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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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This volume presents a design development and logistics schedule in section 1.0, and discusses implementation aspects of the architecture in various stages from a 1977 baseline through mid 1979. Included in this section are software topics, as well as hardware, personnel, and facilities topics. Time-phased system architecture costs are presented in section 2.0 for all components of the architecture domain, while a detailed data system risk analysis is given in section 3.0. Section 4.0 presents various aspects of the validation and verification of the proposed data system, including hardware and software topics.

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RELATIONSHIP OF VOLUME STRUCTURE TO DOMAIN

The required content of this document made its structure unsuitable for close conformation to either the architectural, functional, characteristic, or requirements domains. Of the three topics discussed however [(1) Design Development and Logistics Schedule, (2) System Cost Considerations, and (3) Risk Analysis], there is structural resemblance to the architectural domain through a portion of the first two of these topics. In the first section, paragraphs 1.1, 1.3, and 1.4 involve architecture components A10-60, A70, and A90 respectively with 1.2 then focusing in more detail on software (A30.2-30.4). The second section dedicates paragraphs 2.3, 2.4, and 2.5 to A10-A60, A70, and A90 respectively. The third section and the remainder of the first two are concerned with topics either not related to the domain structure, or are general in nature such that they correlate to all aspects of the domains.

To establish traceability between the implementation and development plans and the rest of the architecture, we have defined an implementation plan "domain" whose components are made up of groups of related hardware, software, personnel, and facilities or concepts involved with preparing them for implementation. The elements are listed in detail as "activity codes" in tables 2 through 5. The location in this volume of the discussion, schedules, and costs involved with the implementation plan "domain" are pointed out in the following table entitled "Applicable Domain vs. Paragraph Numbers". Finally the correspondence between the implementation plan domain and the architectural domain is established in the second following table labeled "Volume/ Domain Relationships".

APPLICABLE DOMAIN VS. PARAGRAPH NUMBERS

IMPLEMENTATION PLAN "DOMAIN"	DISCUSSION	IMPLEMENTATION: SCHEDULE	COST
H11	1.1.2	1.5	2.3
H12	1.1.2	1.5	2.3
H13	1.1.2	1.5	2.3
H14	1.1.2	1.5	2.3
H21	1.1.3	1.5	2.3
H22	1.1.3	1.5	2.3
H23	1.1.3	1.5	2.3
H24	1.1.3	1.5	2.3
H25	1.1.3	1.5	2.3
H26	1.1.3	1.5	2.3
H27	1.1.3	1.5	2.3
H31	1.1.4	1.5	2.3
H32	1.1.4	1.5	2.3
H33	1.1.4	1.5	2.3
H34	1.1.4	1.5	2.3
H35	1.1.4	1.5	2.3
H41	1.1.5	1.5	2.3
H51	1.1.6	1.5	2.3
H52	1.1.6	1.5	2.3
S11–S34	1.2	1.5	2.3
P11	1.3.2-a	1.5	2.4
P21	1.3.2-b	1.5	2.4
P22	1.3.2-b	1.5	2.4
P23	1.3.2-b	1.5	2.4
P24	1.3.2-b	1.5	2.4

P31	1.3.2-c	1.5	2.4
P32	1.3.2-c	1.5	2.4
P33	1.3.2-c	1.5	2.4
P41	1.3.2-d	1.5	2.4
P51	1.3.2-e	1.5	2.4
P52	1.3.2-e	1.5	2.4
F11	1.4-a	1.5	2.5
F21	1.4-b	1.5	2.5
F22	1.4-b	1.5	2.5
F31	1.4-c	1.5	2.5
F41	1.4-d	1.5	2.5
F51	1.4-e	1.5	2.5

VOLUME/DOMAIN RELATIONSHIPS

IMPLEMENTATION PLAN "DOMAIN"	ARCHITECTURAL DOMAIN COMPONENTS
H11	not part of new architecture
H12	A112, A121, A123, A311, A312, A516
H13	not part of new architecture
H14	A11, A23, A313, A512, A514, A523, A528, A60
H21	A112, A121, A123, A311, A312, A516
H22	A112, A121, A123, A311, A312, A516
H23	A113, A116, A233, A236, A26
H24	A113, A114, A115, A117, A233, A234, A235, A26
H25	A20
H26	A111, A118, A122, A231, A26, A313, A512, A513, A611, A622, A661
H27	A111, A118, A122, A231, A26, A313, A512, A513, A529, A611, A621, A622, A652, A661
H31	A112, A121, A123, A311, A312, A516
H32	A112, A121, A123, A311, A312, A516
H33	A114, A234, A515, A611, A613, A661
H34	A118, A26, A451, A514, A611, A661
H35	A118, A26, A451, A514, A611, A661
H41	A26, A511, A611, A641, A661
H51	A26, A611, A623, A661
H52	A521, A522, A523, A524, A525, A526, A624, A66
S11	A324
S12	A324
S13	A324
S14	A324
S15	A324
S16	A324
S17	A324
S18	A324

S19	A324
S110	A324
S111	A324
S112	A324
S113	A324
S114	A324
S115	A324
S116	A324
S117	A324
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F22	A93
F31	A934
F41	A93
F51	A92

1.0 DESIGN DEVELOPMENT AND LOGISTICS SCHEDULE

The structure of this discussion of implementation schedules is roughly designed to follow the format established by the architectural domain including: data storage, data transfer and routing, computation and software, terminal interface, consoles, and data input and display (architectural domain components A10-A60). These are discussed collectively in Section 1.1. The discussion is chronological, starting with an assumed baseline in early 1977 and running through the full implementation of the new system in mid-1979. Because of the importance of software (A32-A34 of the architectural domain) on this schedule, it is given special treatment in Section 1.2. Two more of the elements of the architectural domain, personnel and facilities (A70 and A90 of this domain) are introduced in Sections 1.3 and 1.4, respectively. The only aspect of the architectural domain omitted was management (A80), since it only has an implicit bearing on the implementation schedules. Section 1.5 concludes this discussion with a summary of activity schedules which have been developed for input to automated network scheduling and analysis systems.

1.1 TOTAL SYSTEM ARCHITECTURE AND PHASEOVER SCHEDULE (A10-A60)

The driving factor in determining the timing for an implementation plan for the enhanced AFGWC architecture is the schedule associated with established requirements. In order to meet these requirements according to the exact specifications established by the Air Force, certain reliability levels must be met and maintained. To satisfy a given requirement and its reliability, certain hardware components become necessary by specific deadlines and the implementation plan is established. A brief discussion of reliability at this point will help to establish it as this link between requirements and an implementation schedule.

In analyzing user requirements, SDC has found the specification of 97% and 95% reliabilities (assurance of delivery of the product on time) associated with USAFE and WWMCCS requirements which become operational in mid 1978. There are many factors which enter into the successful generation and delivery of a product. The criteria for success often depends on the communications system,

error free operator action, and other external influences which are over and above the reliability requirement of the AFGWC data system. SDC felt that to satisfy the requirement reliability, the data system must have a significantly higher reliability goal.

For the final system, SDC picked 0.995 reliability as a design goal which was conservative in terms of satisfying user needs, yet was within the grasp of AFGWC, based on current technology and cost/risk design criteria. The ground rules for the implementation period have been to use the present reliability associated with AFGWC as a lower limit while striving to meet the new goal. As individual requirements (such as WWMCCS) dictate the lower bound on reliability is increased and new components or architectural elements are implemented. The plan to implement Network Control in early 1979 is a case involving just such a reliability tradeoff. WWMCCS will already have been implemented and Network Control would most certainly have helped the system obtain the necessary 95% reliability, but it would have been overkill. By mid 1978, all major processors would have been available supplying an excess of power to support WWMCCS. Network Control does not become a requirement based on reliability until the final stages of the implementation schedule.

Based on the type of tradeoffs just described for Network Control, implementation of the major subsystems of the AFGWC enhanced architecture have been scheduled to occur in five basic steps following the early 1977 baseline. The time periods associated with these steps are:

a. 1977 to early 1978,

b. Early 1978,

c. Mid 1978,

d. Early 1979, and

e. Mid 1979.

The following subsections discuss the baseline configuration and hardware components to be changed at each of the ensuing five steps.

1.1.1 Baseline

The 1977 baseline is expected to consist of six 1110 computers. The first will handle SX[1] functions with the second processor acting as backup. The third and fourth processors will handle satellite data processing and non-SX communications, respectively. The last two processors will handle most data updates, with one machine running while the second functions as a backup. The four groupings (SX, satellite processing, communications, and data base update) will each have a separate data base and operations center associated with it. The only other major hardware subsystem will consist of the IPADs display system. This whole system is pictured in Figure 1. (The same abbreviations and symbol shapes will be used consistently throughout this discussion.)

1.1.2 1977 to Early 1978

During this period, the data base processor will be installed. This processor will be necessary to handle the many upgrades and model enhancements expected at this time. These include atmospheric and ionospheric analysis and forecasting functions for different grids, resolutions, and purposes (e.g., the advanced prediction model, ZOOM and various SESS functions). The increased automatic handling of new types of satellite data during this time period is also expected to require more computer processing power. At this time, Special Projects communications will also be upgraded to provide a direct link to the processors. Finally, a prototype computer of the 3.5 RP category will be constructed with an array processor, fixed head disk, and other components. Connected to this prototype will be a data base, communications console, forecasting console, and operations console so that all facets of the new system (both hardware and software) can be simulated prior to implementation. Phasing in of programmer consoles will begin at this point as software development requirement dictate with full implementation not completed till mid 1979. The system configuration at this phase is pictured in Figure 2. The following conventions will be used from this point in such diagrams:

---

[1] SX = Special Projects Branch, now designated as WPJ.

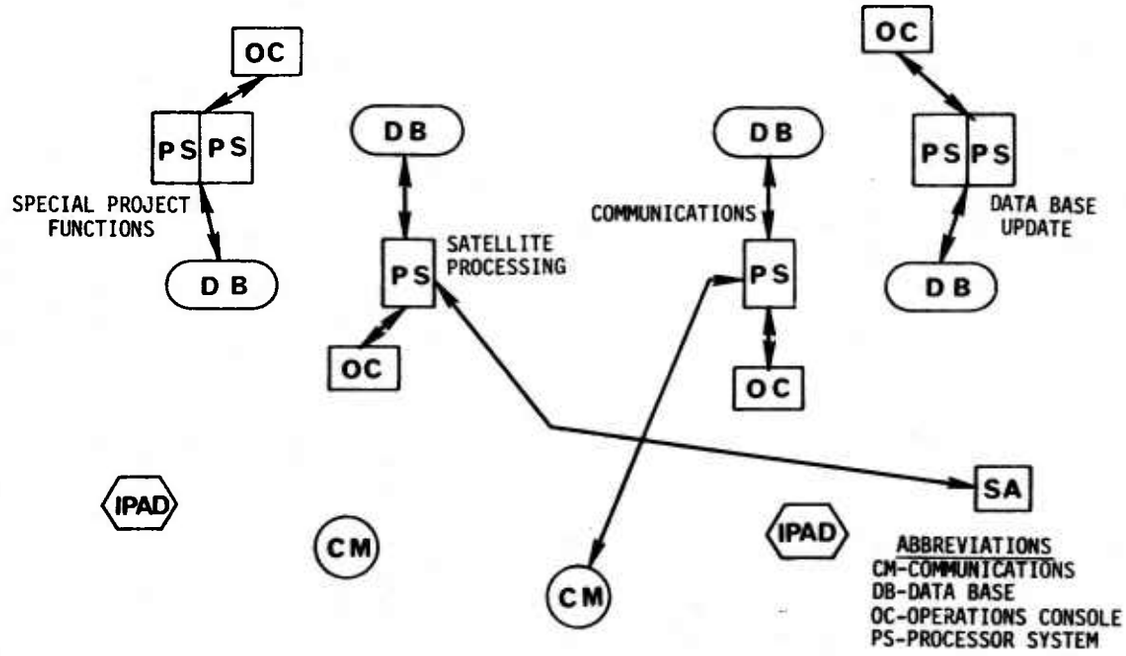

Figure 1. Configuration Baseline - Early 1977.

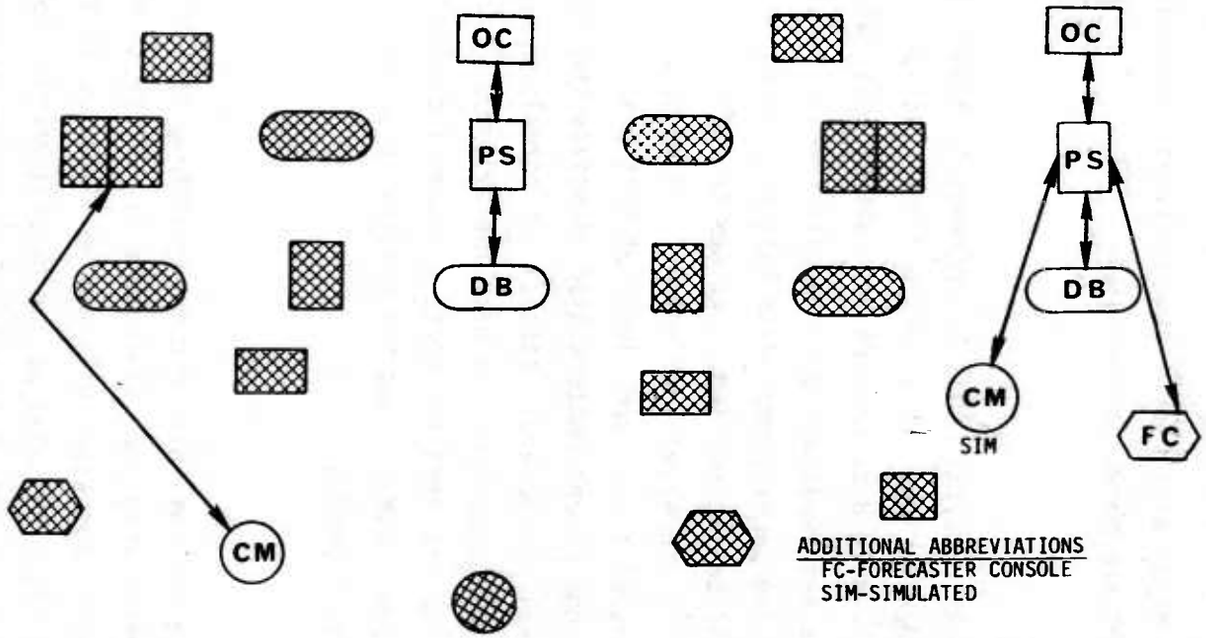

Figure 2. 1977 - Early 1978 Configuration.

a. components which will be eventually phased our are cross-hatched,

b. components which are being installed as part of a step being described are pictured as an outline containing an abbreviation,

c. components which are part of the new configuration but are also part of a previous step are pictured as a blank outline, and

d. only the major data flow lines involving components implemented in a given step are shown in that step.

