairwise Mean Time to Failure Comparison

Failure Criteria	IBM	EMC	Hitachi	StorageTek	Amdahl
IBM	1.0000	1.0000	2.0000	1.0000	1.0000
EMC	1.0000	1.0000	2.0000	1.0000	1.0000
Hitachi	0.5000	0.5000	1.0000	0.5000	0.5000
StorageTek	1.0000	1.0000	2.0000	1.0000	1.0000
Amdahl	1.0000	1.0000	2.0000	1.0000	1.0000
SUM	**4.5000**	**4.5000**	9.0000	**4.5000**	**4.5000**

Maintenance Cost Comparison Results. Monthly maintenance cost is the next criteria the storage units were evaluated against. Table 9 below shows the results of that comparison. EMC has the lowest monthly maintenance cost. The next least expensive choice is Hitachi, followed by Amdahl, IBM, and then StorageTek.

Table 9. Pairwise Monthly Maintenance Costs Comparison

Maintenance Criteria	**IBM**	**EMC**	**Hitachi**	**StorageTek**	**Amdahl**
IBM	1.0000	0.1429	0.3333	2.0000	0.5000
EMC	7.0000	1.0000	5.0000	9.0000	6.0000
Hitachi	3.0000	0.2000	1.0000	4.0000	2.0000
StorageTek	0.5000	0.1111	0.2500	1.0000	0.3333
Amdahl	2.0000	0.1667	0.5000	3.0000	1.0000
SUM	13.5000	**1.6206**	7.0833	19.0000	9.8333

Power Requirement Comparison Results. Power Requirement is the final criteria the units were compared against. Table 10 below shows Amdahl has the lowest power requirement. The next most attractive option is EMC's product, followed by Hitachi, IBM, and then StorageTek.

Table 10. Pairwise Power Requirement Comparison

Power Criteria	IBM	EMC	Hitachi	StorageTek	Amdahl
IBM	1.0000	0.2000	0.5000	4.0000	0.1667
EMC	5.0000	1.0000	4.0000	8.0000	0.5000
Hitachi	2.0000	0.2500	1.0000	5.0000	0.2000
StorageTek	0.2500	0.1250	0.2000	1.0000	0.1111
Amdahl	6.0000	2.0000	5.0000	9.0000	1.0000
SUM	14.2500	3.5750	10.7000	27.0000	**1.9778**

Consistency of Scores

Consistency analysis was conducted on the scores of each alternative with regard to each of the evaluation criterion, in accordance with the AHP model. A consistency ratio of zero indicates the pairwise comparison matrix is perfectly consistent. A consistency ratio of less than .10 indicates a satisfactory degree of consistency is present. Conversely, a consistency ratio of greater than .10 indicates that serious inconsistencies may exist and AHP might not yield meaningful results.

The computations of the consistency ratios for each of the criteria are illustrated below in tables 11 through 17. With consistency ratios of .0472, .0289, .0573, .0392, .0000, .0267, and .0484, the AHP model strongly indicates that the pairwise comparison matrices for price, capacity, size, weight, mean time to failure, monthly maintenance cost, and power requirements, respectively, are highly consistent.

Table 11. Price Score Consistency

Normalized Price Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Price Scores	Consistency Measure
IBM	0.0435	0.0339	0.0189	0.0351	0.0613	0.0385	5.1069
EMC	0.1304	0.1017	0.1509	0.0702	0.1104	0.1127	5.2505
Hitachi	0.1739	0.0508	0.0755	0.0526	0.0920	0.0890	5.0255
StorageTek	0.2609	0.3051	0.3019	0.2105	0.1840	0.2525	5.3346
Amdahl	0.3913	0.5085	0.4528	0.6316	0.5521	0.5073	5.3406

Consistency Ratio: **0.0472**

Table 12. Capacity Score Consistency

Normalized Capacity Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Capacity Scores	Consistency Measure
IBM	0.2625	0.3043	0.3243	0.2478	0.2685	0.2815	5.1921
EMC	0.0375	0.0435	0.0270	0.0619	0.0268	0.0394	5.0431
Hitachi	0.0438	0.0870	0.0541	0.0708	0.0336	0.0578	5.0128
StorageTek	0.5250	0.3478	0.3784	0.4956	0.5369	0.4567	5.2497
Amdahl	0.1313	0.2174	0.2162	0.1239	0.1342	0.1646	5.1496

