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AIR FORCE GLOBAL WEATHER CENTRAL
SYSTEM ARCHITECTURE STUDY.

FINAL SYSTEM/SUBSYSTEM SUMMARY REPORT.

VOLUME 1.

Executive Summary.

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DEPUTY FOR DEFENSE METEOROLOGICAL SATELLITE PROGRAM OFFICE
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This document has been prepared in partial fulfillment of CDRL line item A004 of System Development Corporation's Air Force Global Weather Central System Architecture Study contract. Efforts for this report were expended under Task 6, "Conceptual Design and Development Plan", performed under contract F04701-75-C-0114 for SAMSO, under the direction of Col. R. J. Fox, YDA.

The purpose of this study has been to optimize the entire AFGWC data process-

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ing system from the vantage point of current and future support requirements, addressing the AFGWC data processing system over the 1977 through 1982 time frame. This study was performed under a unique plan which allows complete traceability between user requirements, Air Force Global Weather Central operational functions, requirements levied upon the data system, a proposed component configuration which meets the data system requirements, and a system specification designed to acquire a system which meets these requirements.

The resultant system described has a number of unique features, including total hardware authentication separation of security levels, load leveling accomplished by assigning main processors in accordance with a dynamic priority queue of tasks, and a system-wide network control capability. Other key features include a central data base processor to fill requests for data from other processors, computer operations centers, the use of array processors for accomplishing difficult numerical problems, and sophisticated forecaster console support. These elements have been designed to provide 99.5% reliability in meeting user requirements.

The proposed system architecture consists of five dual processors, each ~~of which is~~ about 3.5 times as powerful as an existing AFGWC processor. ~~(a Univac 1108)~~ Each dual processor has an array processor which will be capable of very high performance on vector arithmetic. The array processors are used to assist on the difficult numerical problems, including the Advanced Prediction Model for the global atmosphere, as well as very fine grid cloud models and cloud probability models. Some of the new requirements that will be supported with this system are a one minute response to query interface, reentry support for Minuteman, and limited processing of high resolution (0.3 nautical mile) meteorological satellite data. In addition, cloud cover prediction for tactical weapon systems, ionospheric prediction for radio frequency management, and defense radar interference prediction will be supported by this system.

Volumes of this final System/Subsystem Summary Report are as follows:

- Volume 1 - Executive Summary
- Volume 2 - Requirements Compilation and Analysis (Parts 1, 2, and 3)
- Volume 3 - Classified Requirements Topics (Secret)
- Volume 4 - Systems Analysis and Trade Studies
- Volume 5 - System Description
- Volume 6 - Aerospace Ground Equipment Plan
- Volume 7 - Implementation and Development Plans
- Volume 8 - System Specification

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System Development Corporation

AIR FORCE GLOBAL WEATHER CENTRAL
SYSTEM ARCHITECTURE STUDY

FINAL SYSTEM/SUBSYSTEM SUMMARY REPORT

VOLUME 1
EXECUTIVE SUMMARY

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This Executive Summary volume, as the name implies, provides an overview of the study and its results. This overview has been constructed as an introduction to the more detailed discussion in Volume 5 but also as a self contained description for readers who do not wish to go into more technical depth.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 STUDY SUMMARY

This section addresses a variety of topics not covered elsewhere within the volumes. It identifies study participants and general study structure. It identifies the contents of the volumes and finally addresses the important topic of traceability within the volumes.

1.1 SDC TEAM

The AFGWC System Architecture was under the project managership of Howard Johnson who reports to Don Biggar, Program Manager of the SDC Satellite Control Program. Ron Knight worked very closely with Mr. Johnson in this project. The principal investigators throughout the project were Gary Billerbeck (head of tasks 2, 3 and 4), Dick Bilek (head of tasks 1 and 6), D. L. Chapman (head of task 5), Jim Wilson (responsible for satellite data processing, and automated work centers), Steve Jermaine (responsible for forecaster console design, network analysis, and the final AGE Plan). Other major participants include Al Tucker, Jerry Peterka, Bill Patterson, Dave Wexler and Bob Von Buelow. For specific problems, we received support from John Evensen, Jerry Cole, Jon Fellows, and Jack Lagas. The task of preparing briefings and project reports was the responsibility of many people but primarily Rita Del Rey, Joyce Ford, Diane Kilpatrick, Jo Marie Tkac, Wayne Shook, John MacDonald and others in the Satellite Control Program.

1.2 STUDY APPROACH

The SDC architectural study was broken into six tasks as follows:

a. Task 1. The purpose of this task was to analyze user requirements, identify resulting AFGWC functions and, using this analysis, to assess system data processing oriented requirements. The sheer volume of user requirements and lack of specific definition prolonged this task beyond what was anticipated. The output is a specification of the data system requirements which must be satisfied to perform the AFGWC mission as interpreted through user requirements.

b. Task 2. The purpose of this task was to survey vendor products. The 1977 baseline system was defined and all viable options for the final configuration were identified. We identified design concepts for the data system with emphasis on control of resources, run execution and intercommunication protocol. The results of task 2 were in the form of a network of options which were to be analyzed and reduced to a single cohesive data system.

c. Task 3. In this task we developed and applied criteria to evaluate the many options which existed. The collection of studies resulting from this investigation were formed into the Systems Analyses and Trade Studies document (Volume 4). Each tradeoff decision resulted in a simplification of the analysis which remained, thereby bringing us closer to the final system.

d. Task 4. This task consisted of thoroughly documenting the system resulting from the tradeoff studies. An analysis was made to insure the system would meet all user requirements. System operations characteristics were determined. A timing analysis was performed to develop a timing budget. Similarly, a reliability budget was developed. Finally a risk analysis was performed on the system. All of these became a part of the System Specification (Volume 8).

e. Task 5. This task involved documenting the system architecture in a System Specification. The System Specification was structured to be similar to the architectural domain. All requirements to be satisfied were identified and the correlation between the System Specification and specific tradeoff studies was established.

f. Task 6. This task involved the preparation of the final report. The final report includes all previously published documents as well as: a) the results of tasks 1-4 in the form of a Requirement Compilation and Analysis document and a System Description document, b) an Executive Summary and c) an Implementation and Development Plan which identifies the schedules associated with design and development activities, logistics of system implementation, a final analysis of total system costs, a detailed risk analysis, and a plan for verification of the system.

f. Final Presentation. SDC has taken the briefing material prepared for the four formal meetings and developed a final briefing for presentation to Headquarters, Air Weather Service and other Air Force organizations.

1.3 AIR FORCE PARTICIPATION

The SDC role involved the assimilation of massive amounts of data. The process of design was often based on conjecture in cases where detailed knowledge was not available to the investigators. Air Force support compensated for this deficit. SDC received extensive support from Col. Fox and Capt. Piddington in their role as contract monitors. They responded immediately to all the requests for information and requests for access. They were quite successful in expediting of all phases of information flow. The single most valuable interface at Air Force Global Weather Center was Lt. Col. Coburn who was an essential ad hoc member of the SDC team continually contributing and enhancing information flow. The Commander and his staff at Global Weather Central were extremely helpful as were each of the branch chiefs. Others who were particularly helpful were Col. Blunk, Lt. Col. Flattery, Lt. Col. Ramsey, Lt. Col. West, Maj. Craw, Maj. Diercks, Capt. Lewis, Capt. Canipe, Capt. Cotnoir, Capt. Simms and numerous others. It is obvious that AFGWC is an organization which takes great pride in all aspects of its work, as much in development as in operations.

1.4 CONTENTS OF VOLUMES

a. Volume 1, Executive Summary. This volume provides a complete review of the architectural study with an overview of the study approach, the key results from each task, a summary of the selected hardware configuration and discussion of the management and operation of that system.

b. Volume 2, Requirements Compilation and Analysis. Included in this volume are the results of the Task 1 investigation and a summary of all user requirements including the numerical model analysis. The document also contains a complete functional description of tasks to be performed at Global Weather Central, phased according to the year of their introduction. The final part of the document contains the results of the analysis of requirements and functions to determine the data system characteristics to be satisfied by the architecture. The network analysis showing the dynamics of system usage was especially important in that it provided the information for a statistical conflict analysis primarily for the computer selection decision.

c. Volume 3, Classified Requirements Topics. A description of the classified requirements and any analysis classified by virtue of requirement association is contained in this volume.

d. Volume 4, System Analyses and Trade Studies. This volume provides some 100 tradeoff studies accomplished in developing the final architectural design.

e. Volume 5, System Description. The nominal theoretical system designed by SDC is described. This system complies with the system specification and is thought to be realizable under state of the art hardware and software. The volume contains a description of that system and identifies operational characteristics. It takes the reader through important design considerations and rationale not covered in the trade studies.

f. Volume 6, Aerospace Ground Equipment Plan. This volume identifies maintenance approaches. It provides a typical framework for a final AGE plan. It deals with all relevant levels of maintenance including preventive, failure response, and depot maintenance.

g. Volume 7, Implementation and Development Plan. Topics pertinent to the procurement of the prescribed architectural data system are discussed in this volume. A proposed design and development schedule, which also treats phaseover, is an important part. The logistics of implementation are described. There is a total system cost analysis and summary which details the estimated time phased expenditure associated with the acquisition and development of the architecture as well as on-going cost considerations. The volume contains a risk analysis associated with the three obvious risk factors: the risk of changing requirements, the probability of vendors providing a system which meets the performance specification, and also the risk associated with schedules. Also addressed is the risk of unknown factors. The final part of this volume deals with system verification planning including a discussion of checkout of components both hardware and software, system testing and final integration testing.

h. Volume 8, System Specification. This volume provides a total set of specifications to be used in acquisition of the proposed architecture system. It not only contains identification of the hardware and software but also addresses personnel, management and facility considerations.