1.1.3 Early 1978

At this time, the AFGWC system will be upgraded to handle the new data base concepts recommended by SDC. This will not only include storage space but also the switches involved in data upgrade and control only data lines. As the new data base concepts are implemented, they will remain invisible to the user programs still operating under former data base procedures; a transparent data base interface will be implemented. Two new processor systems will be implemented to handle the increased load established by data base management; new operations consoles will also come about at this phase. The active implementation of these two operations centers also signifies the formation of the two distinct operational perimeters: special and normal access (which is admittedly only a change in semantics from the baseline system). The driving requirements which will establish the need for these upgrades include: increased Automated Weather Station input, WWMCCS, and the ability to serve as a backup to Carswell. This is pictured in Figure 3.

1.1.4 Mid-1978

At this point, the two remaining processor systems will be upgraded (one of them originally the prototype) and, since this allows the three access perimeters to be established, major functions will now be allocated to the appropriate processors. Specifically, PSI will be for special access; PS2 will be for the variable perimeter; and PS3, PS4, and PS5 will make up the normal access area. This added computer power will be necessary to support Cloud Free Line of Sight programs. With the availability of TIROS-N satellite data and the inauguration

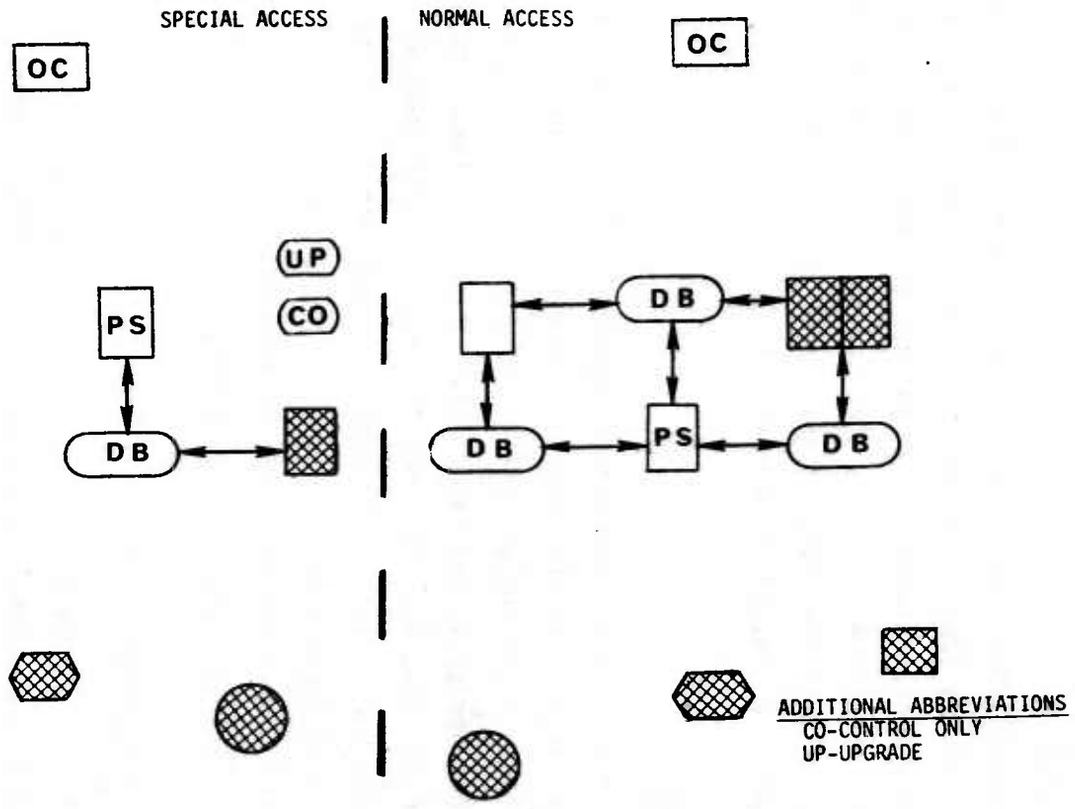

Figure 3. Early 1978 Configuration.

of the SID system, it will be necessary to upgrade satellite processing in general, a function to be assigned to PS5. Finally, the communications upgrade started with the prior implementation of PS1 and PS4 will continue as new communications consoles are actively established for possible side-by-side operation of the new and old procedures. See Figure 4.

1.1.5 Early 1979

The primary accomplishment here will be the implementation of Network Control in its final form, as shown in Figure 5. Where switching the variable perimeter was previously a manual operation, it can now be supervised by Network Control. The predominant requirement in this time period will be increased Minuteman support. (The reliability tradeoff associated with the implementation of Network Control is discussed in Section 1.1.)

1.1.6 Mid-1979

By this time, a full forecaster console capability will be implemented, including forecaster consoles in the special access perimeter and several similar types of consoles in the normal access perimeter, including TAF-METWATCH, Military Weather Advisory, and synoptician consoles. These consoles will be essential when the 0-48 hour Terminal Air Forecast (TAF) becomes operational. Programmer support consoles in the special access and normal access perimeters (initiated in 1977 through early 1978) will be fully operational by this time. Finally consoles associated with quality assurance and special operations will be installed. This is illustrated in Figure 6.

1.2 SOFTWARE DEVELOPMENT SCHEDULE (A32-A34)

The availability of software necessary to support hardware can be the key factor in meeting an implementation schedule. This discussion has classified all major software projects bearing on the enhanced AFGWC architecture into three categories:

a. model and requirement related,

b. enhanced architecture related, and

c. vendor supplied.

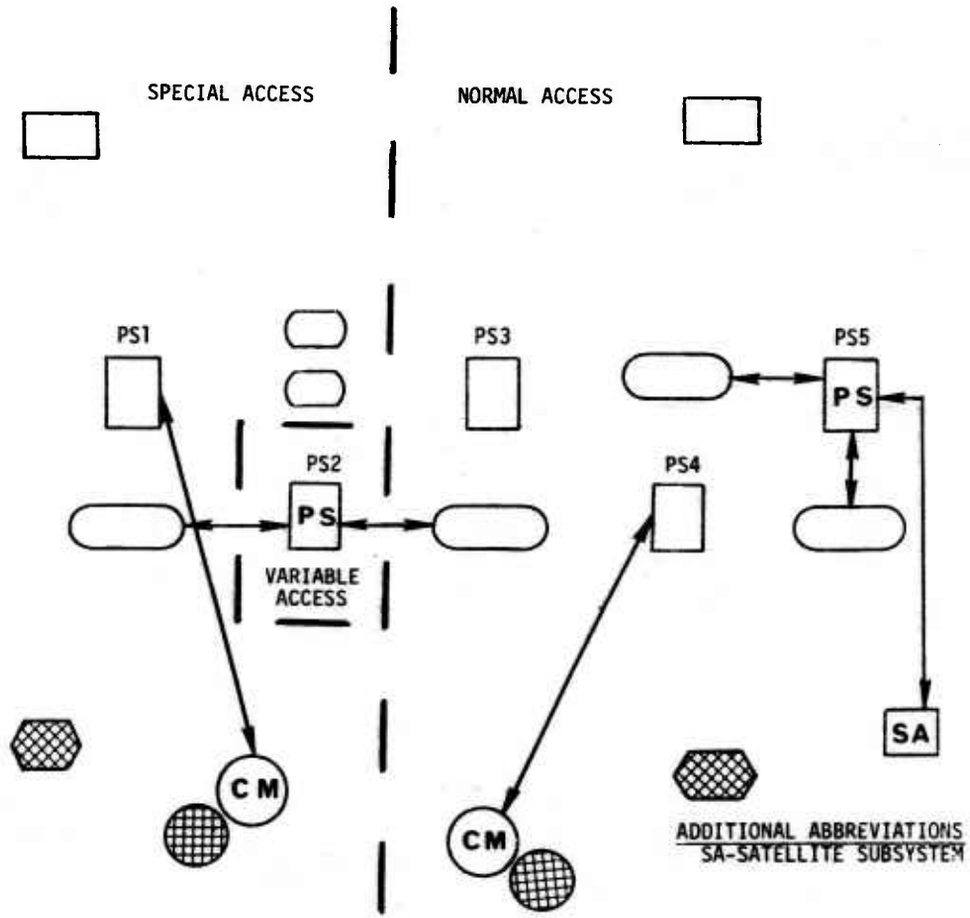

Figure 4. Mid-1978 Configuration.

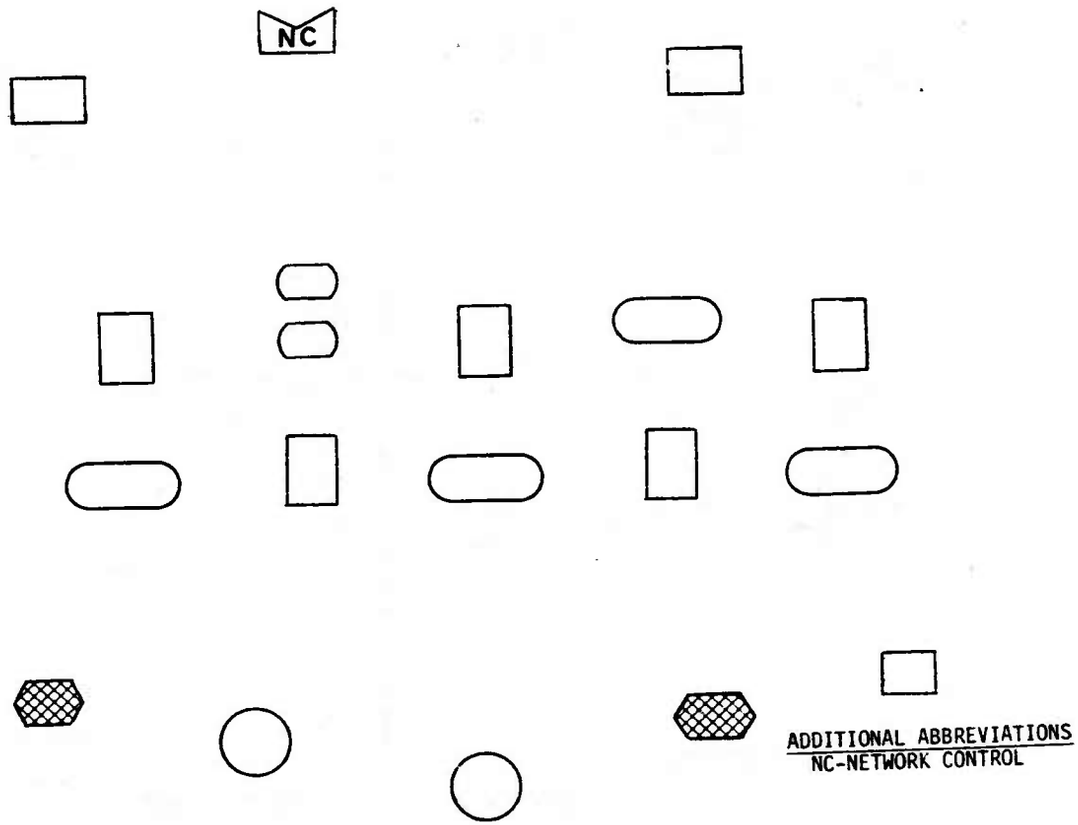

Figure 5. Early 1979 Configuration.

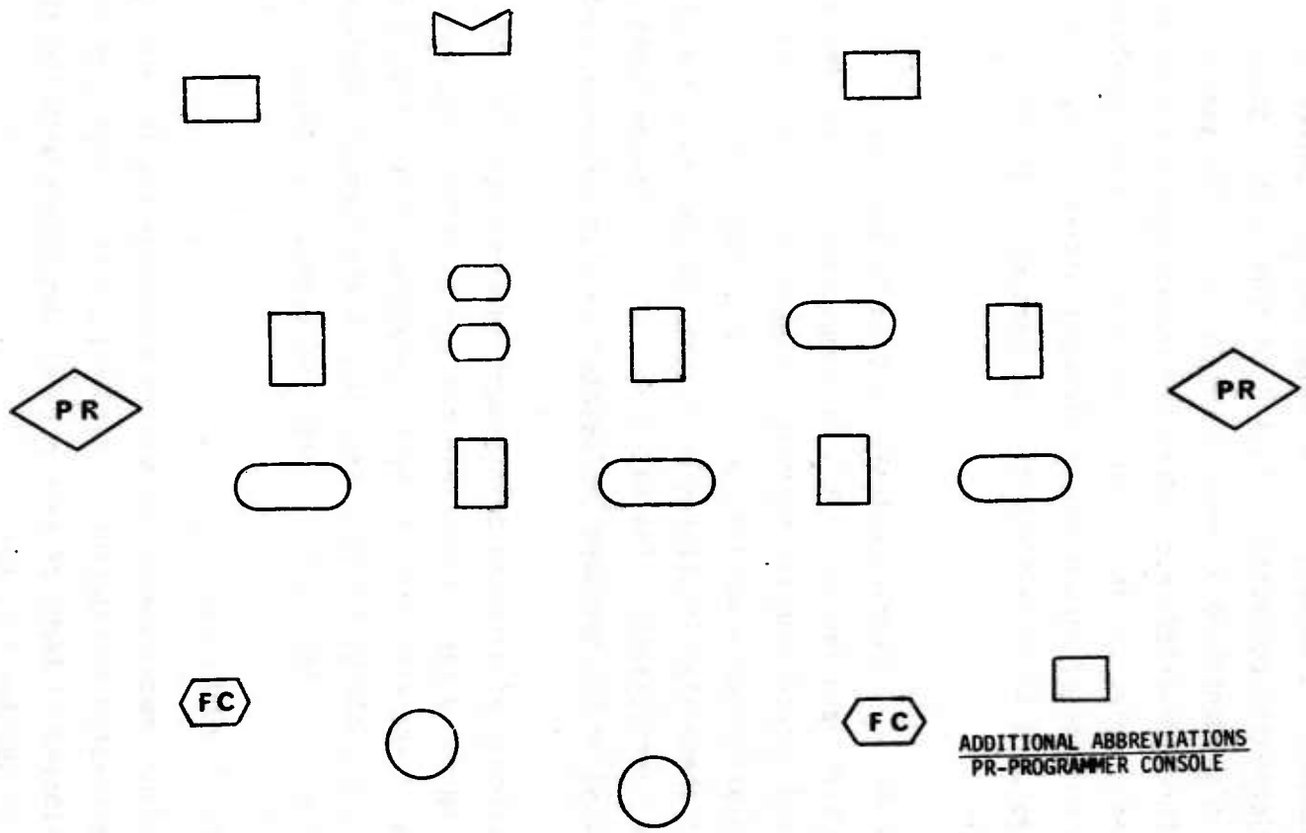

Figure 6. Mid-1979 Configuration.

Those involving models and other requirements are independent of the architecture to the extent that they must be developed regardless of what final hardware configuration is adopted. Dates when they must become operational are based on information collected in task 1 of this study. Since most of these dates were only identified by year, a mid-point of that year was assumed. Based on the Air Force description of these software projects and on SDC's estimates of associated complexity, they were classified as either involving high, moderate, or low amounts of design and development efforts. These three classifications were assumed to correlate with time periods of 18, 12, and 6 months respectively.

The second category, containing tasks related to the enhanced architecture, are those which have resulted from SDC's recommendations. They include the data management and Network Control Systems, to name two. These tasks were classified as involving high, moderate, or low amounts of work in the trade-study analysis and these classifications were again assumed to correlate to 18, 12, and 6 months, respectively. The dates when these software tasks must be completed is based on the hardware implementation plan presented in Section 1.1.