Consistency Ratio: **0.0289**

Table 13. Size Score Consistency

Normalized Size Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Size Scores	Consistency Measure
IBM	0.2912	0.4068	0.3200	0.3818	0.2661	0.3332	5.5278
EMC	0.0485	0.0678	0.1600	0.1091	0.0760	0.0923	5.1916
Hitachi	0.0364	0.0169	0.0400	0.0182	0.0591	0.0341	5.0675
StorageTek	0.0416	0.0339	0.1200	0.0545	0.0665	0.0633	5.0398
Amdahl	0.5823	0.4746	0.3600	0.4364	0.5322	0.4771	5.4563

Consistency Ratio: **0.0573**

Table 14. Weight Score Consistency

Normalized Weight Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Weight Scores	Consistency Measure
IBM	0.2243	0.2424	0.2958	0.2243	0.2045	0.2383	5.2690
EMC	0.0280	0.0303	0.0141	0.0280	0.0455	0.0292	5.0528
Hitachi	0.0748	0.2121	0.0986	0.0748	0.1364	0.1193	5.0907
StorageTek	0.2243	0.2424	0.2958	0.2243	0.2045	0.2383	5.2690
Amdahl	0.4486	0.2727	0.2958	0.4486	0.4091	0.3750	5.1970

Consistency Ratio: 0.0392

Table 15. Mean Time to Failure Score Consistency

Normalized Time to Fail Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Failure Scores	Consistency Measure
IBM	0.2222	0.2222	0.2222	0.2222	0.2222	0.2222	5.0000
EMC	0.2222	0.2222	0.2222	0.2222	0.2222	0.2222	5.0000
Hitachi	0.1111	0.1111	0.1111	0.1111	0.1111	0.1111	5.0000
StorageTek	0.2222	0.2222	0.2222	0.2222	0.2222	0.2222	5.0000
Amdahl	0.2222	0.2222	0.2222	0.2222	0.2222	0.2222	5.0000

Consistency Ratio: 0.0000

Table 16. Maintenance Cost Score Consistency

Normalized Maintenance Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Maintenance Scores	Consistency Measure
IBM	0.0741	0.0881	0.0471	0.1053	0.0508	0.0731	5.0055
EMC	0.5185	0.6170	0.7059	0.4737	0.6102	0.5851	5.3056
Hitachi	0.2222	0.1234	0.1412	0.2105	0.2034	0.1801	5.1669
StorageTek	0.0370	0.0686	0.0353	0.0526	0.0339	0.0455	5.0745
Amdahl	0.1481	0.1028	0.0706	0.1579	0.1017	0.1162	5.0452

Consistency Ratio: 0.0267

Table 17. Power Requirement Score Consistency

Normalized Power Comparison	IBM	EMC	Hitachi	StorageTek	Amdahl	Power Scores	Consistency Measure
IBM	0.0702	0.0559	0.0467	0.1481	0.0843	0.0811	5.0579
EMC	0.3509	0.2797	0.3738	0.2963	0.2528	0.3107	5.4062
Hitachi	0.1404	0.0699	0.0935	0.1852	0.1011	0.1180	5.2003
StorageTek	0.0175	0.0350	0.0187	0.0370	0.0562	0.0329	5.0604
Amdahl	0.4211	0.5594	0.4673	0.3333	0.5056	0.4573	5.3593

Consistency Ratio:	**0.0484**

Criterion Weighted Averages and Final Result

Table 18 below illustrates the relative importance of each of the criteria to the decision-maker. Most important is Price, followed closely by capacity, size and weight, monthly maintenance costs, mean time to failure, and then power requirements.