1.5 TRACEABILITY

1.5.1 Study Structure

A Study Structure aspect of SDC's study approach and a key item of Air Force concern throughout the architectural study has been traceability. SDC provides traceability through development of standard orientations using hierarchical structures. We felt that the optimum number of such orientations (which we call domains) which provide a reasonably uncomplicated link for reference consists of four basic structures, plus time considerations, as follows:

a. The Requirements Domain. This category gives a breakdown of users into different types of missions and identifies the individual requirements associated with each user.

b. The Functional Domain. In this domain all data system associated functions/tasks have been categorized into four separate headings: input, computation, output and support. The next level of the hierarchy is motivated by physical or product structure and, below that, the individual tasks which are part of the system. Finally, task descriptions are the lowest part of the hierarchy identifying each sequence of steps (or potential sequence of steps) required to do a job.

c. The Characteristic Domain. This hierarchy breaks down the data system into categories which describe a data system structure. The highest level corresponds to components. Below the first level are characteristics attributable to components but not necessarily uniquely defining those components (e.g., a storage requirement might be satisfied by tape, disk, drum or core, or all four, and a computation requirement could be satisfied by many sizes of computers within the system and perhaps even by firmware). This domain makes no assumptions about components which currently do the job or about which components might be selected, but tries to put information in a form that all options are open. The lowest level of this domain consists of questions to be asked to obtain the data necessary to describe a systems characteristics.

d. The Architectural Domain. The architectural domain is a hierarchy which specifies the components of the architecture. It includes hardware (e.g., data storage, processors) and also software, management, facilities and personnel. It identifies each component to the depth of the System Specification.

e. Time Considerations. Since AFGWC requirements change from year to year and since the architecture components involve a staggered implementation sequence, we cannot ignore the dimension of time associated with each of the domains provided above. Requirements each have a date of implementation but we only need worry about the significant ones which have an impact on the data system. Correspondly, functions will be incorporated as a result of the requirements. The characteristics follow suit and this dictates when the components need to be available. Other considerations in phaseover and implementation planning finally determine when they actually are implemented.

1.5.2 Application of Domain Structure to Study Documentation

This section describes how these hierarchical structures are used as a basis for traceability within the study documentation. First, the relationships between domain hierarchies must be identified. A list was developed which links requirements with functions. (The number of relationships is on the order of the list size; however some requirements pertain to several functions, and conversely.) The link between data system characteristics and AFGWC functions is one of a matrix rather than a list (since the relationships are of the order of the square of the list size). Theoretically, all characteristics associated with each task must be accounted for. Conversely, any single characteristic must be evaluated across all tasks. This unfortunately produced a 10,000 element matrix which was too large to complete. Instead, the significant characteristics which pertain to any given task were chosen. It was recognized that many tasks have no effect on certain characteristics.

With these basic structures and their relationships in mind, we can discuss the AFGWC architectural study documentation and define the relationship between that documentation and our structures:

a. Requirements Compilation and Analysis Document. This document is organized according to the requirements domain. It provides information about all requirements and models. It addresses the derived general systems requirements, including reliability, maintainability and growth. For each requirement, the link with the functional domain is identified. In addition, there is a matrix which relates all functions with all requirements. The requirements document also defines the functional domain at the task level on a time phased basis. The characteristic analysis is a matrix which relates functions to characteristics and yields a summary of requirements related to the data system. It is organized according to the characteristics domain. The link to requirements is accomplished by simply scanning the list of function oriented characteristics which contribute to the characteristic identified.

b. System Analysis and Trade Studies. This document is basically ordered by the architectural domain and the study numbers are assigned accordingly so that an immediate correspondence can be made. For each study a reference is provided to requirements and functions. In addition, there is a matrix for specifically identifying the system specifications resulting from the tradeoff study. Also included is the analysis of new products. This is presented in the form of the component domain.

c. AGE Plan. The AGE plan is constructed in two parts. The first part pertains to type one maintenance or a preventive maintenance program. It is addressed in the document functionally and in the exact organization of the functional domain. The second half of the document pertains to unscheduled corrective maintenance functions, and is organized according to the architectural domain.

d. System Specification Document. Generally, subsystems are specified according to the structure of the architectural domain. In some places, however, the documentation instruction for system specifications would not allow us to retain the architectural domain structure. In these instances, a correlation table is provided which gives the relationships between paragraphs and the architectural domain. In addition, the specifications are independently numbered according to the architectural domain system (thereby providing total traceability). There is also a matrix within the System Specification which gives system specification number and corresponding tradeoff studies.

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2.0 ARCHITECTURAL SUMMARY

2.1 REQUIREMENTS ANALYSIS

In Task 1 SDC investigated requirements in the areas of: command and control systems, emergency war order support, environment support, space environment support, and special activities (primarily classified). We also investigated requirements in general areas such as growth, manpower productivity, reliability and maintainability. The requirements which were considered to be key in their impact on data system design are as follows:

a. General system key requirements:

   Overall system security (internal),
   System reliability,
   System growth, and
   Manpower productivity.

b. User products key requirements (listed sequentially by requirement number):

   Remotely piloted vehicle systems,
   Electro optical weapons systems,
   Space optical imaging systems,
   High energy laser systems,
   Program D,
   Agency B,
   Use of ZOOM,
   WWMCCS support,
   TAC support,
   AWACS,
   Crisis management,
   Computer flight plans,
   SAC Minuteman,

Satellite Imagery Dissemination,
Interactive Processing and Display System,
Operational security,
Backup to Carswell,
NORAD/ADC,
Over the horizon backscatter radar, and
Tactical frequency management.

c. Advanced models key requirements (listed sequentially):

Tropical prediction spherical harmonics;
Primitive equation window model;
Total electron content model;
Ionospheric ray tracing model;
Macroscale and high resolution cloud prognoses;
Global analysis;
Some high resolution data into 3DNEPH programs;
Advanced global atmospheric prediction model;
Cloud free line of sight probability matrices;
Statistical polar ionospheric propagation model; and
Primitive equation window model for high resolution, short-range forecasts at low altitudes.

d. Input data key requirements:

GOES,
SWI data, and
TIROS-N.

With the assistance of the Air Force we identified requirements which were not to be considered for the architectural study. The following list represents a summary:

Microwave refraction profiles for remote piloted vehicle systems,

Lightning prediction associated with remote piloted vehicle systems,

Optical turbulence prediction for space optical imaging systems and high energy laser systems,

Threat assessment for SATRAN and SAC,

A general class of optimization models associated with WWMCCS for which nature and usage were not specifically identified,

The WWMCCS survivability requirement (pertaining to more than the scope of the architectural study),

Seeability and slant range visibility for tactical systems including AWACS,

and Graphic support capability for AWN beyond that specified for WWMCCS.

In addition, certain assumptions were agreed to concerning some of the stated requirements:

Formats of messages for support of the National Meteorological Center were assumed to be identical to current GWC formats,

The query response and graphics capability for modernized base weather station are assumed equivalent to that provided for WWMCCS support,

AFGWC will not be a major node of the AFOS system,

No automated communications interface is assumed for field Army support and the capability will not exist to provide mesoscale products to remote areas,

In the Carswell backup the NOTAM pilot aid system will not be driven directly by AFGWC, The assumption is made that OTHB data can be as much as 2-3 hours old,

High frequency propagation forecasts will be limited to no more than 1 hour per day computer time on a single computer, and

No support will be provided to the Global Positioning system.

2.2 DATA SYSTEM CHARACTERISTICS

2.2.1 Data Storage

The results of the characteristics analysis yielded the following memory requirements (given in number of characters):

Conventional 57×10^6 (models - 12×10^6, other - 45×10^6)

Array 5×10^6

Disk 7816×10^6 (fixed head - 26×10^6, other - 7790×10^6)

Mass $35,000 \times 10^6$

A key memory consideration was the ability to stage data from a lower rate access device to a higher rate access device where applicable. Satellite data presents the principal storage requirement with analysis and forecast data being second. The primary storage growth occurs in 1980. Other conclusions were that data base management and the ability to monitor data base usage are extremely important.

2.2.2 Data Transfer and Routing

The overwhelming data storage and computation requirements were paramount considerations in data transfer and routing. In addition, the response to query two minute time requirement dictated a very rapid response capability. Together these could have forced the cost to be prohibitive. The only solution was to provide for computer intercommunication and instantaneous computer access to the bulk of the data base (or so rapid as to preclude manual switching).

Such a system required very rapid switching and initialization of data system connections as well as protection against unauthorized connections through some secure authentication scheme. The principle of load leveling of tasks across resources suggested a control system which had total knowledge of tasks, priorities and resources with the ability to activate jobs under the constraints of security.