The final category of software development involves modification of vendor supplied software to make it suitable for use at AFGWC. The work involved in each of these tasks will most likely be completed in less than 6 months time and must be available by the date dictated by the hardware implementation schedule in Section 1.1. The resultant proposed schedule is shown in Figure 7.

1.3 PERSONNEL SCHEDULE (A70)

The new personnel requirements for system operation are integral to total system phaseover/system architecture schedule planning. This personnel schedule will be considered in terms of time periods consistent with the total implementation plan of Section 1.1, i.e.:

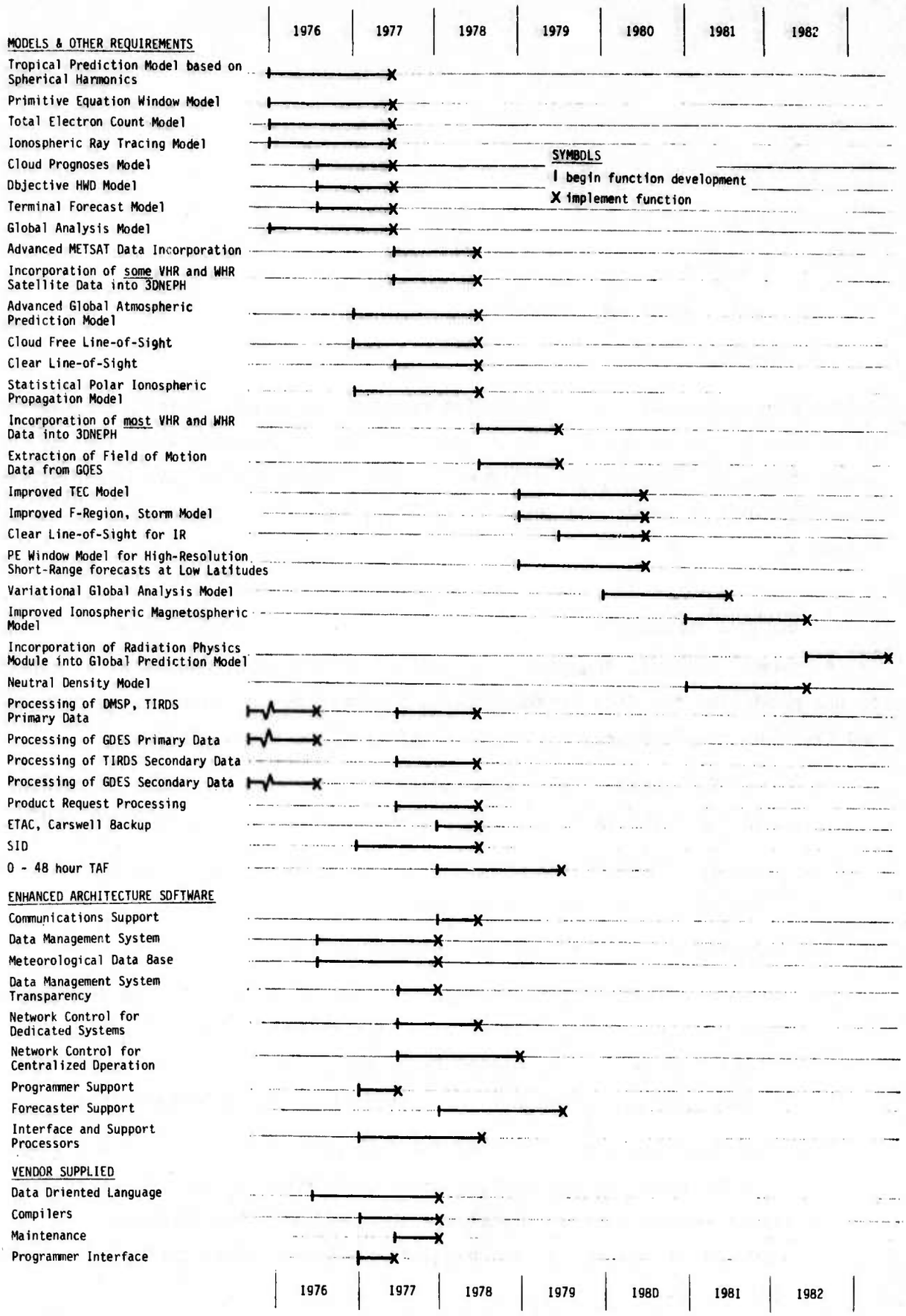

Figure 7. Software Development Schedule.

a. 1977 - early 1978,

b. early 1978,

c. mid-1978,

d. early 1979, and,

e. mid-1979.

Personnel requirements associated with model software development are covered in Section 2.1 of Volume 2. Requirements for the production of other major programs should be based on the estimated sizings and projected characteristics of these routines as described under Trade Study ACI-I in Section 10.0 of Volume 4.

1.3.1 System Requirements

The personnel schedule considers the primary system requirements with respect to accommodation for data system growth, limitations to increases in personnel, and training requirements. Specific considerations are as follows:

a. The 1982 design shall accommodate a 10% growth in number of devices and a 10% growth in traffic per work center between 1982 and 1987.

b. Data system potential growth within the 1982 - 1987 time period shall require no increase in personnel.

c. Operator positions shall accommodate on-the-job training.

d. The number of consoles reflected in the AFGWC Data System Architecture and the number of personnel allocated to console positions (as determined from the System/Design Trade Study Report) are the basis for determining the personnel schedule during system implementation.

e. The prototype system planned for implementation in 1977 - early 1978 will be operated and maintained by contractor personnel; therefore, AFGWC operational personnel are involved only for training (within the context of on-the-job training) as needed for implementation of system phaseover.

1.3.2 Personnel Requirements for System Operation

a. 1977 - early 1978. During this period, the AFGWC will implement the data base system, plus several prototype subsystems connected to a prototype processing system. This period involves the addition of one (1) maintenance console to support the database processor. Based upon console personnel allocations developed during the system/design trade study activity, personnel requirements for this phase of implementation are two slots allocated for this maintenance console. In addition, initial manning of the programmer consoles will commence for software development. Employing the assumptions that programmer consoles will be manned 2/3 of the time, and that these consoles should be utilized as soon as is practical, it is estimated that 10 slots will be devoted to programmer console usage during this period.

b. Early 1978. In the early 1978 period, the processing system in the Special Access Perimeter and a processing system in the Normal Access Perimeter will be implemented. Four data base subsystems and the data transfer and routing components will also be implemented. In addition, the Operations Subsystems for both perimeters (Special Access and Normal Access) will be implemented. This will result in the following additional console requirements:

1) two (2) computer operations consoles,

2) two (2) security downgrade and remote job entry consoles,

3) two (2) maintenance consoles.

This phase of the implementation requires personnel as follows:

1) Twenty (20) slots are required for the computer operations consoles. This is based upon a requirement for two slots per shift, and assumes five shifts per day for 7-day, 24-hour operations, for each of the two consoles.

2) Ten (10) slots are required for the security downgrade and remote job entry (SD/RJE) consoles (one slot per shift for each console).

3) Four (4) new slots are required for the two new maintenance consoles.

In addition, 10 additional programmer slots will be allocated to software development on the programmer consoles.

c. Mid-1978. In mid-1978, the final two processing systems will be implemented, one in the Variable Access Perimeter and the other in the Normal Access Perimeter. Included also are those upgrades/subsystem implementations associated with satellite data input and Satellite Imagery Dissemination (SID) and the active implementation of the communication systems in both the Special Access Perimeter and the Normal Access Perimeter. This implementation period involves the addition of:

1) two (2) communications consoles,

2) two (2) maintenance consoles, and,

3) one (1) SID console.

Personnel requirements for this period involve twenty (20) slots for the communication consoles, four (4) new slots for the maintenance consoles, and ten (10) slots for the SID console. As before, the personnel requirements for the maintenance consoles are based on the total of ten slots for the five maintenance consoles. The ten slots for the SID console reflect a requirement for two slots per shift, while each communications console may require as many as two operators per shift.

d. Early 1979. The projected schedule for Network Control console implementation occurs in early 1979. An additional two (2) consoles are involved in this phase of implementation. However, only one will be manned - the other will be in standby status. Based upon use of two

slots per shift, the personnel requirement reflects a total of ten (10) slots.

e. Mid-1979. The implementation shcedule provides for implementation of the forecaster and quality assurance consoles by mid-1979. The implementation is as follows:

1) Fifteen (15) for TAF/METWATCH

2) Two (2) for SESS (one each in Special Access and Normal Access Perimeters)

3) One (1) for Military Weather Advisories

4) Five (5) synoptician consoles

5) Three (3) forecaster consoles in Special Access Perimeter

6) One (1) special operations console

7) One (1) quality assurance console

Based upon the number of slots per shift for each console, the following personnel requirements for this phase of implementation are as follows:

1) TAF/METWATCH. 150

2) SESS. 15

3) Military Weather Advisories 10

4) synoptician consoles. 50

5) Special Access Perimeter forecaster consoles 15

6) special operations console. 10

7) quality assurance console 5

1.3.3 Summary of Personnel Requirements

Table 1 presents the Production Division personnel requirements in terms of the number of slots required for console manning for each phase of the system implementation from 1977 through mid-1979. The total involved in console/work center operation by mid 1979 is 355.

Based upon the estimates of total AFGWC manpower requirements through 1982, as indicated initially in the task 1 Preliminary Report, the impact of this schedule on total WP manning can be reviewed. The estimated total manpower in Figure 8 reflects personnel requirements to meet new user requirements, augmented by the manpower savings due to automation, from 1977 to 1982, with the maximum number of WP personnel estimated as 755 in 1980 and beyond.[1] Superimposed on the graph of total manpower is the portrayal of the number of personnel required for console and automated work center operation of the AFGWC data system. The stepwise growth in the number of personnel required shows increases from twelve in 1977 - early 1978 to a maximum of 355 in mid-1979.

Figure 9 shows the portion of the total AFGWC manpower required for operation of the data system consoles and work centers in terms of the percentage of the total requirements (assuming a WP staffing level of 755 in 1980). The stepwise growth to mid-1979 shows increases from 1.6 percent to 13 percent of the total manpower. The increase to 47% of total manpower in mid-1979 mainly represents the requirements for implementation of the forecaster consoles in both the Normal Access Perimeter and the Special Access Perimeter.

[1]Tables 8 and 9 are based on an assumed total authorized staffing for the AF GWC Production Division of 720 in 1976. However, it should be noted that this division is operating at well below authorized levels. In late 1975, for example, the six major operating branches of WP (WPF,WPD,WPE,WPP,WPJ,WPA) had 549 assigned personnel.

Table 1. Personnel Schedule for Data System Console Operation

CONSOLES	IMPLEMENTATION PERIODS					
	1977-Early 1978	Early 1978	Mid-1978	Early 1979	Mid-1979	Totals
Maintenance (5)	2	4	4			10
Communications (2)			20			20
Computer Ops (2)		20				20
SD/RJE (2)		10				10
Special Ops (1)					10	10
SID (1)			10			10
Network Control (2)				10		10
Programmer (30)	10	10				20
Forecaster						
- TAF/METWATCH (15)					150	150
- SESS (2)					15	15
- MWA (1)					10	10
- SYNOPTICIAN (5)					50	50
- SPECIAL ACCESS (3)					15	15
Quality Assurance (1)					5	5
Totals	12	44	34	10	255	355

