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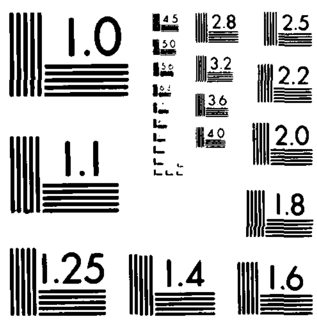

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(10) Robert W. Sittler, Karl Seiler, III

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16. Abstract

The study is a comparative analysis of the costs and benefits from competing distributed and centralized ATARS architectures. The current DABS/ATARS structure is a distributed one; a new architecture is postulated for deployment as a centralized ATARS system.

Distributed and centralized ATARS are compared as to performance, cost, reliability, maintainability, vulnerability and growth potential. Performance and reliability are treated as constraints to be met equally by all architectures. Maintainability is included in cost.

The cost analysis including cost sensitivities forms the bulk of the study. It is found that centralization of most sites is more costly than a distributed deployment and that the individual sites which contribute most to a cost advantage for centralization lie in high density terminal areas.

A most significant finding is that centralized ATARS is inferior to distributed ATARS in vulnerability. The options are about equal in growth potential.

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Preface

The ARCON Corporation, under contract to the FAA, was asked to conduct an independent assessment of the comparative performance, cost, reliability, maintainability, vulnerability and growth potential of siting ATARS computers at surveillance sites vs. ATC facility sites.

The initial assumptions, jointly developed by ARCON and the FAA, and later approved by the FAA, were used by ARCON's Dr. Robert Sittler to conduct the original study.

Based on the approved assumptions ARCON prepared a final report entitled, "ATARS Implementation Tradeoff Study," dated October 1979. ARCON's report makes up Chapters 1-4 and most of Chapter 6 of this report.

The FAA, based on a review of the draft of the original final report prepared by ARCON, found it desirable to extend the ARCON effort by doing a sensitivity analysis. This work, done by FAA's Karl Seiler, appears in Chapter 5. In addition, two paragraphs and a table were added to ARCON's original summary to reflect Seiler's extensions. The net effect of the sensitivity analysis on the results obtained in the original ARCON report is to strengthen the conclusions reached therein.

1.0 INTRODUCTION

1.1 The Problem

The Automated Traffic Advisories and Resolution Service, ATARS*, was conceived in the early seventies to augment the Federal Aviation Administration's air traffic control (ATC) system's capabilities. ATARS [1] is a computer based collision avoidance system which: tracks aircraft from radar/beacon reports, detects midair conflicts, computes appropriate avoidance maneuvers, generates appropriate warnings and maneuver commands for the involved aircraft and alerts the appropriate ATC controllers. ATARS is designed to work in conjunction with a new unified system for air surveillance, the Discrete Address Beacon System (DABS) [2], [3], and to communicate with aircraft equipped with a DABS transponder and special ATARS cockpit display.

The current DABS/ATARS design and development places the DABS and ATARS processing in a single multiprocessor computer complex at each DABS site. It is the purpose of this study to reconsider this architecture of DABS and ATARS processing and to determine whether ATARS processing can be profitably relocated at central facilities.

The current architecture of DABS/ATARS leads to a multisite distributed ATARS, where each site handles its own local ATARS processing for aircraft within its area of responsibility. Relocation of the ATARS processing from several such sites to a common facility produces a more centralized ATARS. In this study the current distributed ATARS provides a baseline for evaluating and comparing the consequences of various possible ATARS centralizations.

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*Previously named IPC (Intermittent Positive Control).
[1], [2], etc. Numerals refer to references cited.

1.2 Background

A brief description of the DABS/ATARS system and of terminology useful in understanding this report is given in Appendix A. Unless otherwise noted in what follows, the terms DABS and ATARS refer to the ground computer hardware/software function complexes with are part of the overall operational DABS/ATARS system.

DABS has an intimate connection with its sensor. DABS controls the interrogation of aircraft and uplinking of commands as well as processing target reports and downlink messages. These tasks are sufficiently demanding so that, from the first, it has been evident that DABS should be located physically close to the radar/beacon site. In effect, DABS acts as an advanced radar/beacon signal processor requiring only relatively minor coordinations with adjacent sites.