The security requirements on the system dictated the need to pass data from one device to another and to protect the security level of information without compromise. Thus, the capability was required for automated upgrading of classified data, and manual downgrading and certification of data in an efficient manner.

Economy forced the consolidation of certain functions to minimize component costs and to eliminate personnel in such areas as computer operations, communications, and data input/output support.

It was obvious that very strict protocol would be necessary in the type of environment we were evolving toward. The need for a central data base processor was obvious and that presented a significant transfer problem. Satellite data quantities had always posed a difficult problem and the decision to process high resolution (fine) DMSP data and to additionally process TIROS-N and GOES data presented an additional challenge. The computer flight plan requirement of 3000 per day or 250 per hour presented a significant transfer and response problem as did the digital radar which requires ingestion at a transfer rate of 2 x 10^{15} bits per second for four seconds every fifteen minutes under severe weather conditions.

2.2.3 Processors and Software

The processor problem is a multivariate. Considerations encompassed: 1) very high computational throughput for difficult numerical problems, 2) simultaneous availability of computation resources because of conflicting needs within the system where conflicts arose due to time considerations as well as security considerations, 3) the dedication of computation resources to specific tasks traded against the highly complicated flexibility of resources to perform multiple functions, and 4) the natural redundancy required to meet the high reliability goal of certain requirements traded against the obvious disadvantages of homogeneity. When the average CPU usage over a twelve hour time period was plotted, the peak loading would require twelve UNIVAC 1108 CPUs operating at 100% efficiency. The requirement grows from approximately five in 1977 to eight in 1978 and 1979 with ten in 1980 and twelve in 1981 and 1982. About 75% of the computation requirements are mathematical. An evaluation of current CPU efficiency showed that approximately 39% was wait time with much less than half of the input/output transfer time overlapped with computation.

The primary CPU users were predicted to be the advanced prediction model, sprint, satellite data ingestion, zoom windows, cloud free line-of-sight, and Minuteman. Of these high usage requirements (assuming processing capability of 10 million instructions per second), five requirements could be in conflict.

Separating the high throughput and the normal computation load requirement from one another, it was determined that five 10 MIPS computers (six or more, with reliability taken into account) could satisfy the primary computation users, with the rest satisfied by a single 9 MIPS computer (plus a factor for reliability). All of these computations were based on 100% efficiency.

Thus, the requirements could be satisfied by very fast processors (the TI ASC, CDC Star, or one of the many Array processors) or several medium speed processors to handle the same problem, along with many function dedicated minicomputers for such things as communication and console support.

In considering software, new areas of concentration become evident. AFGWC would be developing software for the very large models, as well as network control and data base management. Other new areas of software support are communications management, generalized work center interface, programmer interface, performance monitoring, and diagnostic software for both hardware and software. There is a potential for multi-tasking software and many advantages to be gained by strict protocol standards.

2.2.4 Terminal Interface

Terminal interface has the problem of accommodating many data lines interfacing with the AFGWC system. The desire has been that all data links be automated (direct computer interface). This resulted in a cumbersome mixed mode security problem because all normal access circuits interfaced with one computer.

Normal access circuits provide classified interfaces with the AUTODIN II system, the AUTODIN system, the SAC and NSA direct links. Unclassified data links include 20 ASR/KSR teletype circuits, MAC Det. 14, AWN, Navy, NOAA, DSP, digital radar, lines for back up of ETAC and Carswell and the satellite imagery dissemination system. To support the facsimile requirements, there are analog interfaces with STRATFAX, PACFAX, RAFAX, and the National Weather Service. Future facsimile requirements include interface with AFOS, a back up capability to the National Weather Service, and a digital interface with the 1979 Weather Graphics System. Thus, a consolidated communications terminal was needed to interface with these lines. In addition, three data interfaces would exist in the special access area.

Data transmission rates are 4800 baud or under with four exceptions: digital radar, AUTODIN II, Fleet Numerical Weather Central, and satellite data. Digital radar will have a data rate of 2 x 10^{15}. bits per second in four second bursts which can occur as often as every 15 minutes. AUTODIN II and Fleet Numerical Weather Central information will be transferred at rates up to 50 kilobaud. Input rates for satellite data are up to 2.6624 megabits per second.

The ingestion of satellite data requires the following:

a. Total processing of all DMSP and TIROS-N smooth data,

b. 3% processing of DMSP fine data in 1978 and 10% in 1980, and

c. The processing of five (20^o x 20^o) windows of GOES data in 1977.

The daily volume associated with the satellites is:

a. DMSP (two vehicles) - smoothed data, 266 x 10^6 words per day; fine data, 23.94 x 10^6 words per day (1978); fine data, 79.8 x 10^6 words per day (1980);

b. TIROS-N - smoothed data, 266 x 10^6 words per day; fine data, not required; and

c. GOES-42 readouts, 2142 x 10^6 words per day.

2.2.5 Automated Work Centers

The need for automated work centers arose because of the potential for reducing manpower as well as providing for new support requirements. This resulted in specification of the following console areas:

a. Mission support consoles: network control (1), computer operations (2), security downgrade/remote job entry (2), communications (2), satellite imagery dissemination (1), and maintenance (probably 1 per main processor).

b. Mission operations consoles: TAF/Metwatch (13), military weather advisory (1), synoptic (5), forecaster special access (3), SESS normal access (1), SESS special access (1), quality assurance (1), programmer special access (4), programmer normal access (22), studies and analysis (4), and special operations forecasting (1).

2.2.6 Input and Display

For the man-machine interface, the requirements were diverse and had to be satisfied in many different ways. This dictated the following basic characteristics:

a. Rapid response visual: standard alphanumeric CRT/control, CRT, high resolution CRT (on the order of six bits per element and 1000 by 1000 pixels), CRT hardcopy device, and high speed printers with special character capability. The printers must support ten classification levels and print spooled data at a peak output of 25,000 lines per minute.

b. Miscellaneous status: configuration display for network control, security display, switch and master switching capability, card reader/punches, alphanumeric fixed function keyboard, light pen, magnetic cursor capability, and digitizing table capability.

2.2.7 Personnel

SDC determined that the expected manning requirements for the six major branches of the AFGWC Production Division would be 659 slots by 1982. This is predicated on a baseline of 605 slots which were assigned in early 1975 plus an additional 54 slots that will be necessary to support increased 1977-82 requirements. However, it is assumed that 17 slots can be saved by automation, resulting in a net of 642 personnel slots in these six organizations. Of these 642 slots, 355 men are expected to be directly involved in the use of automated work centers. Thus, over 50% of the operational personnel can be expected to be using automated means for task performance.

The savings of 17 slots through automation are based on the following analyses of operations in three branches in the AFGWC Production Division. One area where savings can occur is in the development and maintenance of computer programs and models. A recent one-year study that involved automation of the programming function with interactive CRTs and automated peripherals. The result was that programs were developed four to six times faster.

In comparing the models developed at AFGWC with the programs developed during this one-year study, the AFGWC models are much more complex and scientifically oriented. Also, some uncertainties that currently exist regarding the final approved AFGWC architecture require a conservative estimate of the manpower savings due to automation. The SDC estimate for a more appropriate figure for the savings in the function of developing new programs is approximately 20%. Using this 20% as a guideline, the following figures result:

<u>WPA (approximately 20 programmers)</u>

70% of the programmers involved in new program development.

70% X 20 = 14

X 20% savings through automation

3

<u>WPD (approximately 100 programmers)</u>

30% of the programmers involved in new program development

30 X 100 = 30

X 20% savings through automation

6

For program/model maintenance, a 3% savings was considered appropriate. This resulted in the following:

<u>WPD</u>

70% of the programmers involved in maintenance

70% X 100 = 70

X 3% savings through automation

2

WPF

With automation of many of the WPF functions, there will be no requirement for some of the manual operations being currently performed. Thus, it should be possible to reduce the number of observers supporting the forecasters. At this point, SDC estimates that approximately six observers would no longer be required.

The total approximate savings in current manpower through automation is therefore:

WPA	3
WPD	8
WPF	6
Total	17

2.2.8 Management

External direct control of the data system (beyond that accorded in the query response capability) would cause many problems and is therefore prohibited. The exception to this rule is the existing direct interface with the SAC Control Center. Internally, the operational responsibility for the data system needed to be centralized. This function developed into a single network control position.

Operationally, the single most important set of design characteristics arose from security considerations. The need exists for physical isolation of the entire data system to prevent any external intervention. Physical protection is also needed within the data system for separation of special access and normal access operations. Between system components, there must be isolation of distinct levels of security. This can be accomplished either physically or electronically (through authentication encoding). With this in mind, the system is designed to minimize the amount of software needed for proper security control, but maximize the amount of software for checking and enforcing it. The overall goal was to hold data and resources to the lowest security level possible.

Automatic upgrading of information is needed from a lower security level component to a higher level component with no risk of security compromise in the other direction. Conversely, unclassified information messages from high level components need to be passed to low level components in order to accomplish resource allocation and job assignment. Mixed mode security exists in only two areas: one at human interfaces (in which case the security responsibility is assigned to the operator), and the other in the interface with the external mixed mode communications systems. In addition, rapid and accurate certification or downgrading of small amounts of data is needed. This will be accomplished at a security monitor console.