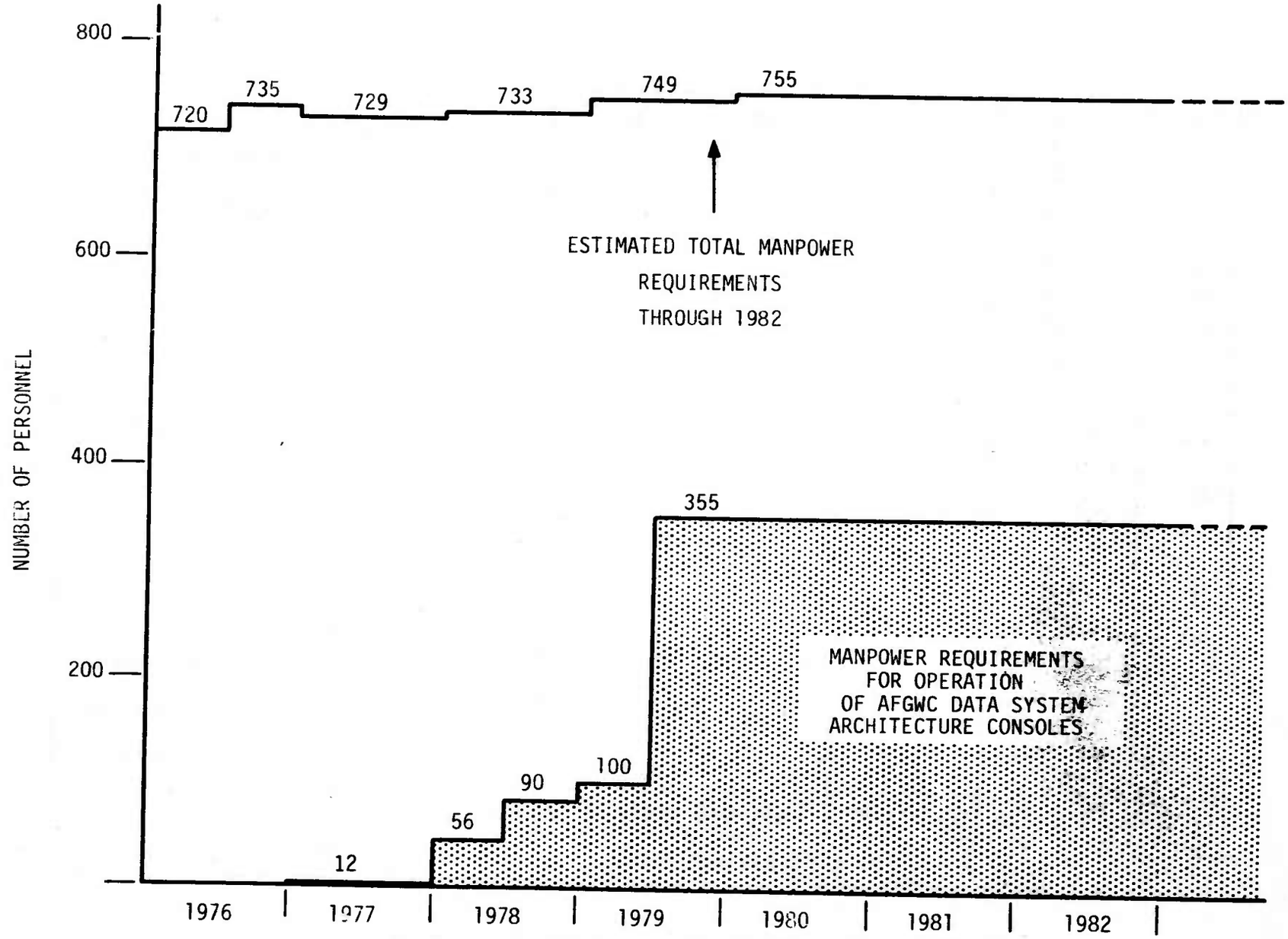

Figure 8. AFGWC Personnel Schedule

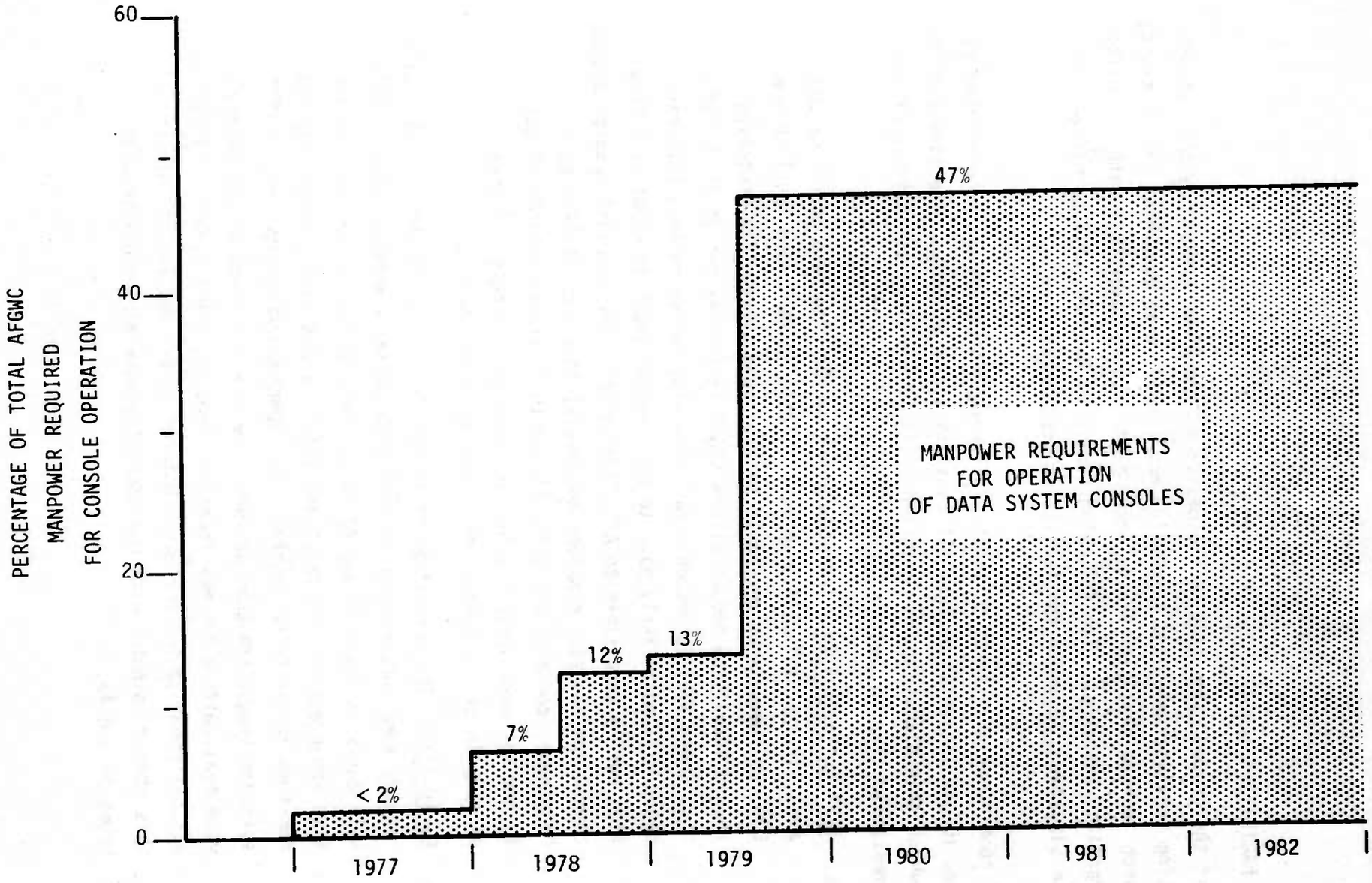

Figure 9. AFGWC Manpower Requirements For Console Operations (As Percentage of Total Requirements)

1.4 FACILITIES (A90)

One of the ground rules used in the design of the AFGWC system has been to use existing facility space and supporting environment when possible. As a result, the architecture that has been designed is by nature compatible with the existing facility resources. The following sections, however, will summarize some of the situations to which the facilities must react.

AFGWC room numbers referred to in the following discussion are as described by Figures 10 and 11, which picture all facility space at AFGWC. The time periods over which this discussion is organized again follow those established by the implementation plan in Section 1.1.

a. 1977 to Early 1978. Implementation of the data base processor will most likely use facility space available in the lower level in Room L30, as adequate space should be available there. The prototype should ideally be housed within AFGWC facilities but it is doubtful that there will be enough room. The alternative to this temporary setup will most likely have to be a vendor supplied depot at a location easily accessible to AFGWC personnel. The upgraded special access communications link provides no special impact on facilities. Programmer consoles are being placed in locations outside of the larger hardware areas housing the processor systems, in areas already in use as normal work areas by programmers.

b. Early 1978. The establishment of centralized operations consoles will require some construction to make them suitable working areas. This will occur in Rooms 17 and 43 on the main floor. Since the new data base and processor are replacing existing components, supplying room for them should be no problem. The upgrade and control only data switches should not take up much more room and there should be ample room available in the new location, Room 43. This period will see the establishment of the perimeter between normal and special access but this should coincide with the present adequate boundary between Rooms 38 and 43.

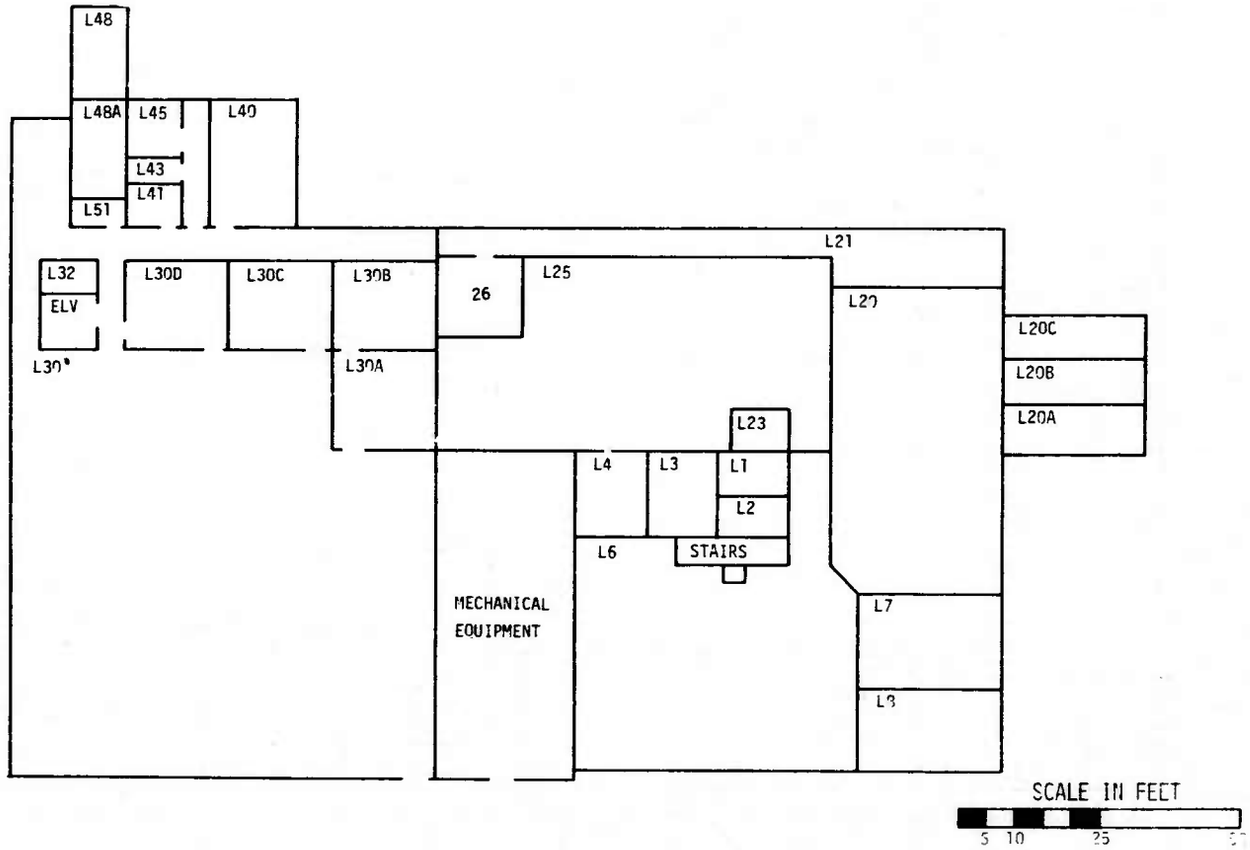

Figure 10. AFGWC Lower Floor Facility

Figure 11. AFGWC Main Floor Facility

c. Mid-1978. The implementation of the final two processors will allow the three distinct perimeters to be established. This will require necessary security reinforcements betwen Rooms 17 and 38, the boundary between the normal and variable perimeters. Facilities for the new communications hardware and consoles should be adequate in Rooms 43 and L30.

d. Early 1979. The implementation of the network control console in Room 43 will require construction to isolate this working area from the noise in the remainder of the special access area.

e. Mid-1979. Forecaster consoles are being placed in locations outside of the larger hardware areas housing the processor system. Some minor re-organization may be necessary to ensure their proper placement, since they will be established in areas already in use as normal work areas by forecasters.

1.5 NETWORK SCHEDULING ASPECTS

SDC has assessed many of the time-dependent implications and interdependencies of components of the architectural domain, and has prepared associated data for input to automated network scheduling programs. Activities associated with the implementation of hardware and software, as well as personnel training and facility modification tasks, are presented in Tables 2-5. In each of these tables, SDC has established nominal durations for activities, as well as nominal start and end dates (with estimated tolerances). Included also are required predecessor activities. All of these efforts are based on the presentations developed in Sections 1.1 - 1.4, and will be instrumental in establishing a complete scheduling network with all interdependencies, so that critical paths, variances, and allowable slack times may be assessed and optimized.

Table 2. Hardware Implementation Schedule

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD [1] PREDECESSORS
H11[2]	PS(NA) "Brand X" [4]	1/77	2/77	3/77	6	7/77	8/77	9/77	-
H12	Prototype Processor	8/77	9/77	10/77	6	2/78	3/78	4/78	F11
H13[2]	SP Projects Comm UG	6/77	9/77	1/78	4	10/77	1/78	4/78	-
H14	Prototype Components[3]	7/77	9/77	12/77	5	12/77	2/78	5/78	H12
H21	PS (SA)	3/77	4/77	5/77	5	11/77	12/77	1/78	F22
H22	PS (NA)	3/77	4/77	5/77	5	11/77	12/77	1/78	F22
H23	DB (SA)	8/77	9/77	10/77	3	2/78	3/78	4/78	H21, S22, S23, S24
H24	DB (NA)	8/77	9/77	10/77	3	2/78	3/78	4/78	H22, S22, S23, S24
H25	UP, CO	10/77	11/77	12/77	4	2/78	3/78	4/78	-
H26	Ops (SA)	10/77	1/78	2/78	2	1/78	3/78	4/78	H14, F21, F22
H27	Ops (NA)	10/77	1/78	2/78	2	1/78	3/78	4/78	H14, F21, F22
H31	PS (VA)	12/77	1/78	2/78	5	5/78	6/78	7/78	F31
H32	PS (NA)	11/ 77	12/77	1/78	5	4/78	5/78	6/78	F31
H33	SID	1/78	2/78	3/78	4	5/78	6/78	7/78	H32

[1] Indicates activities that must be completed before this activity can be totally completed.

[2] Not part of new data system architecture.

[3] Including programmer work centers.

[4] AFGWC "Data Base Processor"

Table 2. Hardware Implementation Schedule (Continued)

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD PREDECESSORS
H34	Comm (SA)	11/77	12/77	3/78	4	3/78	4/78	7/78	H21, F31, S211
H35	Comm (NA)	11/77	12/77	3/78	4	3/78	4/78	7/78	H22, F31, S211
H41	Net Control	7/78	9/78	12/78	4	11/78	1/79	4/79	H21, S25, S26
H51	Programmer Consoles[1]	12/78	1/79	2/79	5	5/79	6/79	7/79	H11, H32, S27, S34
H52	Forecaster Consoles	12/78	1/79	2/79	5	5/79	6/79	7/79	H21, H32, S28

[1]Implementation of prototypes into final configuration.

Table 3. Software Development & Implementation Schedule

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD PREDECESSORS
S11	M1[1]	1/76	1/76	4/76	18	3/77	6/77	12/77	-
S12	M2	1/76	1/76	4/76	18	3/77	6/77	12/77	-
S13	M3	1/76	1/76	4/76	18	3/77	6/77	12/77	-
S14	M4	1/76	1/76	4/76	18	3/77	6/77	12/77	-
S15	M7	5/76	7/76	9/76	12	4/77	6/77	9/77	S12
S16	M8	5/76	7/76	9/76	12	4/77	6/77	9/77	-
S17	M9	5/76	7/76	9/76	12	3/77	6/77	9/77	-
S18	M10	1/76	1/76	4/76	18	3/77	6/77	12/77	-
S19	M11	5/77	7/77	9/77	12	3/78	6/78	9/78	S125
S110	M12	5/77	7/77	9/77	12	3/78	6/78	9/78	S125
S111	M13	10/76	1/77	4/77	18	12/77	6/78	12/78	H11, S11, S12
S112	M14	10/76	1/77	4/77	18	12/77	6/78	12/78	H11
S113	M15	5/77	7/77	9/77	12	3/78	6/78	9/78	H11
S114	M16	10/76	1/77	4/77	18	12/77	6/78	12/78	-
S115	M17	5/78	7/78	9/78	12	3/79	6/79	9/79	S125
S116	M18	5/78	7/78	9/78	12	3/79	6/79	9/79	S126
S117	M23	10/78	1/79	4/79	18	12/79	6/80	12/80	S13
S118	M24	10/78	1/79	4/79	18	12/79	6/80	12/80	-

[1] "M1" indicates model no. 1 - see Section 2.0 of Volume 2.