The computation of the consistency ratio for the criterion weights is shown in Table 19. As presented earlier, a consistency ratio of less than .10 indicates an acceptable degree of consistency. A consistency ratio greater than .10 indicates the existence of serious inconsistencies. The score of .0104 for criterion weighting indicates a high degree of consistency.

Table 18. Criterion Weights Ratings

Criterion Weights	Price	Capacity	Size	Weight	Failure	Maintenance	Power
Price	1.0000	2.0000	3.0000	3.0000	5.0000	4.0000	7.0000
Capacity	0.5000	1.0000	2.0000	2.0000	4.0000	3.0000	5.0000
Size	0.3333	0.5000	1.0000	1.0000	3.0000	2.0000	4.0000
Weight	0.3333	0.5000	1.0000	1.0000	3.0000	2.0000	4.0000
Failure	0.2000	0.2500	0.3333	0.3333	1.0000	0.5000	2.0000
Maintenance	0.2500	0.3333	0.5000	0.5000	2.0000	1.0000	3.0000
Power	0.1429	0.2000	0.2500	0.2500	0.5000	0.3333	1.0000
SUM	**2.7595**	**4.7833**	**8.0833**	**8.0833**	**18.5000**	**12.8333**	**26.0000**

Table 19. Criterion Weight Consistency

Normalized Criterion Weights	Price	Capacity	Size	Weight	Failure	Maintenance	Power	**Criterion Weight**	**Consistency Measure**
Price	0.3624	0.4181	0.3711	0.3711	0.2703	0.3117	0.2692	0.3391	7.1829
Capacity	0.1812	0.2091	0.2474	0.2474	0.2162	0.2338	0.1923	0.2182	7.1967
Size	0.1208	0.1045	0.1237	0.1237	0.1622	0.1558	0.1538	0.1349	7.1290
Weight	0.1208	0.1045	0.1237	0.1237	0.1622	0.1558	0.1538	0.1349	7.1290
Failure	0.0725	0.0523	0.0412	0.0412	0.0541	0.0390	0.0769	0.0539	7.0264
Maintenance	0.0906	0.0697	0.0619	0.0619	0.1081	0.0779	0.1154	0.0836	7.0509
Power	0.0518	0.0418	0.0309	0.0309	0.0270	0.0260	0.0385	0.0353	7.0779
SUM	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000	

Consistency Ratio: **0.0104**

The last step in the AHP model is the implementation of the final scoring model, illustrated in Table 20. The weighted average scores for the IBM RAMAC, the EMC Symmetrix 5100-9M04, the Hitachi HDS 7700, the StorageTek Iceberg, and the Amdahl Spectris Platinum are .1725, .1351, .0887, .2429, and .3608, respectively.

Table 20. Final AHP Scoring Model

Criterion	IBM	EMC	Hitachi	StorageTek	Amdahl	Criterion Weight
Price	0.0385	0.1127	0.0890	0.2525	0.5073	0.3391
Capacity	0.2815	0.0394	0.0578	0.4567	0.1646	0.2182
Size	0.3332	0.0923	0.0341	0.0633	0.4771	0.1349
Weight	0.2383	0.0292	0.1193	0.2383	0.3750	0.1349
Failure	0.2222	0.2222	0.1111	0.2222	0.2222	0.0539
Maintenance	0.0731	0.5851	0.1801	0.0455	0.1162	0.0836
Power	0.0811	0.3107	0.1180	0.0329	0.4573	0.0353
Wt. Avg. Score	0.1725	0.1351	0.0887	0.2429	**0.3608**	1.0000

V. Conclusions and Recommendations

With the increasing reliance on and continued expansion of space operations as a means of supporting the global interests of both the federal and civilian sector, ensuring the effective and efficient accomplishment of the mission of our space assets is essential. This study of Air Force Space Command's satellite command and control mission has identified the inadequate performance of the mission critical IBM 3380 DASD storage units as major shortcomings and the frequent cause of its inability to achieve many mission objectives. The sponsor provided seven criteria with which to evaluate five potential alternative devices against.