Certain resources such as main processors, array processors, and selected consoles must be able to operate at different security levels at different times due to varying product requirements. This implies a rapid cleaning/change of level capability as well as increased redundancy.

To minimize system cost, it is advantageous to provide a means for shared redundancy between the normal access computer area and the special access area by means of a "variable perimeter" set of main processors. These processors can be switched to either area at any level within that area.

In the area of quality assurance, it was apparent that the quality assurance task should be further automated with a centralized control position.

The two principal logistics problems were phaseover and the spare parts philosophy. These can only be addressed generally until a specific architecture has been approved. Nevertheless, the phaseover was dictated by the time phasing of the key driving requirements for individual components within the system.

In readiness planning, the system must accommodate readiness exercises in preparation for support of a new activity and also in preparation for support of peak load and abnormal conditions. A system simulation capability must allow operating the system independent of the outside world with simulated data and the ability to simulate operational loading conditions. A capability must also exist for long-term scheduling.

The requirement exists not only to support development during the phaseover of any new data system but also to support augmentation on a continual basis both in hardware and software.

The data system must accommodate preventive maintenance with a full failure response capability without jeopardizing the overall timing and reliability requirements. It is also important that a graceful degradation feature will exist in the system whereby lower priority tasks are sacrificed before higher priority tasks.

2.2.9 Facilities

An uninterruptable power system (similar to the existing system) must exist to accommodate the reliability requirements. The environment for both personnel and paper products must be considered as well as the support of the basic component operations. Personnel work areas must be in accordance with favorable human working conditions. There must be adequate storage and support. It is desirable to minimize the amount of reconstruction for the data system because of time delay and additional cost. There must be adequate storage area for support of the required data system. The data system must be designed for the appropriate technical level of assigned personnel. Training at a reasonable level must also be a design consideration.

2.3 RESULTS OF VENDOR SEARCH

Realizing that we could not explore the total industry in the time available, we limited ourselves by concentrating on large computers and memory systems. We dealt with vendors who previously had been involved in the meteorological problem or had shown a recent interest in such involvement, and we concentrated on large computer manufacturers. Our final basis for concentration had to do with responses to initial vendor contacts requesting a nondisclosure agreement for advanced information during the period of time of the architectural study. Initial contacts with specialty computer houses revealed consulting services to be too expensive so we relied on other studies (e.g., SADPR 85) to draw our conclusions.

From our vendor search we concluded that there will be no computer generation announced until approximately 1980. A new generation would not be available for AFGWC until approximately 1982; therefore, we did not consider that possibility for our study.

However, we found that higher order languages are being microcoded. There were faster and larger main storages associated with computer systems, which met one of our primary objectives. Certain operating system functions are also being microcoded to reduce system overhead.

In the low to medium size CPUs, performance gains were approximately a factor of two, and for large CPUs there appeared to be no appreciable gain. Therefore, we looked to the current computers as solutions to our problems. Medium processors (which we referred to in our study as the main processor) ranged from zero to twenty RP. (An RP is a Relative Performance Unit which is our assessment of the computing power of an 1108 processor; however, it must be realized that there are many factors which are taken into account when doing a performance valuation of a computer). Looking at the Amdahl, the IBM 370 series, the CDC Cyber and the Univac 1100 series, there seems to be groupings centered around 3.5 RPs and 12 RPs. We considered these groupings in our Tradeoff Analysis and processor selection.

Fast computers fall into two groups: large, expensive, general purpose vector/pipeline processors and the special purpose less expensive array processors. The first group includes the TI ASC and CDC STAR. The second group includes parallel, associative, and vector/pipeline processors. These were available from most major computer manufacturers and many small companies. Although they are very fast and inexpensive it is difficult to determine efficiency, the ease of programming, the distribution of workload with a host computer which must support them and the difficulty to formulate problems to properly adapt their special characteristics (usually developed for another application).

The disk technology forecast can best be portrayed by what was written in the SADPR-85 study. Disks will be doubled in density by 1982 to 68 million words per pack for approximately a 10% cost increase over current 8433 types of disk. There probably will be no noticeable improvement in the access time due to head motion. (There may be double the number of tracks on a disk and double the rotation rate, which results in no noticeable decrease in track access time but a doubling of disk transfer rate.) Vendors may delay release of the new disks based upon amortization of current units in the field. In the early 1980's, bubble or charge coupled device memories will be available, but based on our requirements and the high risk associated with delivery of these devices, we decided not to consider them in our current study.

We looked at vendor data management software systems only to find that their orientation is primarily commercial and they do not seem to fit the AFGWC requirements without significant changing. Most vendors are reluctant to change their standard software packages.

We discussed security with many vendors only to find that there is little application for existing privacy capabilities in a DOD security environment, and that the capabilities of isolated executive and data management systems will not be a reality for some time. Even then, there will be a tough battle passing strict DOD security requirements.

Looking at tape technology, it is best described by the SADPR 85 study write-up. "There will be no increase in linear density with a maximum of 10,000 bits per inch. There is a possibility of doubling the number of tracks on a tape from eight to sixteen in parallel and tape speed may double using a smaller inter-block gap, higher transfer rate (though probably resulting in a higher error rate)." Large vendors are moving away from conventional tapes toward mass storage facility systems which are automatic and provide better efficiency with smaller tapes.

2.4 KEY TRADEOFF AND ANALYSIS STUDIES

Our tradeoff studies yielded many important conclusions. The major ones are presented below.

2.4.1 Data Storage

Mass memories should be used for unclassified archival storage.

Fixed head disks should be used for staging and for rapid cleaned applications.

Staging should be incorporated throughout the system.

Redundant disk and drum should be used for backup.

Multiple processors may access single disks theoretically; however, in practice, this will be minimized.

Communication buffering should be on system disks instead of independent disks.

A single universal data base should be used with classified overlays based on security requirements.

There is no need for data compression of satellite data merely for the purpose of saving storage.

The concept of a WWMCCS data base should be generalized to include all query type requirements.

Data base structure should be transparent to application of programs.

The meteorological data base structure should be redefined for higher efficiency.

A special data base management system should be developed for AFGWC rather than the procurement of a vendor produced system.

The capability to collect data base usage statistics should exist to the extent practical.

A data oriented language should be considered to augment FORTRAN at AFGWC.

2.4.2 Data Transfer and Routing

Parallel upgrade, communication link and control-only data link should provide primary intercommunication between main processors and disk devices within AFGWC.

A delimiting device should be used to filter control information in the control-only data link.

An encryption type of device should be used for authentication purposes to establish appropriate links between processors and data bases in the multi-security environment of AFGWC.

Master data base processor should transfer both to disk and directly to processors.

2.4.3 Computation and Software

Faster machines begin to be limited by their transfer rates.

AFGWC models will require the equivalent computing power of ten Univac 1108 computers operating at 100% efficiency.

95% of computation is unclassified.

Pipeline type of array processors show more application at AFGWC than parallel or associative processors for models.

Dedicating processors to special functions should be avoided.

Large jobs should be split into smaller components to meet time requirements and save computer power.

Multiprocessors are advantageous if they have the capability to become part of distinct data paths at different security levels.

Centralized data base management should be dedicated to specific processors.

Each processor system should have its own dedicated array processor.

There should be as many communications processors as there are security levels of data lines.

2.4.4 Terminal Interface

The Air Force Communications Service should be responsible for the communications systems and the decoder router while AFGWC should be responsible for the disk interface and the communications console.

Message logging should be employed in the communications system.

The system must accommodate data rates of 4800 baud with the following exceptions: AUTODIN II and satellite data to Fleet Numerical Weather Central are 50 kilobaud and digital radar is 200 kilobaud.

The capability should exist to filter satellite data using predefined data base values and/or user time criteria.

The satellite imagery dissemination system should only be able to interface with gridded imagery.

Satellite data gridding and mapping should be accomplished by the main processor by increasing the central system processor storage to implement significant input/output overlays.

Forecaster consoles which produce facsimile products should be connected to the Interdata 50s which will interface with all of the facsimile circuits.

2.4.5 Consoles/Data Input Display

Automatic work centers should use a "mail drop" disk communication technique.

Operations consoles should be placed in centralized positions in both special access and normal access perimeters.

AFGWC should develop the capability for interactive satellite imagery compression rejection for display.

Remote terminals are recommended for terminal interface rather than remote run card entry readers.

2.4.6 Personnel

AFGWC requires more personnel to perform the programming tasks.

There should be a mix of commercial software, contract programming software and Air Force programming software.

2.4.7 Management

The 1977-1982 requirements can be accommodated with modest changes to the AFGWC organizational structure.

Greater emphasis should be placed on acquisition/integration activities in the operations staff.

Operations management is changed as a result of network control to the extent of: a) consolidating the operational control function, b) putting preplanning parameterization in place of real time planning, and c) providing direct single point control when unforeseen anomalies arise.

Multi-tasking should be used to the maximum extent allowed by individual functions and their time lines.

Functions should not be dedicated except in the area of network control and master data base management.

A fairly complex run characteristic feedback capability is required.

A multiprocessor should be scheduled as a unit.

Software should be modularized with the capability to perform computation at the lowest security level.

There is no advantage in pursuing a design to accommodate a secure operating system.