Table 3. Software Development & Implementation Schedule (Continued)

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD PREDECESSORS
S119	M25	5/79	7/79	9/79	12	3/80	6/80	9/80	S112, S113
S120	M26	10/78	1/79	4/79	18	12/79	6/80	12/80	S11, S12
S121	M27	10/79	1/80	4/80	18	12/80	6/81	12/81	-
S122	M34	10/80	1/81	4/81	18	12/81	6/82	12/82	-
S123	M37	5/82	7/82	9/82	12	3/83	6/83	9/83	S111
S124	M38	10/80	1/81	4/81	18	12/81	6/82	12/82	-
S125	DTPRI	-ALREADY STARTED-			30 (2 phases)	1/78	6/78	1/79	-
S126	GOESPRI	-ALREADY STARTED			18	3/76	6/76	12/76	-
S127	TIRSEC	5/77	7/77	9/77	12	3/78	6/78	9/78	-
S128	GOESSEC	-ALREADY STARTED			12	3/76	6/76	9/76	-
S129	PRODREQ	5/77	7/77	9/77	12	3/78	6/78	9/78	H34, H35
S130	ETACCARS	12/77	1/78	2/78	6	4/78	6/78	8/78	-
S131	SID	10/76	1/77	4/77	18	12/77	6/78	12/78	H33
S132	048TAF	10/77	1/78	4/78	18	12/78	6/79	12/79	H52
S21	Comm	12/77	1/78	2/78	6	4/78	6/78	8/78	-
S22	DMS*	4/76	7/76	10/76	18	6/77	12/77	6/78	S31
S23	METDB*	4/76	7/76	10/76	18	6/77	12/77	6/78	S31
S24	DMSTRANS	6/77	7/77	8/77	6	10/77	12/77	2/78	S31
S25	NCDED	5/77	7/77	9/77	12	3/78	6/78	9/78	-
S26	NCCENT	4/77	7/77	10/77	18	6/78	12/78	6/79	-
S27	PROGSUPP	12/76	1/77	2/77	6	4/77	6/77	8/77	S34

*Start date suggests this software development should be initiated about 6 months prior to the first hardware implementation in early 1977. This is necessary due to the complexity of the tasks involved. We feel that this initial period can be spent in designing the functions on paper and attaching that part of the coding (e.g., FORTRAN) which will be relatively independent of hardware used.

Table 3. Software Development & Implementation Schedule (Continued)

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD PREDECESSORS
S28	FCSTSUPP	10/77	1/78	4/78	18	12/78	6/79	12/79	-
S29	IFSUPPR	10/76	1/77	4/77	18	12/77	6/78	12/78	
S31	DOL	4/76	7/76	10/76	18	6/77	12/77	6/78	-
S32	Compilers	11/76	1/77	3/77	12	9/77	12/77	3/78	-
S33	Maint	6/77	7/77	8/77	6	10/77	12/77	2/78	-
S34	PROGIF	12/76	1/77	2/77	6	4/75	6/77	8/77	-

Table 4. Personnel Implementation Schedule

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION[1] (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD PREDECESSORS
P11	Maintenance	3/77	4/77	5/77	4	7/77	8/77	9/77	H11
P21	Maintenance	8/77	9/77	10/77	3	11/77	12/77	1/78	H21, H22
P22	Comp Ops	11/77	1/78	2/78	2	1/78	3/78	4/78	H26, H27
P23	SD/RJE	9/77	10/77	11/77	2	11/77	12/77	1/78	H21, H22
P24	Sp Ops	9/77	10/77	11/77	2	11/77	12/77	1/78	H21, H22
P31	Maintenance	2/78	3/78	4/78	3	5/78	6/78	7/78	H31, H32
P32	Communications	1/78	2/78	5/78	2	3/78	4/78	7/78	H34, H35
P33	SID	2/78	3/78	4/78	3	5/78	6/78	7/78	H33
P41	Net Control	7/78	9/78	12/78	4	11/78	1/79	4/79	H41
P51	Forecaster	1/79	2/79	3/79	4	5/79	6/79	7/79	H52
P52	Quality Assurance	1/79	2/79	3/79	3	5/79	6/79	7/79	P41

[1] "Duration" for personnel refers to phase-in/training period.

Table 5. Facilities Implementation Schedule

ACTIVITY CODE	COMPONENT	-START DATE- EARLIEST	NOMINAL	LATEST	DURATION (Months) NOMINAL	-END DATE- EARLIEST	NOMINAL	LATEST	REQD PREDECESSORS
F11	Depot Setup	1/77	2/77	3/77	2	3/77	4/77	5/77	-
F21	Ops Console Const.	5/77	6/77	7/77	3	8/77	9/77	10/77	-
F22	NA, SA Perimeters	12/76	1/77	2/77	1	1/77	2/77	3/77	-
F31	Security Reinf.	8/77	9/77	10/77	1	9/77	10/77	11/77	-
F41	Net. Control Isolation	10/78	12/78	3/79	2	12/78	2/79	5/79	H41
F51	Console Reorganization	4/79	5/79	6/79	2	6/79	7/79	8/79	H51, H52

2.0 SYSTEM COST CONSIDERATIONS

2.1 SYSTEM COST SUMMARY

Table 6 summarizes time-phased system costs from 1977 through 1981, which are detailed in Sections 2.3 through 2.6. All costs are based on 1975 dollars, reflecting current prices for analogous components and SDC's best estimates for new state-of-the-art equipment.

It should be noted that many factors will influence the actual dollars that must be incrementally appropriated to procure this data system. In most sectors of the economy, inflation is resulting in increased prices for goods and services, and will most probably continue to do so for the foreseeable future. The general rate of inflation, however, does not entirely apply to the data processing industry. While costs for software services are continuing to rise (due largely to increases in programmer salaries), several avenues of the hardware acquisition and maintenance worlds are experiencing price reductions for given capabilities. Such reductions are partly due to dramatic decreases in main memory costs, higher reliabilities, and lower production costs associated with LSI and CMOS technologies. In fact, it is conceivable that as more advanced technologies emerge, lower prices than those shown herein could result in the long term.

Unfortunately, in meeting AFGWC needs in the 1977-1982 time frame, much of the associated R&D costs of the vendors have already been expended. Since the emphasis on the acquisition of new architecture components to meet user requirements will be in the 1977-1979 period, hardware component costs cannot realistically be expected to drastically go down during this relatively short-term period. Software costs, however, will most certainly continue to in-increase in proportion to inflation rates. Thus, for the acquisition of the new AFGWC data system, system acquisition over the 1977-79 period can be expected to be higher than these 1975 prices, but possibly not in direct

Table 6. Time Phased System Costs (Numbers in Millions of Dollars) Through 1981

ITEM	1977-Early 1978	Early 1978	Mid 1978	Early 1979	Mid 1979	1980-1981	1977-81 Totals
Architecture (A10-A60)	27.2	29.7	9.5	2.0	5.2	1.4	75.0[4]
Personnel[1] (A70)	0.3	0.5	0.5	0.9	0.9	1.1	3.9
Facilities[2] (A90)	-	-	-	-	-	-	-
Maintenance[3]	3.35M per year	→					16.8

[1]These are increased personnel cost figures to support new requirements for the periods shown, based on the levels shown in Figure 12.

[2]Not considered (see Section 2.5).

[3]Not considered are personnel costs involved with software production or maintenance.

[4]Additional software costs will be expended after 1981, as well as prior to 1977. (Architecture costs in 1980-81 are for software only.)

proportion to inflation. In the final analysis, however, decisions must be made regarding the adequate meeting of user requirements and the appropriate allocation of funds to meet these requirements.

2.2 TIME PHASED COST SUMMARY

Tables 7 through 11 detail estimated time phased costs of hardware components for the AFGWC system. These tables coincide with the five periods associated with the implementation schedule presented in Section 1.1. Software development and conversion costs are also listed in these summaries. Symbols and abbreviations for hardware components are those appearing on the system diagram foldout enclosed with Volume 1, "Executive Summary."

2.3 SYSTEM ARCHITECTURE COSTS (A10-A60)

Tables 12 through 17 summarize the total costs associated with the AFGWC system architecture, organized to follow the first six divisions (the hardware components) of the architectural domain:

a. data storage (A10)

b. data transfer and routing (A20)

c. computation and software (A30)

d. terminal interface (A40)

e. consoles (A50)

f. data input/display (A60)

Personnel (A70) and Facilities (A90) are covered below. The management division (A80) is assumed to have no direct bearing on costs. A total cost summary for hardware and software components appears in Table 18.

2.4 PERSONNEL (A70)

Using the estimates of manpower established in Section 1.3 and assuming an average cost of $30,000 per man year, Figure 12 depicts the increases in yearly

AFGWC personnel requirements to support new requirements and operate the new data system configuration, partially offset by manpower savings that would arise through the use of automated techniques (see Section 5.6 of Volume 2 for details).

It should be noted that $30,000 per Air Force man year is merely a gross estimate of the government's cost to provide a man to perform these functions. Capabilities may range from those of a medium grade enlisted man to a senior level officer, depending on the function. Thus, assuming that the government's cost would be well below that of a vendor, an overall figure of $30,000 has been assumed. However, it should also be noted that personnel costs, while included herein to provide an overall picture of costs associated with the data system, will not be part of the same budget used to acquire hardware and vendor-supplied software for the data system.

Table 7. 1977 - Early 1978 Costs

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
Processing System (Normal Access Perimeter)	MP/IO, MPSW	1	1206K	1206K
	MEM (MP)	1	3511	3511
	MEM (MP) - AUX	1	2304	2304
	AP	1	500	500
	K	2	5	10
	CONT (FH)	2	104	208
	FH DISKS	4	79	316
	MAINT. CONSOLE	1	72*	72*
Programmer Subsystem	SW	2	10	20
	ACRT	30	4	120
	ANK	30	2	60
	PLOTTER	4	15	60
Prototype Processing System	(Same as processing system above)	1	8127	8127
	PR	1	56	56
Communications System Simulation	SP	1	300	300
	LHDR	2	20	40
	LCSD	2	8	16
	COMM CONSOLE	1	5	5
	ACRT	2	4	8
	ANK	1	2	2
Forecaster Console Prototype	SP	1	300	300
	CONSOLE	1	13	13
	HCRT	2	50	100
	CCRT	2	5	10
	ANK	2	2	4
	FFK	1	2	2
	DT	2	5	10
	HC	1	5	5
	LP	1	1	1

*Cost based on: 1 - LPR @ 56K and 1 - CRDR @ 16K

Table 7. 1977 - Early 1978 Costs (Continued)

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
Prototype Data Base	COMB DISKS	4	39	156
	CONT(C)	2	68	136
	BULK DISKS	8	39	312
	CONT(B)	2	102	204
	MSF	1	676	678
	TAPE UNITS	2	26	52
	CONT(T)	2	78	156
Software Development and Conversion		-	-	8100K
			TOTAL	27180

Table 8. Early 1978 Costs

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
Processing System (Special Access Perimeter)	(See components listed in chart for 1977 - Early 1978.)	1	8127K	8127K
Processing System (Normal Access Perimeter)	(See components listed in chart for 1977 - Early 1978.)	1	8127K	8127K
Data Base Subsystem (Special Access Perimeter)	SW1 and SW8	2	10	20
	CONT (C)	6	68	408
	CONT (T)	3	78	234
	TAPES	6	26	156
	COMB DISKS	24	39	936
Data Base Subsystem (Normal Access Perimeter)*	SW4 and SW19	2	10	20
	CONT (C)	6	68	408
	CONT (T)	2	78	156
	TAPES	6	26	156
	COMB DISKS	21	39	819
	SW7 and SW8	2	10	20
	CONT (B)	1	102	102
	CONT (C)	3	68	204
	BULK DISKS	10	39	390
	COMB DISKS	16	39	624
	DBSW	1	10	10
	SW5 and SW6	2	10	10
	CONT (SAT)	2	165	330
	SAT DISKS	13	60	780
Data Transfer and Routing Components	UP ROUTER	1	15	15
	CO ROUTER	1	15	15
Ops Subsystem (Special Access Perimeter)	SP	4	300	1200
	SW	3	10	30
	OPS CONSOLE	1	5	5
	SD/RJE CONSOLE	1	5	5
	ACRT	3	4	12
	ANK	3	2	6

*To be augmented by Prototype equipment

Table 8. Early 1978 Costs (Continued)

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
	LCSD (FDU)	1	8	8
	CONT (S)	3	18	54
	SUP DISKS	3	7	21
Ops Subsystem (Normal Access Perimeter)*	SP	5	300	1500
	SW	3	10	30
	OPS CONSOLE	1	5	5
	SD/RJE CONSOLE	1	5	5
	K	4	5	20
	ACRT	3	4	12
	ANK	3	2	6
	PR	3	56	168
	SPR	2	310	620
	LCSD (FDU)	1	8	8
	CONT (S)	3	18	54
	SUP DISKS	3	7	21
Software Development and Conversion:		-	-	3825K
			TOTAL	29682

*To be augmented by Prototype equipment

Table 9. Mid-1978 Costs

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
Processing System (Variable Access Perimeter)	(already costed as prototype processor)			
Processing System (Normal Access Perimeter)	(See components listed in chart for 1977 - Early 1978.)	1	8127K	8127K
SID Subsystem	CONT (S)	1	18	18
	SUP DISK	1	7	7
	SID CONSOLE	1	5	5
	ACRT	1	4	4
	HCRT	1	50	50
	ANK	1	2	2
Communications System (Special Access Perimeter)	LHDR	3	20	60
	SW	2	10	20
	LCSD	2	8	16
	COMM CONSOLE	1	5	5
	ACRT	1	4	4
	ANK	1	2	2
Communications System (Normal Access Perimeter)*	LHDR	3	20	60
	SW	2	10	20
Software Development and Conversion:				1125K
			TOTAL	9525

*to be augmented by prototype equipment

Table 10. Early 1979 Costs

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
Network Control Subsystem	NCSW	1	10K	10K
	NETWORK CONTROL CONSOLE	2	5	10
	NETWORK SWITCH PANEL	1	1	1
Software Development and Conversion:		-	-	2025K
			TOTAL	2046K

Table 11. Mid-1979 Costs

SYSTEM/SUBSYSTEM IMPLEMENTATION	COMPONENTS	QUANTITY	UNIT COST	TOTAL COST
Forecaster Console Subsystem*	CONSOLES			
	TAF/MET	15	13K	195K
	SESS	2	13	26
	MWA	1	13	13
	SYNOP	4	13	52
	SA FORECASTER	3	13	39
	ACRT	36	4	144
	HCRT	48	50	2400
	ANK	46	2	92
	CCRT	10	5	50
	FFK	10	2	20
	HC	24	5	120
	DT	12	5	60
	LP	24	1	24
	CONT (2)	1	18	18
	SUP DISK	4	7	28
	SP	3	300	900
	STSW	1	10	10
Quality Assurance Work Center	CONSOLE	1	2	2
	ACRT	1	4	4
	HC	1	2	2
	LP	1	5	5
Special Operations Work Center	CONSOLE	1	13	13
	ACRT	2	4	8
	ANK	2	2	4
	CARD RDR	1	16	16
	PR	1		
	SP	1	13	13
Software Development and Conversion		-	-	900K
			TOTAL	5159

*to be augmented by prototype equipment

Table 12. Data Storage Costs (A10)

CATEGORY	COMPONENT	TYPICAL MODEL NO.	QUANTITY	UNIT COST ($)	TOTAL COST ($)
STORAGE DEVICES (A11)	SUPPORT DISK	--	18	7K	126K
	FHD	U8405	20	79K	1,580K
	COMB DISK	IBM 3340	65	39K	2,535K
	SAT DISK	U8440	13	60K	780K
	BULK DISK	U8433	18	39K	702K
	TAPE	U0862-04	14	26K	364K
	MASS STORAGE FACILITY	IBM 3850 B1	1	676K	676K
	LCSD	--	6	8K	48K
MEMORY (A12)	MP MAIN	VARIOUS	524K WDS X 5	3511K	17,555K
	SP MAIN[1]	--	--	-	--
	SP MAIN[1]	--	--	-	--
	MP AUX	VARIOUS	1048K WDS X 5	2304K	11,520K
DATA BASE (A13)	STRUCTURE	--	--	-	--
	MGT	--	--	-	--
					35,886K