The rationale for the location of ATARS has not been so clear. First of all, ATARS is a high level ATC function of a type traditionally implemented in the ATC facility computers. Indeed, there already has been much development of ARTS-III and NAS-Stage A conflict alert software. It is natural to suggest that ATARS and facilities conflict alert functions be combined or merged and implemented in the facility computers.

Second, analysis of distributed ATARS communication requirements indicates that the capacity required on intersite links in order to coordinate adjacent ATARS operations is rather high (for Epoch ATARS). If ATARS from a number of such sites were relocated together at a central site or facility, such intersite communications would be shortened or eliminated.

Finally, the older traditional architecture for major real time control applications of computer systems is to centrally locate hardware/software in order to achieve maximum efficiency in the use of expensive equipment and to facilitate the management and maintenance of the system.

Of course, presumed advantages of an ATARS centralization must be balanced against all the other consequences of such a shift in system architecture. Since there are many conceivable variations in centralized architecture, this balance is greatly influenced by the assumptions and preliminary conditions or constraints placed upon them. Therefore, it is important to make these assumptions and constraints clear at an early point (Section 2.) of the study.

1.3 Objective and Approach

The objective of this study is to compare and evaluate centralized vs. distributed ATARS architectures with regard to performance, cost, maintainability, reliability, vulnerability and growth potential.

Issues to be resolved include the following:

a.) In view of the many possibilities for a centralized ATARS architecture, how can one select a limited set of configurations for study?

b.) What performance requirements are to be placed on a centralized ATARS?

c.) Can existing ATC facilities computers be utilized to perform ATARS functions?

d.) What computer hardware and software requirements are generated by a switch from distributed to centralized ATARS?

e.) What new communications requirements result from a centralized ATARS?

f.) What communications techniques are to be used?

g.) How do the performance capabilities of centralized and distributed ATARS compare?

h.) How do the total system costs compare?

i.) Are there special advantages or disadvantages of a centralized ATARS with regard to system maintainability, reliability and vulnerability?

j.) Does a centralized ATARS allow for easier system growth, in scope and performance, than a distributed ATARS?

k.) How do the use of Sector ATARS and through-the-transponder coordination affect the comparisons between ATARS architectures?

Some of these questions are resolved by preliminary considerations in Section 2. The most detailed and quantitative analyses are applied to the computer and communications requirements and costs of a centralized ATARS and their comparison with the distributed ATARS.

To evaluate total costs, there is a need to be able to reduce fixed (one-time) and recurring costs to a common measure. In order to accomplish this, we adopt a ten-year base period. All recurring costs are totaled throughout the base period and added to fixed cost to get the ten-year system costs, which are used in comparisons.

2.0 ASSUMPTIONS AND PRELIMINARY RESULTS

The following items of this section treat various issues which may be clarified or resolved by assumption or preliminary analysis.

2.1 Commonality of Hardware/Software

The commonality of hardware and software in any centralized ATARS deployment is a very desirable objective. It is not desirable to have more than one version of DABS/ATARS processor architecture or of DABS/ATARS software design because of the substantial additional development and maintenance costs incurred by a multiple approach.

In this study we postulate that only one basic set of DABS/ATARS hardware and software building blocks can be used to construct various centralized ATARS deployments. This is accomplished by separating the original DABS/ATARS processor configuration of distributed ATARS into two parts (See Figures 2-1, 2-3). The first part retains the DABS functions and remains at the radar/beacon site. The second part contains the ATARS functions and may be located either remotely or collocated at the site. These parts are independent processor complexes which exchange data through I/O communications.

For a multisite environment in which adjacent ATARS service areas overlap, the ATARS complexes can be removed to a central location. Then their communication lines to their respective DABS sites are long, but the intersite ATARS communications are short (See Figure 2-3). On the other hand, at an isolated DABS site, the ATARS complex can be collocated (but not merged with DABS as in the distributed base architecture). Then, DABS to ATARS communications are short.