No simulation models should be incorporated other than the scheduling prediction and exercise support capability.

Present software should be brought under structured programming.

Programmer productivity can be increased by better selection of personnel assignments.

Chief programmer teams, top down design, and structured programming should be used.

Interactive programming should be the primary technique of programmer interface.

AFGWC facilities are adequate to house the proposed hardware.

2.5 ARCHITECTURE AND HARDWARE CONFIGURATION

This section deals with the hardware configuration and describes at a conceptual level those resources that are available in the enhanced architecture. Figure 1 shows an architecture overview.

The architecture consists of a network of main processor systems under the central authority of network control. The security levels and functions performed by the main processor systems are not fixed but rather can be varied to meet demands on system resources.

The processors are linked to a set of data bases, which are fixed at security levels and are dedicated to functions. These data bases serve as the primary interface between the major system resource, i.e., the main processor systems, and the functional interfaces with data system users.

Four major subsystems are defined exterior to the nucleus of main processor systems. These subsystems are communications, satellite data ingestion, mission support automated work centers and mission operations automated work centers. The data bases provide a buffer between externally imposed loads and system resources, allowing a central authority to control system resource allocation. This optimizes system responsiveness under a wide variety of scenarios. The communications subsystems are responsible for the handling of

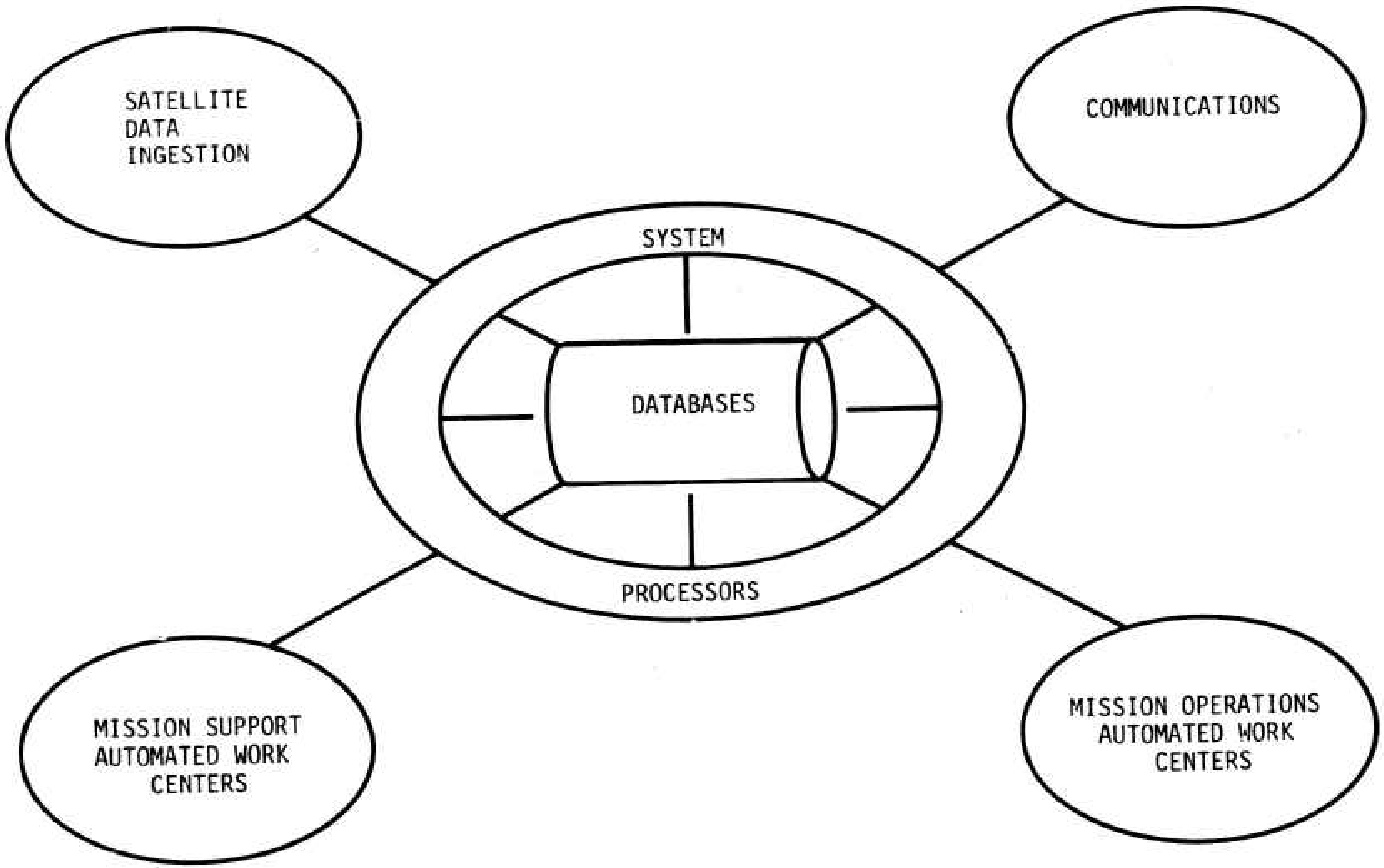

Figure 1. ARCHITECTURE OVERVIEW

normal communications traffic over lines such as AUTODIN and AWN. There are two such subsystems, one located in the normal access and one located in the special access perimeter. A satellite data ingestion subsystem is responsible for the capture of satellite data from meteorological vehicles into the data base. Mission support automated work centers handle those activities that do not perform actual mission-oriented work but are necessary to the success of the data system, such as network control and maintenance. Mission operations automated work centers modify/interact with the data bases to prepare user products (examples are TAF/METWATCH and SESS). The mission support and mission operations work centers are clustered around data entry and display devices located in consoles.

Figure 2 shows a more detailed description of the AFGWC enhanced architecture at a block diagram level without interconnections. This diagram shows the data system when it will have full capabilities (e.g., sometime prior to 1982). A line in the center running from top to bottom divides the system into special and normal access areas. The variable perimeter located in the approximate center of the diagram can be switched physically and electronically from special to normal access, and it acts as a backup for both sides. There are five main processor systems, one located in special access, one in the variable perimeter, and three in the normal access area.

There are four data base subsystems, one for special access and three in the normal access area. The three in the normal access area are divided into the classified data (Top Secret SIOP, Top Secret, Secret and Confidential), raw satellite data, and the unclassified central meteorological data base.

At the top of the diagram are network control and the two operations centers, one for special access and one for normal access. Network control has responsibility for the global scheduling and health of the data system, whereas the operations centers concentrate on each individual main processor system.