[1]Included with processor costs

Table 13. Data Transfer & Routing Costs (A20)

CATEGORY	COMPONENT	TYPICAL MODEL NO.	QUANTITY	UNIT COST	TOTAL COST
HARDWARE LINKAGE (A21)	REMOTE CABLING[2]	--	TBD	--	250K
SECURITY SEPARATION (A22)	AUTHENTICATION DEVICES	--	71	15 X 5K 56 X 7K	467K
CONTROLLERS (A23)	SUPP DISK	--	12	18K	216K
	FHD	U5039-99	10	104K	1040K
	COMB DISK	--	17	68K	1156K
	SAT DISK	U5033-97 U5033-95	2	165K	230K
	BULK DISK	U5039-99	3	102K	306K
	TAPE	U5017-00	9	78K	702K
INTERFACE (A24)	--	--	--	--	--
ROUTING (A25)	CO ROUTER	--	1	30K	30K
	UP ROUTER	--	1	30K	30K
SWITCHES (A26)	MISC	--	24	10K	240K
	MULTI-PROCESSOR	--	5	--[1]	--
COMPATIBILITY (A27)	--	--	--	--	--
MERGING (A28)	--	--	--	--	--
CONCEPTUAL (A29)	--	--	--	--	--
					4,667K

[1]Part of PS cost
[2]Includes allowance for raised flooring modifications for forecaster consoles

Table 14. Computation & Software Costs (A30)

CATEGORY	COMPONENT	TYPICAL MODEL NO.	QUANTITY	UNIT COST	TOTAL COST
PROCESSORS (A31)	MP	U1100/40 2x2	5	1206K	6030K
	AP	--	5	500K	2500K
	SP	PDP 11/70	17	300K	5100K
SOFTWARE (A32-A34)	NEW DEV'T	--	--	--	19900K[1]
	CONVERSION	--	--	--	5000K[1]
					38,530K

[1]These costs are based on an assumed mix of Air Force and contractor-developed software, as depicted in Section 10.0 of Volume 4, "Systems Analysis and Trade Studies." In reality, the net architecture cost for software development should be considerably lower, since manpower costs borne by the government associated with the Air Force portion of this development activity are not expected to be part of the same budget used to acquire the data system.

Table 15. Terminal Interface Costs (A40)

CATEGORY	COMPONENT	TYPICAL MODEL NO.	QUANTITY	UNIT COST	TOTAL COST
NA (CLASS) (A41)	ALL	--	--	--	--
NA (UNC) (A42)	ALL	--	--	--	--
SA (A43)	ALL	--	--	--	--
SATELLITE DATA (A44)	ALL	--	--	--	--
ROUTING (A45)	LHDR SATELLITE DATA ROUTER	--	8	20K	160K
GENERAL (A46)	ALL	--	--	--	--
OTHER (A47)	ALL	--	--	--	--
					160K

Table 16. Console Costs (A50)

CATEGORY	COMPONENT	TYPICAL MODEL NO	QUANTITY OF CONSOLES	CONSOLE UNIT COST	CONSOLE SUB-TOTAL COST	QUANT OF BARE MINIs	MINI UNIT COST	MINI SUBTOTAL COST	TOTAL COST
MISSION SUPPORT (A51)	NC		2	5K	10K	---	--	--	10K
	OPS		2	5K	10K	--	--	--	10K
	SD/RJE		2	5K	10K	--	--	--	10K
	COMM		2	5K	10K	--	--	--	10K
	SID		1	--	--	--	--	--	--
	MAINT		5	--	--	--	--	--	--
MISSION OPS (A52)	TAF/MET		15	3K	45K	15	10K	150K	195K
	MWA		1	3K	3K	1	10K	10K	13K
	SNPT		5	3K	15K	5	10K	50K	65K
	Forecaster (SA)		3	3K	9K	3	10K	30K	39K
	SESS (SA)		1	3K	3K	1	10K	10K	13K
	SESS (NA)		1	3K	3K	1	10K	10K	13K
	QA		1	2K	2K	--	--	--	2K
	PROG		30	--	--	--	--	--	--
	SPOPS		1	3K	3K	1	10K	10K	13K
			73			28			393K

Table 17. Data Input/Display Costs (A60)

CATEGORY	COMPONENT	TYPICAL MODEL NO	QUANTITY	UNIT COST	TOTAL COST
RAP. RESP. VISUAL (A61)	ACRT		87	4K	348K
	CCRT		16	5K	80K
	HCRT		51	50K	2550K
DOCUM. VISUAL (A62)	SPR		2	310K	620K
	MPR	U0770-04	8	87K	696K
	LPR	U0770-02	5	56K	280K
	PLOTTER		4	15K	60K
	HC		26	5K	130K
MISC. STATUS (A63)	CONFIG. DISP. PANEL		2	1K	2K
	SECURITY LEVEL DISP.		7	1K	7K
SELECTION (A64)	NETWORK SW PANEL		2	1K	2K
	UNIT SW PANEL		5	1K	5K
	DB SELEC PANEL		1	1K	1K
	PROCESSOR SELEC. PANEL		1	1K	1K
MISC COMM. (A65)	PTRP		--	--	--
	CRDR	U0716-02	6	16K	96K
	CPCH	U0604-99	6	22K	132K
	INTER-CONSOLE COMP.		--	--	--
MANUAL INPUTS (A66)	ANK		97	2K	194K
	FFK		11	2K	22K
	LP		26	1K	26K
	MCSR		--	--	--
	DT		14	5K	70K
					5322K

Table 18. Data System Architecture Cost Summary

A10:	Data Storage	35,886K
A20:	Data Transfer and Routing	4,667K
A30:	Computation and Software	38,530K
A40:	Terminal Interface	160K
A50:	Consoles	393K
A60:	Data Input/Display	5,322K
		84,958K

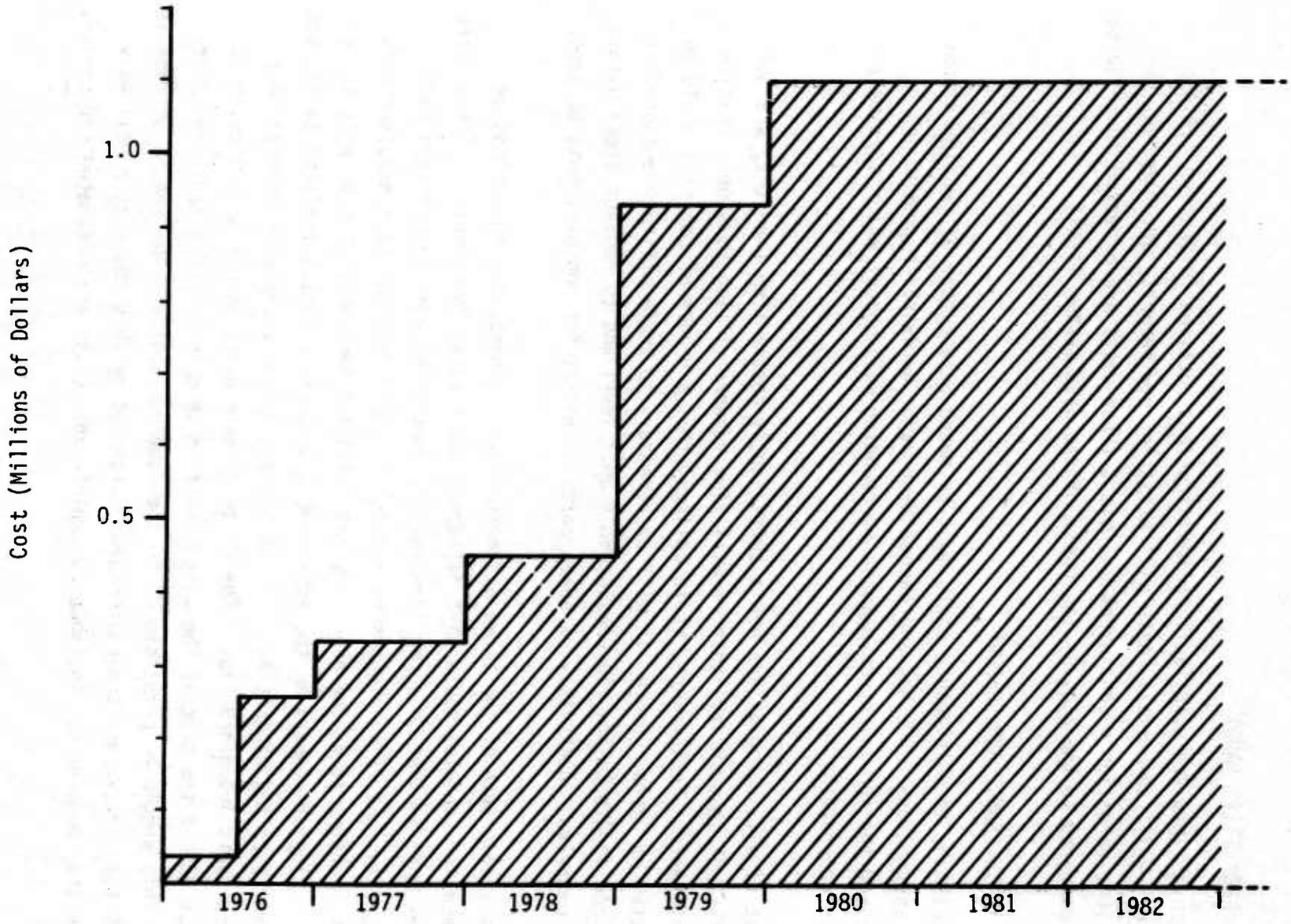

Figure 12. Increased Annual Personnel Cost Summary

2.5 FACILITIES (A90)

The costs involved with facility modifications outlined in Section 1.4 are minor. While some small costs will exist for new security arrangement, re-cabling, partition reconfiguration, etc., these costs are expected to be quite low compared to the acquisition costs of the data system itself.

2.6 MAINTENANCE AND SUPPORT

Calculation of maintenance costs must be based on a number of considerations and assumptions. SDC has approached each major hardware component and assessed the special circumstances surrounding maintenance which applies to these components.

First of all, consoles are not a sufficiently costly item (and they are not sufficient in quantity) that we will find vendors willing to supply on-site maintenance. Furthermore, it is unlikely that a vendor of consoles would be located in Omaha. Hence, it will be necessary to train military personnel to isolate faults to the plug-replaceable unit level and to replace items within the consoles. Accordinly, a spare parts inventory for consoles must be kept.

Most likely each of the three different kinds, programmer, operations and forecaster consoles would have different spare parts inventories. These spare parts must be kept in an environmentally controlled area to maintain their longevity. If array processors are not procured from the same manufacturers as the hosts, it may be necessary that military personnel also be able to re-place pluggable units on the array processors after having isolated faults via vendor supplied diagnostics. In this case, again, there will have to be a spare parts inventory kept. The cost of spare parts should be estimated at about 10% of the cost of the unit itself in terms of a spare parts inventory and this should be proportional to the number of units. The amount of time it will take to exhaust the spare parts purchased by this 10% factor will vary with the components. In Table 19, maintenance costs are estimated for various

Table 19. Life-Cycle Maintenance Costs

I. MAINTENANCE BASED ON PARTS COST

SYSTEM COMPONENT	SPARE PARTS COST (10% OF PURCHASE COST)	YEARS TO EXHAUST SPARE PARTS	TOTAL 10-YEAR LIFE CYCLE COST
Mass Storage Facility Media	$.175K	1	$ 2K
Switches	$24K	10	$24K
Authentication Chips	$38K	5	$76K
Array Processors	$250K	5	$500K
Forecaster Consoles	$300K	2	$1.5M
Operations Consoles	$4K	2	$20K

II. VENDOR SUPPLIED MAINTENANCE (PARTS INCLUDED)

SYSTEM COMPONENT	ANNUAL COST	
Main Processors	$1.75M	$17.5M
Support Processors	$250K	$2.5M
Disks	$350K	$3.5M
Programmer Consoles	$10K	$100K

III. ANNUAL AFGWC TRAINING - $50K $500K

TOTAL ≈ $26M

system components over an expected 10-year life cycle. These costs are "average" since they are based on the expected system configuration in 1982, the mid-point of the 10-year period.

Although hardware maintenance is definitely the largest recurring system cost, there are others which must be considered:

a. software maintenance,

b. power and environmental support, and

c. supplies and consummables.

Based on previous software experience, SDC believes that a maximum of 5% of software personnel need be dedicated to the function of software maintenance. (Software maintenance as used here consists of error corrections and minor engineering changes. It only involves clean-up of existing code and design and not program development). This estimate may seem low based on AFGWC experience since the software development branch, WPA, is much smaller than the sections in WPD dedicated to program maintenance. The conflict lies in the fact that much of the work done by WPD maintenance programmers consists of much more than error correction and cleanup. SDC further feels that the 5% figure will decrease after late 1978 when the large influx of new models slows down and those in production become more stable.

Power and environmental support (air-space conditioning, water, etc.) will remain a comparatively minor recurring cost at AFGWC. It is estimated that this aggregate cost will be much less than the cutoff of 1% of system cost. Amounts significantly below this limit have been ignored in this analysis.

Supplies and consummables include:

a. Punched cards,

b. Magnetic tapes,

c. Paper for printers,

d. Paper for CRT hard/copy devices,

e. Paper for facsimile display.

These materials are estimated to have an annual cost of $750,000. Being ignored is film for satellite display processing. Film usage should be greatly reduced with the advent of forecaster consoles. Moreover, film usage has been associated with Site 3 satellite data communications--this area has, for the most part, been outside the scope of SDC's analyses.

In summary, annual maintenance of the system should run at approximately $3.35 million dollars, including hardware, supplies and consummables.

3.0 RISK ANALYSIS

"Risk" can be defined as the expected impact of failure, or equivalently, the probability of failure multiplied by the quantified result (such as dollar cost) of failure. Under this definition, risk can be separated into the following categories:

a. Performance
b. Cost
c. Schedule
d. Mission Suitability
e. Scope

These five topics are discussed individually in the sections that follow. The discussions are mostly subjective rather than quantitative, and deal with the means by which risk was minimized. Architectural features which are of higher than average risk are identified.

3.1 PERFORMANCE

Failure of a system to perform adequately can be the result of either inadequate estimates or faulty design (changing requirements are dealt with under 3.4, "Mission Suitability"). In the paragraphs that follow, inadequate estimation is dealt with first, followed by design characteristics. The design characteristics are further broken down into throughput, storage capacity, reliability, operation, and security.

3.1.1 Estimation of Requirements

The risk of erroneous estimates was minimized at several stages during the study. During task 1, several requirements were "white-papered" and excluded from further consideration because they were ill-posed problems or were without serious foundation. These were coordinated with the Air Force. In addition, the translation of the impact of operational requirements into data processing

requirements was a joint effort by SDC and cognizant AFGWC personnel. The measurement space used was familiar to AFGWC personnel; for example, CPU time was measured in terms of 1108 CPU time. SDC then converted this measurement space to other computers using conservative relative throughput values. This conversion was done using industry accepted values.