Utilizing the Analytical Hierarchy Process Model, the five devices were rated according to each individual criterion. Weights were then assigned to each criterion, indicating the relative importance of that attribute to the decision-maker. The weighted average of each alternative storage device with regard to all criteria was calculated. Amdahl's Spectris Platinum was the alternative with the highest weighted average score and should be selected. By definition of its intent, the AHP Model indicated this was the alternative that maximized the sponsor's desire to minimize purchase price, maximize capacity, minimize size and weight, minimize monthly maintenance costs, maximize typical mean time to failure, and minimize power requirements. Amdahl's weighted average score of .3608 is significantly higher than the next closest score of .2429 for StorageTek and shows this is the alternative to be selected.

When reviewing the results of the study, it seems apparent that AHP worked as advertised and did, in fact, select the alternative that would best meet the needs of the sponsor when considering the relative importance of each of the seven criterion. Amdahl's Spectris system ranked first in four comparison areas (price, weight, mean time to failure, and power), second in one area (size), and third in two areas (capacity and monthly maintenance costs). This is compelling evidence to support the selection of this alternative.

In spite of the highly structured and formalized acquisition process Department of Defense (DoD) agencies must follow, a very realistic case can be made that the results of this thesis could serve as the basis for an acquisition of the identified alternative. The Federal Acquisition Regulation (FAR), which governs all DoD acquisition initiatives, provides for the possibility of conducting an acquisition while limiting competition. This is provided one of seven allowable, situational exceptions is present. In this case, considering the importance of Air

Force Space Command's mission, a strong case could be made that "the agency's needs are so urgent that the Government's interest will be seriously injured unless a limit on sources is permitted" (Arnavas and Ruberry, 1994:2-17). Under these circumstances, Air Force Space Command could be permitted to specifically select the Amdahl Spectris Platinum storage system for acquisition.

Recommendations for Further Research

This study was promulgated on the concept that any replacement storage device would have to be able to interact and function with the command and control system operating in its current configuration. This configuration necessitated the elimination from the study other storage architectures that might more effectively meet the current and future needs of the sponsoring organization. Various architectures and configurations, such as open systems and network storage, could be the subject of future study in order to identify potential systems that could more effectively and efficiently meet the needs of the Air Force. Whether it is an open system, distributed architecture, or some type of network configuration, Air Force leaders should consider sponsoring future research to determine what the optimal system architecture and configuration for satellite command and control is.

This research effort highlighted only a few of the decision-making tools available for use and AHP's apparent effectiveness in determining the most desirable alternative was clear. However, the subject of this research was only one type of problem decision-makers face. Future research could explore AHP's potential effectiveness in problems of a different type, such as those with more alternatives, less alternatives and more or less evaluation criteria.

Also, even though AHP was an effective technique in determining the alternative that would seemingly best fit the sponsor organization's needs under these circumstances, many of the steps involved in using that technique were potentially confusing and tedious. Research into the possibility of modifying the technique in order to make it more user-friendly is another potential subject of future research. Automating manual computation or perhaps developing a user survey to help further refine decision-maker ratings and improve consistency are some areas to be considered.

Finally, there is the distinct possibility that, for all of its apparent effectiveness in this case, AHP may not be the most appropriate technique for use in decision-making circumstances of this kind. Future research could explore the possibility that another comparison tool may have been more effective or easier to use.

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13. ABSTRACT (*Maximum 200 Words*)

Two of Air Force Space Command's primary missions are ballistic missile warning and global navigation, accomplished by commanding and controlling Defense Support Program and Global Positioning System satellites respectively. The computerized ground control system, called the satellite command and control system (CCS) used to perform command and control of the satellites currently uses antiquated peripheral storage devices. These storage devices are critical components, but are often prone to failure, possibly resulting in adverse mission impact. The Air Force must choose an alternative storage device for use in conjunction with CCS in order to accommodate planned operations tempo increases. This thesis compares five alternative storage devices based on seven criteria supplied by the sponsor. The comparison method used in this thesis is the Analytical Hierarchy Process model. The results of this study indicate that Amdahl's Spectris Platinum storage system will most effectively meet Air Force Space Command's needs in terms of the seven criteria each alternative was evaluated against.

14. Subject Terms

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