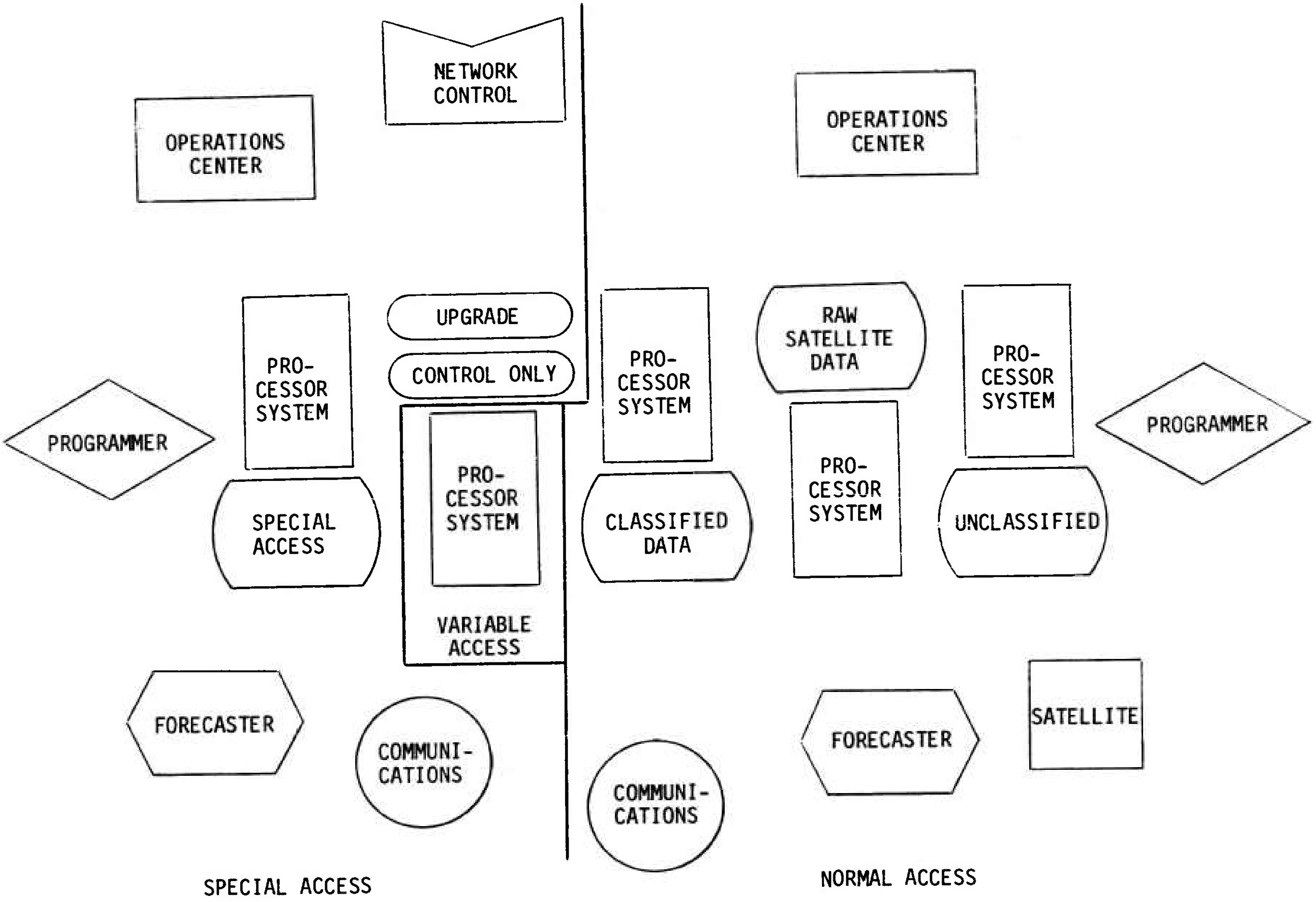

Figure 2. AFGWC ENHANCED ARCHITECTURE

Programmer support areas are located in both special and normal access. These consist of alphanumeric CRTs attached to support processors (which may be either minicomputers or control units) and are linked directly to processor systems. They are not interfaced through the data base and are the only exception to this rule. This route was chosen to preserve vendor-supplied software development packages.

Forecaster and communications support areas located in the lower portion of the diagram are linked to the main processor system through the data base. Within the normal access area, satellite ingestion processors interface with satellite-relay communications. Satellite and forecaster support processors are pooled to allow common backup units, which increase reliability at minimal cost.

The data system has a hierarchy of processing power to be applied against any given job. At the top level in terms of millions of instructions per second (MIPS) are the array processors, which are attached locally to each main processor system. Following them are the powerful general purpose processors which form the main processor systems. Each of the five main processors has approximately 3.5 times the throughput of a Univac 1108, currently used at the Global Weather Central. Within each functional area (such as communications, forecaster, programmer, or operations) are support processors which supply local computing capability and act as an interface between work center peripherals and the computer network.

At the bottom of the hierarchy are the interface processors used between individual consoles and support processors, or to handle complex non-vendor-supported interfaces. These interface processors consist of mini or micro processors which have little main memory.

Although most system communication takes place through the data base, direct processor linkages are provided for the transfer of large volumes of data between main processor systems. This is accomplished via a "wagon-wheel" approach, where any processor sends data to a central point, from which it is routed to other processors. This can be done either for two unclassified processors, or data can be sent from a lower to a higher classification level. The focal point for this activity is the upgrade processor, shown in the special access perimeter just above the variable perimeter. On the diagram, beneath this upgrade processor, is a control-only link. The control-only path has a highly limited bandwidth and allows only certain character sets to be sent between processors. This enables a processor of a higher classification level to request data base elements or interrupt a lower classification level processor. This control-only link is the mechanism whereby the network control computer schedules the remainder of the data system. The network control computer resides in special access because it must have knowledge of all activity within the data system including those at the highest classification level.

Figure 3, the AFGWC system architecture, illustrated in the enclosed foldout, shows an expansion of the block diagram of Figure 2 with interconnections and each block developed in fuller detail. For your convenience in locating items mentioned in the text, a coordinate system has been established in the diagram. Along the left hand side are a set of numbers from 1 to 12 and along the bottom are a set of letters from A through Q. When a major subsystem is mentioned, a coordinate location will be given next to it in parentheses. In the upper right hand corner of the diagram (Q-12) is located an abbreviations table. In the lower center of the diagram (H-5) is located a symbol table. References such as (AXXX) found with the abbreviations, symbols, or the diagram itself refer to the architectural domain. A vertical line (G-1 through G-12) divides the normal from the special access perimeters. The variable access perimeter (E-6) contains only a main processor system and the variable perimeter switch, which alters status from normal to special access by changing the peripheral sets attached to the main processor system. The variable access perimeter contains only rapidly cleanable devices so that it can be switched quickly from one mode to another.

Arranged in a checkerboard fashion between the processor systems are the data bases. Subsystems that deal with subsystem interfaces such as communications, operations, or programmers are located around the central nucleus of data bases and main processor systems. In the sections that follow, the hardware configuration is examined in more detail, beginning with processor subsystems.

Main processor subsystems consist of a hierarchy of processing capability and memory speeds. The general purpose processing capability is provided through a dual multiprocessor system in which two CPUs access common main memory. The general purpose computing capability is augmented by a more specialized array processor capability. The system may be split in the security verifiable manner to run as separate uniprocessors.

The main memory on the system which may consist of both main and extended memory can be split in a nonsymmetric fashion between the two uniprocessors. Attached as the next hierarchy of memory are fixed head disks which provide scratch areas for the execution of models and as work areas for the operating systems.

All input/output is shown as redundant and symmetrical. Each individual connection to the input/output unit of the multiprocessor is intended to correspond to an individual channel, although the number of channels will depend on the individual vendor architecture. Fixed head disks are shown redundantly on separate control units so that they can be split when the multiprocessor is segmented.

An authentication chip memory is shown for each half of the multiprocessor. The authentication chip memory is set by network control via an authentication key link and determines the security level of the processor by establishing what connections are accessible to it. The maintenance console is provided for each main processor system and is intended to contain all necessary peripherals for stand alone maintenance of the processor.

Support processors provide a minimum computing capability for short term responses to individual functions. In addition, they provide an interface between the automated work center personnel using peripheral devices and the major processing capability of the system via a data base.

The only support processor which is directly attached to a main processor system, rather than going through the data base, is the programmer support processor (E-3, M-3), as previously mentioned. Programmer consoles are provided in both the special and normal access perimeters. In the special access perimeter, they will be enclosed in the vaulted area. In the normal access perimeter, the consoles will reside in the individual offices of programmers or groups of programmers. The console itself consists of an alphanumeric CRT with a keyboard.

Processors that support forecaster functions (F-3, N-6) have been pooled with those that provide for the ingestion of satellite data. They have the similar characteristic of high bandwidth for data transfer and pooling provides a higher degree of reliability at a lower cost than would be possible otherwise.

Forecaster consoles have been broken out according to function. For example, there are TAF/METWATCH consoles, SESS consoles, MWA consoles and synoptician's consoles. Satellite imagery dissemination (SID) is accommodated by the satellite ingestion processor. Support processors for satellite imagery dissemination and forecasters have a local scratchpad data base (E-2, N-5) for manipulation of displays and the receipt of data base elements from the central unclassified meteorological data base. Each console consists of a mixture of devices such as alphanumeric CRTs, high resolution black and white CRTs, and color CRTs.

The communications subsystems (B-2, O-2) consist of several computers, one for each security level. These computers are designated "line handler/decoder routers". They have the responsibility for all line-oriented functions, such as acknowledgements, retries and error correction. Because secured lines may contain a mixture of security level messages, each line handler/decoder router (LHDR) must be capable of downgrading messages to a lower security level. In order to confine mixed mode security to the smallest possible subset of the data system, each line handler/decoder router passes these lower security level messages to another line handler/decoder router at the appropriate security level. This line handler/decoder router simply views this transaction as coming from an additional communications circuit that it must handle.

All line handler/decoder routers are interfaced with the communications console (D-3, L-2) which has responsibility for unscrambling garbled messages and passing them to the appropriate security level. Data passed through the communications console is buffered on a low capacity storage device. This low capacity storage device (LCSD) can then be physically removed and transferred to a reading device which has been switched into the appropriate security level. This provides physical isolation so that there is no path for accidental leakage of data from one security level to another. Redundant line handler/decoder routers are provided for complete availability of the communications subsystems.

Subsystems provided for mission support are network control (B-6), the printer subsystems in the normal (I-11) and special access (C-11) areas, the operations centers in the normal (K-11) and special access (D-11) areas, the data downgrade for normal (L-11) and special access (F-11), and the special operations console (H-11) in the normal access area. Centralized printer subsystems contain data spooling areas and printers which are separated according to classification level. The operations center contains alphanumeric keyboards and displays for messages from individual processors. Centralized operations centers are backed up by the processor consoles, although they contain internally redundant hardware. Data downgrade provides a manual path for the downgrade of data using low capacity storage devices in a configuration similar to the communications subsystems, with switches for connection into each security level data base. Remote jobs may be entered from the special access and normal access data downgrade consoles as an additional responsibility of the subsystem. This allows the capability for a higher classification area to initiate lower classification runs. The special operations console allows the entering of data directly to different security level data bases and the initiation of runs. This console is mainly switched between security levels. Support processors are clustered together to provide the computing power in a pool for the operations oriented subsystems. These subsystems are located along the top of the AFGWC Data System Architecture diagram.

Data storage subsystems are located in the special and normal access perimeters but not in the variable access perimeter. This is to allow the variable access perimeter to switch from special to normal access support as fast as possible without any possibility of a security violation due to data reamining. If peripheral sets were located in the variable access perimeter there would be the possibility that a disk pack or a tape would be left there as well as causing a several minute delay for dismount and storage. Instead a switch has been located in the variable access perimeter which allows physical isolation.