SDC then performed an analysis of the 12-hour AFGWC production cycle, termed a "Network Analysis" for the network of predecessor-successor relationships. This Network Analysis was performed for both the peak and the average cases. The peak case was used to design the hardware resources required. This peak is significantly higher than the average, and thus a safety factor has been built into the architecture for peak loads, which also guards against mis-estimation of requirements.

In the process of compiling requirements, it became clear that the character of the data system must change considerably with respect to security in the next four years. Externally induced and unpredictable workloads would be imposed on the system due to Query/Response support of Command and Control Systems. This workload would have a variable mixture of security levels. Furthermore, the requirement was of highest priority yet still at the conceptual level, making definition of characteristics difficult. To account for the large error ellipsoid in these requirements, SDC designed a data system in which processors can "float" between security levels under a central Network Control. With knowledge of AFGWC resources and loading that spans the data system, the Network Control can shift resources to meet varying demands. Without this concept, processors must be dedicated to security levels and to functions, providing only fixed resources that must be predetermined. With global Network Control capability and "floating" processors, AFGWC can react to crisis or wartime conditions that have unpredictable loads at each security level.

3.1.2 Design Characteristics

Given a proper interpretation of requirements, there still remains the risk that the architecture may not function properly. This risk was minimized by SDC through the architectural feature discussed in the following paragraphs.

3.1.2.1 Throughput

SDC minimized the risk that the architecture will not have sufficient computing power in several different ways:

a. SDC has chosen a general purpose processor size (3.5 X 1108) that is well within the mainstream of the data processing community. The performance of such processors is less dependent on special features than the very large systems, and this provides assurance that promised throughput rates can be easily achieved.

b. For key driving requirements that need extremes of processing power, SDC has chosen to use array processors. In general, high MIP applications fail due to insufficient compute power. Array processors, which take advantage of problem characteristics, can supply many times the effective computing power that general purpose CPU's can provide. In addition, the array processors are modularly expandable to additional levels of compute speed at reasonable increments in cost. This is a vital characteristic in the solution of problems that are so complex that they must actually be implemented to determine compute levels with accuracy.

c. By 1982, AFGWC must support several time-critical requirements simultaneously. SDC has chosen an architecture utilizing multiple CPU's to minimize potential conflicts due to security levels and/or processing time. The network can be segmented (by 1982) into ten distinct processors, five of which can act as hosts to array processors. This provides assurance that multiple satellite passes can be mapped and gridded, multiple numerical models can be run, and multiple security

levels can be maintained concurrently. Architectural alternatives such as fewer but larger general purpose processors would have a higher rate of failing to handle such conflicts.

d. The system is normally run with main processor systems operating in a multiprocessor mode for greater reliability and simple scheduling. These multiprocessor systems have less throughput than dual uniprocessor systems due to such problems as memory conflicts. This means that the system has potential reserve computing power which has not been counted on in design estimates. By 1982, this reserve will reach 2.5 times the performance of an 1108 (2.5RP = 10 X 2RP - 5 X 3.5RP; a multiprocessor derating factor of .9 is standard, giving 2-2RP uniprocessors a rating of .9X2X2RP = ~ 3.5RP in multiprocessor mode).

Throughput areas which have a higher than average risk are listed below.

Data Upgrade Link - This link is a solution to the problem of an N^2 interconnection matrix, where N is the number of processors. In the architecture, processors span a large number of functions and security levels. Because of this, each processor must be able to send data to each other when the data path is from a lower to a higher security level. To avoid an N^2 proliferation of channel interconnections, SDC has used a control upgrade path. This "wagon wheel" approach requires only one channel from each of N processors. This data path has a throughput requirement that is not sizable from operational requirements. The risk seems small that channel speeds, delayed by cascaded encryption, will be insufficient.

Disk Interface - The risk associated with the disk interface stems from the large number of processors that must have an access path to disk storage. This risk is higher than average because the number of processors that must be wired into a single disk string exceeds that

found in normal data systems. The risk is one of potential bottlenecks rather than a hardware feasibility problem. Off-the-shelf hardware can be used to provide multiple paths, expandable to enormous powers of two. No more processors need be active on a disk string than is normally accomplished in a large number of installations, however. SDC has minimized the risk here by specifying multiple controllers (additional paths to disk storage) and combination disks where the most frequently accessed data is kept on fixed heads, areas reducing the potential of conflict.

In part, the risk stems from the very detailed hardware levels that must be understood to make a judicious choice of vendor and configuration. Additionally, the risk stems from the possibility that CPU's from different vendors must use the same disk, with problems in word length, disk format, access methods, etc. This latter risk can be minimized by staging with IBM plug compatible disks, which have become the industry standard.

Authentication Devices - Authentication devices represent SDC's only departure from the use of existing commercial capabilities. SDC believes, after discussion with hardware vendors, that this capability will shortly be available with transfer rates matching channel capacity. SDC has also confirmed the existence of non-commercial devices that have the necessary characteristics. If, for some reason, authentication devices were not brought out commercially, these other devices could be used instead. The impact would primarily be an increase in the cost per device and the need for detailed systems engineering to insure compatibility with disk interface protocol, access methods and diagnostics. SDC feels confident that a commercial capability will be available shortly and has therefore costed these devices at projected unit prices in all architecture cost estimates.

Cable Lengths - Careful physical planning will be required to insure that maximum cable lengths are not exceeded in providing system interconnections. Cable lengths can be extended in most cases with line drivers, but these have not been costed because their cost is small compared to the overall data system cost and because SDC's physical planning with generic components indicates that there is no need for line drivers. Maximum cable lengths should, however, be an evaluation criteria in equipment selection because this single feature has great impact on flexibility. This is especially true of processor to disk cabling because the more data bases a processor can be cabled to, the more functions can be performed on that processor; this simplifies scheduling, minimizes the probability of unresolvable conflicts (security or loading), and aids in failure recovery.

While the probability of failure is low, the cost impact is high, giving this area a higher than average risk. (SDC has used 150 feet as maximum channel cable lengths.)

3.1.2.2 Storage Capacity

The primary architectural feature which minimizes the risk that storage capacity will be insufficient is the Mass Storage Facility. The Mass Storage Facility acts as an extension of disk storage by moving data sets to and from disk without main processor intervention on a demand basis; this action is called "staging". Data sets are staged to disk prior to the execution of jobs requiring them. Disk data sets not in use are de-staged to a slower, far less expensive media to make room for active data sets. The criteria for releasing data sets is called the "least-recently-used" algorithm, used in virtual memory machines for paging of main memory. In this respect, the Mass Storage Facility provides an extension of virtual memory to another hierarchy of storage. With this capability, disk space becomes a tuning parameter rather than a hard-and-fast limitation.

In addition to the Mass Storage Facility minimizing the risk of insufficient storage capacity, projected technological advancement indicates that disk capacities will double or quadruple within the 1977-1987 period. The cost per disk will be minimally increased to protect rental revenues, but the cost per character stored will, of course, be approximately a half or fourth of what it was before.

3.1.2.3 Reliability

The risk of an unreliable data system has been minimized through several standard techniques, such as use of redundant critical components and design to a peak load,which provides additional throughput for failure recovery.

In addition, several technological features inherent in the components available today offer increased reliability. The clear trend of hardware manufacturers is to provide higher reliability. By staying within the mainstream of the data processing community, SDC has allowed AFGWC to take advantage of these improvements. For example, the IBM plug-compatible 3340-type disks (an example of the combination disk used in the architecture) requires no preventive maintenance and is capable of detecting and correcting errors up to 3 bits long per record. Also, it seems clear that semiconductor memory prices are dropping rapidly on a per bit basis, and that this cost savings will be used to provide better error correction and detection techniques for main memory. Since most processor hardware failures are due to memory errors, this trend promises dramatic reliability increases for main processor systems. Executive systems are also showing a decrease in failure rate due to maturing of code,use of structured programming,and the use of self-repair techniques.

There is an area of reliability, however, in which a higher than average risk exists. The direction of the industry is towards remote debugging of main processors from a remote central location. Security constraints dictate that

this is not possible at AFGWC. The impact of this is a possibility that SDC estimates of vendor supplied maintenance will be low. The risk, of course, increases towards the end of the study period. At this time, no cost estimates can be realistically assessed for this trend, and so SDC has used traditional maintenance values. (For more information on this subject, see the Security Considerations paragraph of the introduction to the AGE Plan, Volume 6.)

In software, the reliability risk is higher than average for Network Control and Central Data Base Management because the entire network of computers is affected by a failure of either of these software modules. This risk can be minimized by proper design of the code, with reliability and recovery an integral feature of the processing.

3.1.2.4 Operation

Due to the increase in requirements, the AFGWC data system will increase considerably in size and complexity from 1975 to 1982. The attendant risk is that it will become unwieldy from an operational viewpoint. SDC has minimized this risk by grouping functionally related operations into centralized work centers, by providing a network control capability, and by routing production messages to concerned personnel directly rather than through a console operator.

3.1.2.5 Security

The risk of security violations has been minimized in several ways:

First, mixed-mode security has not been used with one exception: because an individual communication line can carry messages at several security levels, the line handler decoder routers must have mixed-mode security. This exception is imposed on the architecture by the presence of mixed-mode in external systems.

Second, manual handling of multiple security levels has been restricted to low traffic levels. Printers have been provided for all security levels to

avoid bursting errors. Tape drives have been specified to have visible indicators that display security, and all unclassified tapes are handled via a separate, automated facility. The high transfer volume needed for the data upgrade path has been provided by an automated facility using channel transfer through cascaded authentication devices.

Third, authentication devices have been used to prevent inadvertent access of classified information. These devices are highly reliable hardware with fail-safe characteristics.

3.2 COST

SDC has minimized the risk of the data system exceeding estimated cost in several ways. First, all hardware cost were estimated conservatively by using a maximum cost within a category of equipment rather than an average. Second, SDC has chosen, almost without exception, existing hardware capabilities and so the costs can be estimated with high accuracy. Third, the technological trend is strongly towards more performance per dollar indicating that despite inflation, the actual hardware costs will average less than SDC has projected.

Software cost risk was also reduced by a conservative approach. The enhanced architecture has been specified with two powerful tools for increasing programmer productivity, interactive (online) programming and structured programming.

Software costs, however, were estimated with the minimum improvement in productivity needed to cost-justify the investment in these two techniques. In addition, SDC has specified main and support processors that are well within the general commercial capabilities. As a result, AFGWC is assured of reliable executives, a full range of software facilities, and essential software development tools.

Cost-benefit analyses were also very conservative and use the least-favorable conditions rather than typical or most-favorable ones. By using the minimum justification and the fastest payback period, the risk that an architectural feature will not prove to be cost effective was minimized. An example of this is the Mass Storage Facility which was justified on a basis of manpower savings over only a year, whereas the savings will accrue over a longer period and will also come from other than manpower reduction.

Two areas of cost stand out as having higher than average risk. First, authentication devices are not yet commercially available, as discussed under 3.1.2.1. Second, maintenance costs are a function of salaries as well as technology and are indicating a 3-4% rise every year. This is less than the current inflation rate and so represents an actual drop in cost in constant (inflation-adjusted to 1975) dollars. Hence, SDC has been conservative by assuming a constant maintenance fee in 1975 dollars. These conditions may not always prevail, however. This risk is also increased by a trend toward remote debugging as discussed in 3.1.2.3 and in the introduction to the AGE plan, Volume 6 of this final report. (Because AFGWC security constraints eliminate the possibility of remote trouble-shooting, more than the typical number on-site customer engineers may be required, resulting in an additional unpredictable cost.)

3.3 SCHEDULE

By using existing hardware capabilities, schedules for hardware delivery have been virtually eliminated as a risk factor.

Physical plant expansion beyond current plans is unnecessary as all components and maintenance areas fit within the planned space. This eliminates the risk of failure to meet schedule due to construction, a lengthy process for AFGWC.

The risks of not meeting software schedules was minimized as follows:

a. The use of contracted software was specified for 50% of the effort, alleviating USAF manpower constraints.

b. Techniques were specified for increasing programmer productivity and lowering maintenance activity on code via training, structured programming, on-line programming, and an improved test plan.

c. SDC assumed no slippage of requirements, although several key requirements have a high probability of a late realization.

3.4 MISSION SUITABILITY

Mission suitability is primarily a question of having the flexibility to accomodate changing requirements and growth. The enhanced architecture has several features which provide flexibility in meeting requirements:

a. Network Control. The central scheduling and status monitoring capabilities of the Network Control function provide an ability to react to changing workloads or priorities.

b. Security Approach. Processors can be quickly changed from one security level to another due to the authentication devices and the modularization of the network into main processor subsystems that contain only rapidly cleanable devices. This allows flexibility in applying resources at differing security levels.

c. External Interfaces. The major resources of the computer network, the main processor subsystems, are decoupled from external interfaces because work is logged into the data system through the disk subsystems. Main processors are not directly on-line to any external communication lines or support processors (the one exception is the programmer consoles which will be directly linked to preserve vendor-supplied software support). Thus, changes to communication links are isolated to the communication subsystems, and even total replacement

of line handler data router hardware will not affect the main processor interface to the outside world (as they still will be linked only to the disks). The use of disks as an interface also provides timing and loading isolation. Support processors can be modified or increased in number (as well as fail, or change missions) without a hardware or software impact within the main processor subsystems.

d. Centralized Data Bases. Data bases for a given function are centralized into subsystems; e.g., meteorological and satellite data base subsystems. This provides for modular growth of a data base without the cost being multiplied by repetition on each processor system. It also allows easy expansion of the number or power of processor subsystems. Multiple computers can be brought to bear in a functional area, such as satellite data mapping and gridding because the data base is centralized and shared.

In addition to the need for flexibility to accommodate change, there is the need to avoid the risk of designing an architecture that is obsolete due to technological advancement. Without proper safeguard, a 1975 design could be totally inappropriate by 1982. SDC has minimized the risk of obsolescence by examining technology projections (e.g., SADPR-85) and by obtaining proprietary information from vendors under non-disclosure agreements. This information was discussed during formal briefings and will not be treated here. The result of the SDC investigation has been an architecture that allows AFGWC a growth path compatible with the foreseeable direction of the industry.

3.5 SCOPE

Scope is the ability to encompass all requirements and treat all aspects of the data system. SDC emphasized scope in the Task 1 briefing as a characteristic of both Task 1 and the succeeding tasks. The use of the requirement, functional,

and architectural domains as organizational frameworks provided a mechanism for insuring that the architecture was treated from all perspectives. Additionally, the flexibility and throughput of the enhanced architecture, as previously discussed, are guarantees of the ability to supply a total range of support to AFGWC customers.

4.0 SYSTEM VERIFICATION PLANNING

The delivery and integration of a complex hardware/software system is supplemented by independent integrated test disciplines which should ensure that the enhanced architecture implementation meets all functional and technical performance requirements presented in the system specification. Essential follow-up to the specification requirements for the AFGWC architecture are the testing approaches which assure the installation of a quality system in a controlled and timely manner.