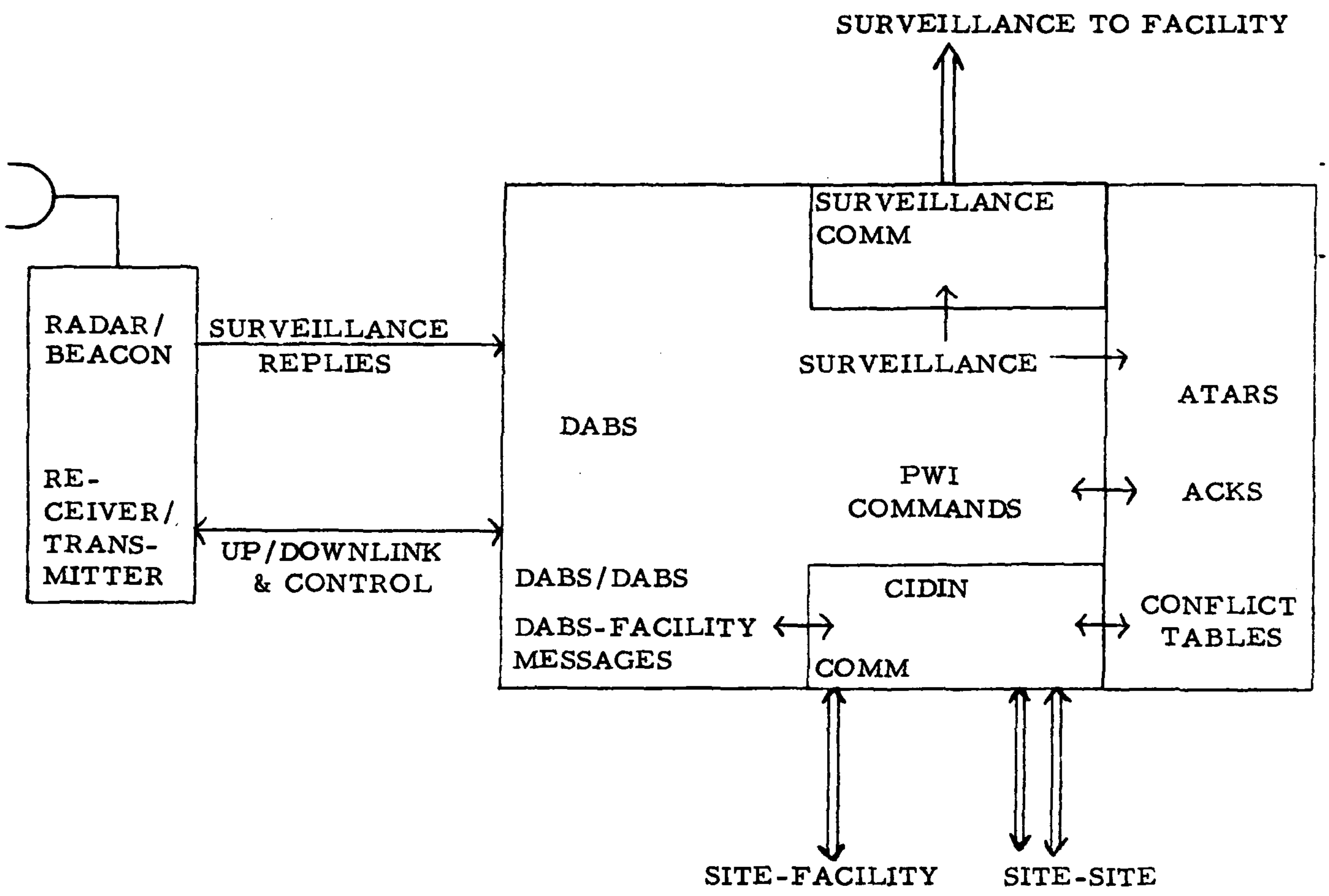


FIGURE 2-1 DISTRIBUTED DABS/ATARS BASELINE CONFIGURATION

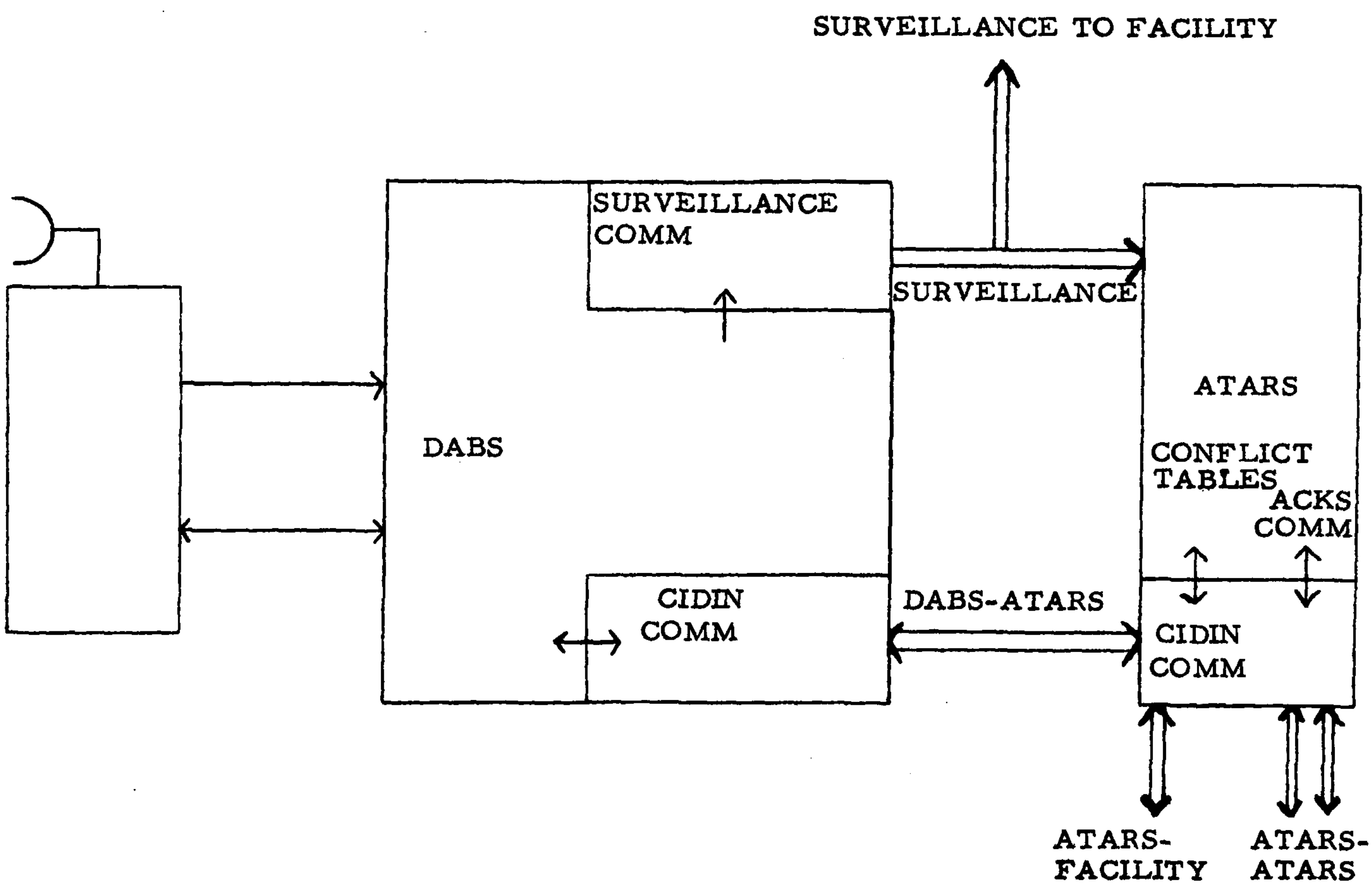


FIGURE 2-2 CENTRALIZED DABS/ATARS CONFIGURATION

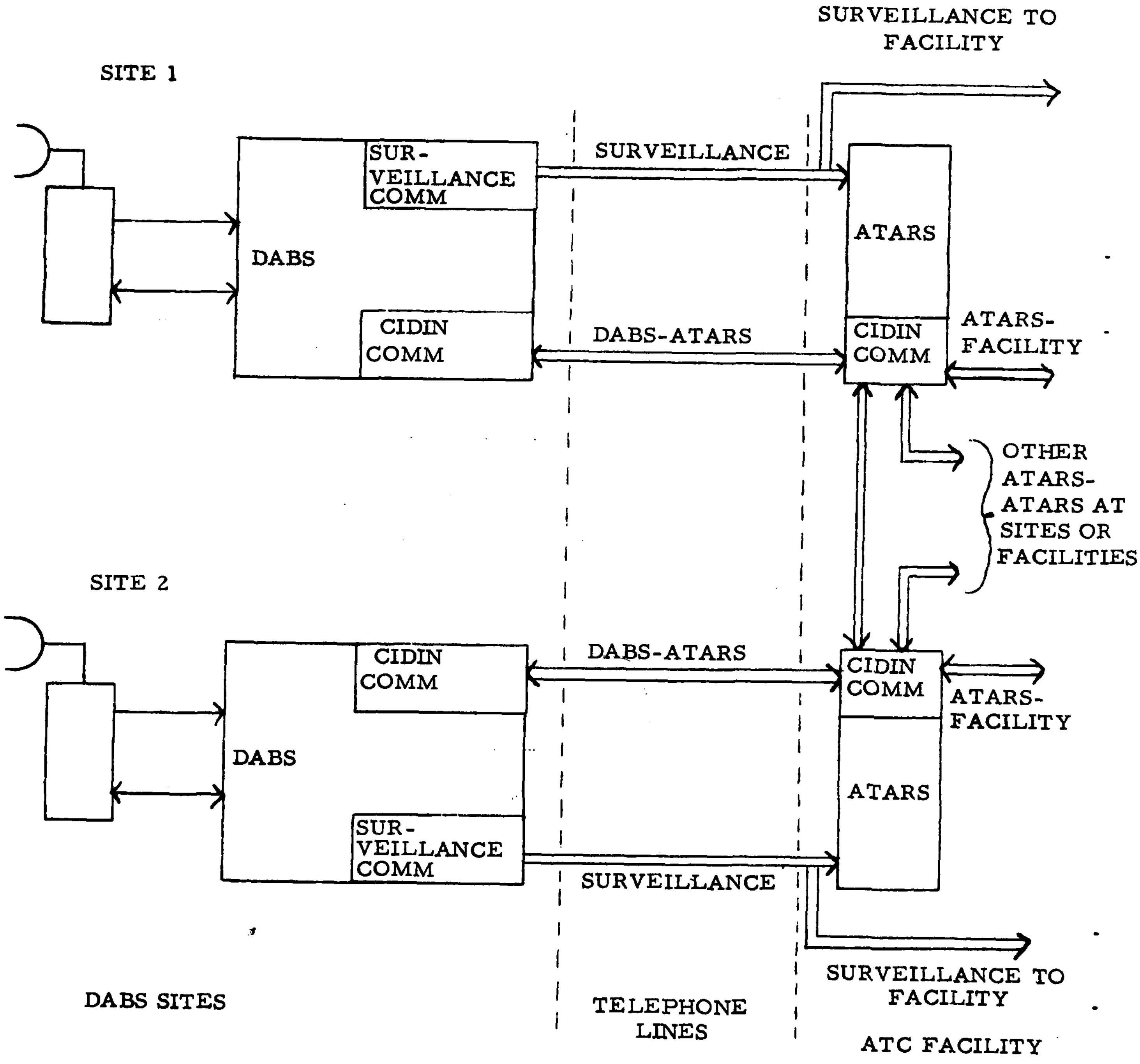


FIGURE 2-3 CENTRALIZED ATARS LOCATED AT FACILITY

To separate DABS and ATARS processor complexes, additional ATARS processing hardware is required to handle new communications functions and to provide appropriate redundancy. According to the commonality concept employed here, any centralized ATARS deployment consists of exclusive use of such separate DABS and ATARS blocks even though some (or even most) are collocated at radar/beacon sites. Thus, an equipment cost penalty is incurred immediately because of this DABS and ATARS separation, even in the degenerate "centralized" deployment where DABS and ATARS are collocated at each site.

The consequences of relaxing the commonality requirement will be considered briefly where appropriate. The most sensible relaxation takes the form of employing the combined DABS/ATARS distributed baseline everywhere except at some heavy traffic, multisite areas where DABS and ATARS are separated and ATARS complexes are centrally located.

2.2 Load Capacity Specifications

For the purposes of this study we accept the load capacity specifications given in the DABS Engineering Requirement (ER), [3], as based on the 1995 Los Angeles Basin Model [4]. In those cases where the necessary quantities are not specifically given in the ER, they may be derived from given quantities by a simple argument.