Classified data base subsystems are structured such that disks at each classification level are isolated on individual control units which are dedicated to classification levels. This allows the disks to be accessed and have a physical path only from certain processors without any possibility of inadvertent access of data by unauthorized users.

Control units for the disks at a given security level are redundant to provide the ability for preventive maintenance while the system is still accessible to processors. When one of the disk control units is not taken for preventive maintenance dual control units provide additional performance through separate paths to disk packs.

To provide for the number of interconnections necessary for processors to be attached to many different data bases, it is also necessary to have a switching matrix between the channels and the disks' control units. This is an electronic device with an extremely high reliability; it is modular in nature such that individual switching matrix nodes can be replaced by pulling out a module and replacing it with another.

These switching matrices essentially allow all processors to be connected to all data bases within their security span all the time. This avoids switching transients when changing roles between the processors. Therefore, the possibility of processor failure due to unpredictable transients on the channels is eliminated. Protection between security levels is provided using the authentication chips. Authentication chip keys for data bases are manually loaded. They have no link to network control. This is an additional check against the possibility of inadvertent access since their authentication keys do not change (unlike the processors which are modified).

Redundant disk units can also be shared among security levels through manual switching arrangements. Such a possibility may lower the cost below SDC costing with redundancy at each security level. (SDC did not cost the lesser alternative because it is not available from all vendors and because of the possibility that it is not security acceptable for disk subsystems DS1 (B-5) and DS2 (I-6)) Tape control units are connected to the disk control units to provide a path for data to be destaged from disk-to-control-to-tape drives. Thus, processors can leave data on disks that will eventually be written to tape without direct connection.

This alternative may or may not be cost effective for individual vendors and so SDC has specified a hierarchy of alternatives in this area, the preferred one being that shown in the diagram. The preferred alternative here illustrates the use of manually mounted and dismounted tapes. However, two other alternatives exist, one of which is to use a mass storage facility which contains automated mounting and disk mounting facilities and the other is to dedicate tape drives to processor systems.

Four different kinds of disk drives have been used in the data base subsystems. The largest capacity drive termed "bulk" is similar to the IBM 3330 Model II.

This disk drive provides approximately 200 million characters of capacity per drive and is the most cost effective in terms of dollar per bit stored.

The second type of disk drive that has been used, termed "combination", provides faster access by spreading data over more disk drives and by providing fixed head areas as a portion of each disk drive. The prototype for this is the IBM 3340 disk drive.

In the satellite data ingestion area, the satellite disk has been specified. The prototype is the Univac 8440. Specification of this category of disk drive allows continuation of current software and AFGWC hardware. In addition, for good performance on mapping and gridding it is necessary to have the data spread over more disks than would be possible with the 3330 Model II type of disk.

Because the support processors might be any type of computer, disks currently available for attachment to support processors have been specified for all of the automated work center data storage subsystems. The following identifies all of the storage subsystems on the AFGWC Data System Architecture diagram. Special access (B-5, DS1), normal access classified (H-6, DS2), satellite data (L-9, DS3), unclassified central data base (O-7, DS4), normal access forecaster support (P-4), special access forecaster support (E-2), special access printer spooling (C-11), and normal access printer spooling (I-11).

Interprocessor communication is provided through the control-only and upgrade links. These links are in the form of a central routing hub rather than individual interprocessor connections. The use of the central routing hub provides a means for growth. Each individual processor that is added need only be connected to this hub rather than connected to all of the additional processors which exist in the network.

The path for control information exchange between a processor at one security level and another at a lower security level is provided through the control-only link. The control-only processor not only provides routing of information but restricts the bandwidth and symbol set which can be exchanged between processors from higher to lower security levels.

The upgrade link provides an exchange of information between processors from a lower to an equal or higher security level. This is accomplished as follows. The processor may request an upgrade path from network control. For example, suppose that the requesting processor is Unclassified and the destination is Top Secret. Network control would provide the path by establishing hardware mechanisms within the upgrade link. Once these hardware paths were set up transmission can begin from the unclassified processor. The data is routed from Unclassified to Confidential level and from Confidential to Secret level and from Secret to Top Secret level through cascading authentication devices. Because the hardware paths always take data from one level to a higher level, there is no possibility of inadvertent access of classified information by a lower classification level.

2.6 SYSTEM MANAGEMENT AND OPERATION

This section provides an overview of how system management and operation is accomplished within the enhanced architecture. Topics discussed include security, network control, data base management, and data system interfaces. Security in the enhanced architecture has been effected without the use of mixed mode. The one exception to this is in the communications area where mixed mode is already present within the communications lines themselves. For example, Top Secret AUTODIN can carry Secret, Confidential and Unclassified messages in addition to Top Secret messages. Therefore, it is essential to be able to discriminate the classification levels of messages within communications lines and downgrade them at the earliest possible opportunity within the data system. To provide for this, downgrade takes place within the communications line handler/decoder router. Several different mechanisms are used in the software to verify the classification level of messages and those which are doubtful can be routed to a communications console for manual interpretation. The communications console provides a means for the storage of messages and the display of these messages on a CRT. Once the communications officer determines the security level of the message, he has a physically separate device for reading the message back into the system which can be switched into any security level line handler/decoder router. The interface between line handler/decoder routers and the interface between the communications console and the line handler/decoder routers are treated as communications interfaces; therefore, they are not included in hardware and software costs. (The line handler/decoder routers and the communications console are included in the system cost.)

The bulk of AFGWC equipment is contained within vaulted areas, the exceptions being forecaster and programmer consoles. Their access is limited to processors and data bases that are operating at an unclassified level. All classified software development takes place from programmer consoles located within the vaulted areas. Isolation of processors to security levels is accomplished through authentication devices capable of encryption and decryption at channel transfer rates. Authentication devices attached to processor systems and data bases have non-vulnerable memories. Those which are attached at data bases are set for long periods of time and can be loaded via locally attached devices through manual actions. Processor systems have their memories remoted to the network control computer and console, so that they can be switched between classification levels in a relatively short period of time.

When a processor system is set to a security level its input/output access paths become encrypted at that security level. In addition, the operating system for that security level has in its input/output device tables only those devices which are classified. If, through an error in software, an access is attempted to an improper security level, the result will be an authentication error which will cause termination of any further access attempts. The status will be returned to the processor which can in turn pass this information to the operations console and the network control console so that appropriate recovery action can be taken.

These authentication devices will be transparent to diagnostics and access methods. In the event of an authentication device failure, the fail-safe mode will be to block data passage. The device can be switched out and replaced in a matter of minutes.

All downgrading of information is manually approved with the exception of control-only information. Control-only paths exist within the architecture to allow the triggering of predetermined responses for higher and lower classification levels (such as those for network control, directing of processor, and telling the processor to look on its job queue). This control-only link consists of a highly restricted bandwidth and a checking mechanism to determine the validity of control characters that are being passed.

A wide range of possibilities is required so that the fairly restricted, acceptable ones have a low probability of accidental passage. Attempts to pass illegal characters will be immediately blocked. This security approach provides protection only against inadvertent access data rather than penetration of the data system by a hostile intelligent penetrator. Protection can be restricted to this level because the entire data system is encompassed within a classified area and is physically protected and because unclassified communication links cannot introduce new software into the system.

Because processor systems can be rapidly switched between security levels, either upgrade or downgrade, resources can be allocated in response to priority missions regardless of their security level. In addition, the processor systems can be segmented into area processors which can be run at different security levels.

Network control provides essential authority for resource allocation, system scheduling and status monitoring. To prevent an overloading of network control, some of the functions which are processor system peculiar have been off-loaded to another hierarchy of scheduling and system response, the operations console. Network control establishes the state of the data system in response to the average load. If peak loads occur, network control can modify the state by switching in backup resources to provide more throughput. In the event of a failure, network control provides a means for determining the most appropriate response on a system wide basis. To do this, we resort to a shifting of functions among several processors. This is possible because there is a single job queue maintained by network control which is parceled out to individual processors and because all processors are physically connected to data bases while they may be isolated from the access via authentication chips.

Detailed job parameters and data base elements are left at individual classification level data bases by support processors or communications oriented line handler/data routers. Network control then determines which processor should operate on these jobs and interrupts it to notify it to look on that classification level data base for the work to be done. When the processor is finished, it interrupts network control to provide the information as to the location of the final results. Network control, having kept a record of where the job came from, then tells the requestor that his information is ready and can be obtained from the appropriate classification level data base. Network control is also responsible for setting the switches which determine the hardware interconnections such as those for switching in backup computers.

Network control maintains a nominal predicted load schedule and a maintenance schedule and provides the authority for the actual removal of components from the data system for maintenance. Network control also provides a central point for the integration of work in progress status and for the status of hardware components within the data system.