The following sections outline system verification philosophy disciplines for both hardware components, software components, and the integrated system which will insure this level of integration.

4.1 SYSTEM TESTING PHILOSOPHY

4.1.1 Test Evolution

The first things that need to be established are the steps of the total test planning effort. These steps are identified as follows:

a. Test Requirements. This step is a production of a document either by the government or by an outside vendor. The basis for the test requirements document depends on the nature of the procurement of components of the architecture and the relationship of the testing to that procurement or procurements (part of the fulfillment of the delivery or level of effort). Depending on the circumstances, the design specification may be used as a first iteration; however, test specifications normally deviate from design specifications since some design specifications are non-testable, others are trivial, and often the design encompasses details testable at a lower level than was originally specified.

b. Test Planning. As in the management of any large effort, a test plan is written which identifies the conduct of tests, the relations between tests (in the form of a network analysis of the total effort), a philosophy of verification by the government as well as other management details (see Section 4.5.1). Because of the inter-dependencies in testing and the high probability that events will not progress according to schedule, test planning is very important.

c. Test Description. In this effort, the organization doing the testing describes in detail how the test requirements are to be met. This description gives the test procedures for every test including parameters, data, and verification procedures (see Section 4.5.2). (It is recommended that the test procedures be written in two parts: first the overview, and then more detailed description in order to accommodate a total review.)

d. Test Accomplishment. During actual testing (depending on the size of the effort and the dependency and the detail to which the test process needs to be observed), this effort must be documented in detail. A testing configuration management board is essential, and must have the authority to change schedules, monitor activity, and report progress.

e. Test Analysis and Documentation. The outputs and products test are then analyzed and formally documented.

4.1.2 Test Concepts

The overall test concept which SDC recommends is a top down approach (usually following the top down design if applicable). In this type of testing the component residing at the higher level of abstraction is tested with all other components at that same level of abstraction. Components existing at a higher level (in this case, components and modules are synonomous) will have already been tested and those at a lower level have yet to be tested. The existence

of components at a lower level will be simulated using small simulation packages called "stubs" which effectively act as if they were the lower level. Hopefully the definition of the module was such that it could be tested independently and simply; however, if this is not the case, preparation for testing at a single level might be extensive. In this case, within a module, a bottom up testing scheme is utilized where the smallest pieces are tested individually then gradually put together into a package. This also describes exactly how the components at a single level are tested, first individually and then put together one at a time.

4.1.3 Levels of Testing

The various levels of testing are applied no matter what size the development; however, in some cases, especially in small developments, the levels are run together.

a. Component Checkout. The first level of testing is called component checkout and is usually accomplished by the programmer. This is the testing of the individual components in either static or dynamic states.

b. Validation Testing. This is the ongoing testing effort that tests levels of abstraction until the entire system has been tested. This level precisely follows the test plan.

c. Acceptance Testing. In cases where the operational element of the buyer are different than the agencies doing the developing, acceptance testing is the name given for the demonstration that the product works as advertised. This is accomplished by selecting a reasonable set of validation tests to be performed.

d. Integration Testing. Where there are several contractors, several subsystems, or hardware and software being procured simultaneously, the testing effort which integrates these into a single system is called integration testing. It can be accomplished using the

philosophies described earlier, and as before, requires a complete set of documentation and planning.

e. Rehearsal. This phase of testing is the linking of man to machine and programs. This is the test in which the final users of the system run the system and the builders of the system are available for assistance.

4.2 HARDWARE COMPONENT CHECKOUT

The hardware associated with AFGWC data system architecture can be viewed as either commercial or program unique equipment. Program unique equipment is subject to the same validation procedures as commercial equipment after it goes into production. The following hierarchy of hardware testing will provide AFGWC with the highest probability of a successful integration of the architecture.

4.2.1 Component Testing

This testing consists of reviewing the hardware element in both static and dynamic states. This inspection will be performed during and immediately after manufacture. When appropriate, this will include the use of reliability and diagnostic systems provided by the manufacturer. This level of testing includes: (a) Bench tests performed using standard lab equipment (oscilloscopes, waveform generators, etc.) to verify unit performance; and (b) Tests performed in a test bed environment, sometimes requiring special-purpose test equipment (e.g., data generators, displays, etc.) to verify assembly performance specifications (e.g., throughput, bit error rate, code conversion, etc.).

4.2.2 Hardware Integration Tests

This series of tests will be performed at a subsystem and system level. As individual components are integrated into subsystems and systems, the manufacturer will provide viable techniques for ensuring that the design performance continues to be adhered to. This level of testing includes:

a. Subsystem Testing. Tests performed in a test bed environment, generally requiring special-purpose test equipment for interface simulation, to verify subsystem performance specifications. Also reverifies assembly performance in a subsystem environment.

b. System Testing. The final phase of testing is the assembling of the set of subsystems/systems and verifying that these subsystems/systems will support the mission which has been specified in the operational requirements; i.e., the AFGWC architecture as it is specified in the specification requirements.

If software components are necessary at this level of testing and the operational software is still in the development stage, the manufacturer should provide simulation software drivers that can support this testing effort.

This level of testing should verify the hardware's capacity to support the system integration tests and formal demonstrations.

4.3 SOFTWARE COMPONENT CHECKOUT

Two major categories of tests will be utilized for the testing of software components for the enhanced AFGWC architecture. The two major categories are: (a) functional testing, and (b) performance testing.

4.3.1 Functional Testing

Functional testing is an exhaustive one-for-one test of each cause that can produce an effect or a test for each and every condition that can occur.

Functional testing can be divided into the following subcategories: new function testing, functional regression testing, and functional stress testing.

New function testing refers to the testing that must be done to new programs or changes to existing programs to verify their new capabilities. For each new function or change to a function, a test or series of tests must be designed to exercise that new function to ensure it operates correctly. This becomes a particularly involved problem in a meteorological environment such as AFGWC's. The large grids, vast amounts of input data, and many time steps or successive iterations make it no easy task to ensure that a function is operating correctly. Often, it may be impossible to predetermine what "correct" behavior is. Meteorological models which are driven by complicated mathematical algorithms may appear to be malfunctioning when in fact it is only the programmer's understanding of the physics involved which is in error. Once a new capability is verified, it still must be determined whether the change has inadvertently affected another phase of the function's operation; for example, it can now predict temperature changes within a tenth of a degree as expected, but has unexpectedly lost the ability to predict vertical winds. New function testing must involve as a minimum the following:

a. Identification of all <u>new</u> capabilities provided.

b. A manual analysis of the changes the new capabilities should generate.

c. Testing of the new capabilities with a wide cross-section of input data.

d. Successive iterations of the new function (if it feeds on itself) out to the farthest point feasible, with careful examination of the outputs at each step.

e. A functional regression testing on other portions of the function which should remain unchanged or on functions which use the new output as a source for their data.

Functional regression testing will verify that unmodified elements of the environment remain intact and that there have been no changes caused by the

modification of other elements of the function. In order to accomplish this testing, complete functional regression testing must be performed against all programs once any element of that environment has been modified. The number of functional regression tests for any particular function will be directly correlated with the size of the function. There may be one or several hundred tests associated with each major change.

This form of testing will ensure that errors are located and corrected in the test environment and that any modifications presently performed on the system will not affect any previous system capabilities other than those in the desired modification. The fundamental concept of regression testing is that each and every test case that is run successfully against the old unmodified code must produce identical results when run against the modified code. A related type of testing involves the determination that an unmodified element will not be harmfully effected by data which is now defunct (but hopefully better) produced by an element which has been modified. This would be the type of regression testing referred to in step e. of the paragraph describing new function testing. When such changes in new data are injected, the basic premise of regression testing cannot be met since it is unlikely that two different data sets will produce the same results. The task becomes more difficult, since changes must be predicted and these used as the goal of regression. Since many functional changes at AFGWC involve enhancements in the actual data rather than just changes in the manner they are calculated, this type of testing cannot be overlooked. It is preferred that regression testing be run in automated manner, using system simulation or other verification resources. The work load would be intolerable if the tests were run in the manual mode. If during this testing, a regression or an error occurs, the new code must be corrected or made compatible with the old code in order that the test can run as planned.

Functional stress testing will ensure that the system can respond under heavy loading conditions as it does in the low load condition as performed in both the new function testing and the functional regression testing. Often, programs will execute properly under minimal loading conditions but will fail when the system is heavily loaded. Functional stress testing is used to locate this type of a failure. Given the wide range of loading found in AFGWC computers, stress testing is very important to ensure functions will not err at what could be the worst time.

4.3.2 Performance Testing

Performance testing will attempt to recreate or simulate a specific AFGWC production environment. The specific test will be derived or produced from user profiles provided by AFGWC. Performance testing can be divided into the following subcategories: performance load testing, regression performance testing, and performance measurement testing. The desirability of performance testing cannot be overlooked. With Network Control handling the allocation of functions, particular elements could find themselves competing for resources under many conditions. If the conflicts can be determined in advance, then Network Control can be prepared to resolve such conflicts.

Performance load testing will determine whether or not the programs that have been modified or newly implemented can indeed handle the planned load with adequate throughput and an acceptable response. It is important that this capability be tested in a test environment rather than the production environment. It is extremely important to this type of testing that accurate profiles be established. Otherwise programs may appear to execute adequately in the test environment, but fail in the actual production environment.

Regression performance testing, again, tests whether or not newly modified code or implemented code effects capabilities and capacities in the previous system. This type of testing is conducted to determine the extent of change

in throughput and response on any portion of the environment that has been modified. If for some reason, the throughput is not acceptable, changes to the system, either to the newly implemented or the previously existing system, are necessary.

Performance measurement testing is performed in order to locate critical bottlenecks in the system and aids the system designers in tuning the system for the production environment. In this particular type of test, various systems parameters will be varied and measurements can then be made to show the effect of the new code on both response and throughput. This contrived environment is really in no way representative of any production environment. It is, however, an experimental environment which causes certain effects to become obvious in the newly implemented code.

4.4 SYSTEM DEMONSTRATION

System demonstration will perform an integrated test on both the hardware and software components of the AFGWC architecture. Demonstration will consist of both the dynamic operation of increments of the system and of the system itself. Verification techniques utilized for the system demonstration will be via both system displays and other input and output devices. System demonstration is the final step in establishing that all AFGWC requirements are verified. It consists primarily of repeatedly exercising the system under realistic conditions and carefully reviewing all operations and outputs for any anomalies. Both off-line manual examination of the data and computer analysis of the test results are recommended for the AFGWC architecture.

4.5 SYSTEM TEST PLANNING

Each level of testing associated with the enhanced AFGWC architecture comprises a similar set of activities. For each level, the activities to be performed are as follows:

a. Develop test plan

1) Identify all input/output data paths.

2) Identify program tasks (requirements, interfaces/functions) to be tested.

3) Delineate validation methods to be employed (i.e., inspection, analysis, demonstration, or usage).

4) Identify types and sources of acceptance criteria, and tolerances where applicable.

5) Specify test tools, equipment configurations, and organizational roles.

6) Specify test data requirements.

7) Schedule test activities.

b. Develop test procedures

1) Acquire test tools.

2) Generate test data (as required).

3) Design test cases.

4) Specify acceptance criteria and tolerances where applicable.

c. Conduct tests.

d. Prepare test analysis and generate report, analyzing performance against criteria.

4.5.1 Test Plan Development

The test plans will provide the following:

a. Identification of All Input/Output Data Paths. All input/output data paths will be identified. "Data" in this case also includes parameters, conditions of indicators, results of logical tests, or any other controlling input or output.

While for component level testing, there is some latitude available in the determination of material to be explictly tested, the decision for implicit testing should not be taken lightly, since the time to determine whether requirements have been properly satisfied or whether the integrity of interfaces has been maintained is during this level of testing.

b. Identify Program Tasks (requirements, interfaces and functions) To Be Tested. The title of the test plan for a component test will identify by name or number the particular component under test. However, the test plan will also describe the task of that component related to the specification requirement that is being implemented. If the component satisfies more than one requirement, this will be stated, and the parts of the test to demonstrate each requirement will be clearly identified.

c. Selection of Validation Methods. Validation will be by means of inspection, analysis, demonstration, or usage.

d. Types and Sources of Acceptance Criteria and Tolerances. Acceptance criteria may be quantitative (e.g., accuracy of results or speed of operations) or qualitative (e.g., legibility and understandability of output). The sources of criteria in the quantitative case should be drawn from benchmark results from existing operations which are to be supplied by AFGWC. Qualitative criteria will have emanated from the system specification.

e. Test Tools. Test tools will be selected to provide:

   1) Accurate listing of input data for each test case.

   2) Means of exhibiting data base integrity.

   3) Execution frequency and time consumption of tests.

   4) Fault location (e.g., dumps or traces).

   5) Complete presentation of output results.

f. Test Data Requirements. The media, formats, ranges, and volume of test data will be specified, as well as the sources of data.

g. Test Activities Scheduling. Each activity for each test or set of tests within the test plan will be scheduled. Emphasis will be placed upon the need dates for test tools or test data, particularly in cases where test data or reviews involve AFGWC. Subsystem tests must be scheduled in accordance with the integrated system testing schedule.

h. Test Plan Review. Test plans will be reviewed for acceptability and adequacy by AFGWC. When these reviews have been successfully completed, the test plan will provide a basis for the development for the test procedures.

4.5.2 Test Procedure Development

The test procedures will provide a detailed step-by-step scenario of the testing by which all hardware and software will be validated.

a. Test Tools Acquisition. The test tools and equipment configurations that are required will be specified, since successful testing will depend upon these being "up and running" for the start of testing.

b. Test Data Generation. If test data generation is required, that task will be initiated immediately after the approval of the test plan to make certain that the test data will be available.

c. Test Case Design. Test cases will be designed to demonstrate for each component or subsystem the acceptability of logic, computations, data handling, interfaces, and data base integrity.

d. Acceptance Criteria and Tolerances Specifications. Utilizing the sources and techniques to be found in the test plan, acceptance criteria will be specified unambiguously for each test case, and in those cases where the criteria are quantitative, tolerances that will define the range of acceptable performance will be provided.

e. Test Procedures Review. Test procedures will be reviewed for their acceptability and accuracy by AFGWC. Upon the successful completion of these reviews, these test procedures will provide a scenario for the testing to follow, and will make up a portion of the documentation to be delivered with the product.

4.5.3 Testing

Tests may be executed in any convenient order. However, when checkout of all test cases is complete, the entire test procedure scenario will be rerun in documented sequence. This rerun will be monitored by AFGWC.

a. Error Correction. Errors in component will be corrected by the vendor responsible for the component, and the component with modifications will be retested by the vendor. If design errors are encountered, they will be documented by the test team and directed to AFGWC. AFGWC will resolve all design errors.

b. Test Results. When the completion scenario of the tests procedure has been successfully completed as documented, a copy of the test output is reserved so that it will be available along with the test procedure.

4.5.4 Performance Analysis

The primary purpose of the test report is to evaluate the performance of the system against the criteria established in the test procedures. The test output will be liberally annotated and tabbed for subsequent reference, and will serve as a part of the test report along with a written synopsis of the analysis.