The meteorological data base has been centralized and is under the control of the central data base manager. This data base manager is one of the main processor systems and has a backup which is ready to take over in the event of a software or hardware failure and which is a different main processor system. The central data base manager receives requests from other processor systems for data base elements, locates those data base elements, and transfers them to the requesting processor. Because the data base is unclassified, it is necessary to have overlays which are contained on the classified disks. The processor requests geographically classified information from the central data base via a broad geographical area which camouflages the nature of the true request. As data are being sent to the processor, they are filtered down to the necessary data base element and stored on disks. At the same time, the classified overlay information is applied to the data. Therefore, in addition to the central data base management software, it is necessary to have local data base management within each main processor which is less elaborate than the central data base software. Central data management is also responsible for the paging of data sets to and from the mass storage facility. Central data base will also attempt to preformat data during slack periods for optimum running of models. Data requests are scheduled ahead of time because network control knows of the upcoming jobs and can request these from the data base manager. The data base manager in turn can make certain that the data base elements required are available on disk by staging them from the mass storage facility and assure that they are in the proper format and ready to be accessed. Centralized data base is really an essential point of the architecture because it is necessary to distribute the work load among multiple processors in order to meet scheduling deadlines. As a result, the data base must be updated concurrently from several different processors. Without a central data base it would be necessary to distribute updates among all processors resulting in very high traffic and the possibility of conflicts in updates. It should be noted that processors will be downgraded to Unclassified as soon as possible after being upgraded and that processor systems will normally be in the unclassified mode.

2.7 SYSTEM DESIGN CONSIDERATIONS

This section discusses those overriding considerations which were taken into account in the architecture and were responsible for its evolution towards a final form. Such considerations include flexibility, growth, the forecast of future technology, interpretation of key driving requirements, questions of reliability and maintainability, manpower and physical space. To provide flexibility in the architecture, it is necessary to provide computational capacity for loading peaks. In addition, it is necessary to make certain that the resources of the architecture can be applied to these peaks both at varying security levels and in terms of varying functions which may occur simultaneously and in conflict with one another. This problem is complicated by the possibilities of different scenarios for peace time crises and war time. In addition, it is necessary to minimize the amount of coupling between functions because changes to functions to adapt to changes in requirements now result in disastrous ripple effects throughout the rest of the data system.

In addition, as time passes, requirements change, and some of the requirements will not materialize while others will. The architecture provides flexibility in many different ways. Protection against loading at different security levels and for conflicting functions provided through the means of network control with the buffering of resource requests on disks prior to the assignment of resources to process functions. In addition, because processors can "float" between security levels, it is possible to apply resources against many different functions and many different security levels. This can be contrasted to the present architecture which involves a dedication of systems to functions. It has the problem that, given an overload scenario, it is necessary to bring about the manual switching of configurations and the difficulty with which additional processors are applied to problems such as computer flight plan generation. Coupling between functions in the enhanced architecture has been minimized by functionally segmenting the system and isolating the nucleus of main processes from individual dedicated functional support processes. Changes in requirements can now be isolated to functional subsystems such as communications or satellite ingestion without an effect on the rest of the data system. Flexibility has also been provided by the use of large scale general purpose processors and where necessary, array processors. Array processors, although problem specific, are still flexible in that they have microcoded control memory and are expandable in arithmetic power and memory elements.

Growth of the data system has been provided by modularization and simple interfaces such that additional computer power or data storage can be plugged into the architecture. Computational power can be increased by a) adding additional processors, either support processors or main processors, b) by upgrading main processors, taking advantage of vendor announcements, or c) by the addition of array processors to handle those key driving requirements with exceptionally high instruction per second requirements.

Storage capacity has been expanded greatly in the enhanced architecture, primarily by the addition of a mass storage facility which will enable the expansion of disks via a demand paging of data sets to and from tape and disks.

Disk subsystems, having been functionally dedicated, are readily expandable either by additional disks on a control unit or additional control units and strings.

Main memory on processors is not as constraining as it is under the current architecture due to the ability of network control to schedule jobs in such a manner to eliminate memory bottlenecks which cause non-optimal CPU utilization. For example, software development jobs and communications handling jobs can now be spread among processors such that they can fill in between numerical models or input/output bound functions. The communications interface has been modularized so that it is readily expandable with the addition of more line handler/decoder routers or the upgrading of existing line handler/ decoder routers. Expansion of functions currently done manually which would require additional (unavailable) manpower has been minimized as a problem area due to automation in the use of interaction with the data system. This can be seen clearly from the automated work centers concept that has been developed for the enhanced architecture.

Satellite data ingestion has been isolated and removed from main processor resources which are now free to take on other jobs while data is being captured. In addition, satellite mapping and gridding can now be distributed over several processors to handle the multiple satellite passes which will occur concurrently in the future. In order to design a data system of this magnitude, it is necessary to make certain assumptions in the interpretation of requirements. These assumptions should always be conservative to protect against the inherent inability of people to define future requirements.
In addition, because requirements are compiled individually by mission oriented groups, it is necessary to define certain overall scenarios. Examples are the conflict probabilities with regard to simultaneous running of numerical models, data ingestion, mapping and gridding of satellite passes, and the simultaneity of multiple occurring responses at different security levels.

Again the data system has been designed with the flexibility to encompass the possibility of error in the definition of requirements or the interpretation of requirements and the fact that the requirements will alter with time. For example, to provide against multiple conflict situations, the architecture has been designed with five main processor systems, each of which can be split into two resulting in a maximum number of ten main processor systems. In addition, each main processor system has its own array processor since physical cabling distance prevents sharing. Also, several array processors were needed due to scheduling conflicts. Although the amount of classified work done in the facility in the normal access area is relatively small, the importance of it is very great. In a crisis or wartime scenario, such type of work will increase unpredictably. Therefore, it is vital that the data system be able to apply resources across security levels with a minimum amount of effort. This, of course, has been provided as mentioned previously.

Cost is always a critical factor in the design of any data system. Cost has been minimized in the case of the AFGWC architecture in a number of ways. First, the main processor systems have been designed around a capacity level which will enable the reuse of existing equipment and therefore existing software. Second, cost has been minimized by the approach of staying within the center of the industry growth pattern, enabling AFGWC to take advantage of a wide customer base for each piece of equipment it will procure. Hence, it will always have good software and maintenance support at reasonable prices. In addition, the enhanced architecture has taken advantage of the decrease in physical space for new generations of processors, so that growth from 1975 to the 1982 configuration can be provided within the existing physical space without expensive construction. Manpower costs, which are perhaps secondary to manpower availability, have also been minimized through automation of functions done manually today and centralization of operations which support the data systems such as printers and tape.

2.8 IMPLEMENTATION AND COST

Table 1 shows an implementation schedule. Note that the majority of requirements require support prior to 1980 and thus the schedule is heavily front-ended.

Table 1. IMPLEMENTATION SCHEDULE

1977 - EARLY 1978	PROTOTYPE DATA BASE PROCUREMENT UPGRADE S/A COMM
EARLY 1978	2 NEW PROCESSORS OPS CENTERS NEW DATA BASE UPGRADE AND CONTROL ONLY
MID 1978	REMAINING PROCESSORS UPGRADE SATELLITE PROCESSING SIDE-BY-SIDE COMM
EARLY 1979	NETWORK CONTROL
MID 1979	AUTOMATED WORK CENTERS

Table 2 shows the acquisition cost for the recommended architecture. These cost figures are really more upper bounds than they are best guesses, i.e., the data system has a 95% chance of costing less than the figures shown. Column 1 shows assets that will be present in 1977 (if current plans are adhered to) and reuseable. The second column shows the total cost of the enhanced architecture, and the third column is the potential 1977 to 1982 cost based on retaining the baseline assets, i.e., column 3 is equal to column 2 minus column 1.

Table 2. ACQUISITION COST FOR RECOMMENDED ARCHITECTURE

HARDWARE	BASELINE ASSETS	ARCHITECTURE COST	POTENTIAL 77 - 82 COST
PROCESSORS & MAIN MEMORIES	$21.9M	$42.0M	$20.1M
AUXILIARY STORAGE	$ 1.6M	$ 6.8M	$ 5.2M
DATA TRANSFER & TERMINAL INTERFACE	$ 0.04M	$ 4.5M	$ 4.5M
CONSOLES, DATA INPUT & DISPLAY	$ 0.4M	$ 6.0M	$ 5.6M
	$23.9M	$59.3M	$35.4M
SOFTWARE			
DEVELOPMENT	$ 2.0M	$19.0M	$17.0M
CONVERSION	$ 2.0M	$ 5.9M	$ 3.9M
	$ 4.0M	$24.9M	$20.9M
TOTAL COSTS:	$27.9M	$84.2M	$56.3M

2.9 SUMMARY

The SDC design is complex; however, it is quite simple compared to the very complex problem that must be solved. A simpler design could undoubtedly be accomplished, but we feel only at a decrease in reliability or a greater component cost.

The present design is the least expensive of the primary options at around $80 million. The alternatives using different processors cost as much as 50% more.

A reassessment of requirements could reduce the cost of this design. The primary targets in such a cost reduction would be high resolution satellite data processing and any of the very difficult numerical problems (e.g., Minuteman, cloud free line of sight, and the query/response capability). A reduction in the reliability requirement would also have some effect but not until it was significantly reduced.

The next steps in this effort are obviously detailed design and study in the areas identified (especially software) and a refinement of the acquisition process. Any deviation to the proposed approach should be thoroughly analyzed since many of the features are subtly interrelated.

SDC is proud of this design and has high confidence that it is a firm basis for an architecture to support AFGWC requirements through 1982.