In particular, the following maximum site loads are important in determining communications requirements:

Number of aircraft in coverage of single site = 400
(Distributed roughly uniformly in 90° of coverage.)

Number of aircraft receiving uplink messages each scan = 200
(Maximum of 100 in a 2 second epoch.)

Number of aircraft conflict pairs in intersite seam areas = 40
(Assume approximately 13 pairs in each of three seams.)

For an ASR site, the 90° of coverage in which aircraft are concentrated is a contiguous 90° sector; a 4 second scan time is assumed. At an ARSR site a back-to-back antenna is used with a scan time of 10 seconds; we assume, then, that the 90° of coverage consists of a 45° sector in one direction and a similar 45° sector diametrically opposed in the other direction. These assumptions lead to the highest surveillance communications loads consistent with the ER specifications.

The following assumed maximum site loads are of lesser importance:

Total number of conflict pairs = 80

Number of aircraft requiring handoff (per adjacent site) = 4

Number of aircraft requiring remote surveillance
(per adjacent site) = 4

In order to consider growth potentialities, we follow the ER and scale the above aircraft numbers from 400 to 700 total. Other aircraft numbers scale up linearly. On the other hand, we assume that conflict pairs scale as the square of the number of aircraft involved because of an increase in traffic density. The appropriate factor is $(700/400)^2 \approx 3$. Therefore, 40 conflict pairs in seams become 120 pairs.

A similar scaling can be performed in the opposite direction for lighter traffic loads.

2.3 Selection of Equipment for the Centralized ATARS Complex

In order to save on equipment costs, the use of ATC facilities computers for implementing ATARS in a centralized configuration might be considered. However, there are marked disadvantages with this approach, especially with regard to the reliability and capacity of current ATC computers.

The current ATC computer designs do not match the DABS/ATARS computer system in reliability. Further, even if upgraded to match the DABS/ATARS hardware reliability, the design of a merged ATC/ATARS system does not provide the operational system redundancy which separate systems can supply. Conflict detection and resolution is a critical function which can be supported most reliably and with least vulnerability by two independent computer systems on the two levels of ATARS and ATC.

An additional consideration is that ATC computers are already well loaded by existing or planned future tasks. The ATARS function of DABS requires a considerable computer capacity (processors and memory). Incorporation of ATARS within the current architectures is not feasible.

For all these reasons we assume that centralized ATARS processing for each site takes place in its own separate computer complex. For purposes of evaluation in this study, to match the distributed ATARS baseline in reliability and to provide equipment commonality, we assume that the centralized ATARS complex consists of an arrangement of standard baseline DABS/ATARS processors, memories, power supplies, interfaces and peripheral equipments.

2.4 Location of Centralized ATARS

In principle, centralized ATARS processing for multiple sites can be located at any geographical point. However, there are convincing reasons for restricting consideration of centralized locations to existing ATC center facilities, terminal or enroute.

First of all, use of existing facilities eliminates costs of new land acquisition and construction. Also, ATC center facilities already contain computer equipment and a supporting staff, so that accommodating additional equipment there is easier and cheaper than establishing a new facility. Finally, the ATC center is a terminal point for communications with the sites it serves. These existing communications may be at least partially shared by ATARS (especially for surveillance input). Thus, the establishment of new communications is minimized.

The location of a centralized ATARS in a new facility such that total communication line lengths are minimized does not minimize overall system costs. Line rental fees are only a weak function of mileage and are far outweighted by the other considerations noted above.

For these reasons, we assume that any multisite centralized ATARS will be located at an existing control facility.

2.5 Processors

Evaluation of processor costs in this study is based on the TI9900 microprocessor, utilized in a hardware system concept similar to the DABS/ATARS engineering prototype. This prototype is a distributed multiprocessor complex, partitioned and extended as required to implement a centralized ATARS deployment.

Even though the final implementation of DABS/ATARS may not use precisely the same processors or the functional assignments of the prototype, it is expected to be broadly similar. Important general properties of any DABS/ATARS implementation are: multiprocessor distributed architecture for the DABS, ATARS or DABS/ATARS processor complex, dual microcomputers with voting logic for each processor, spare processors and redundant (dual read/single write) memories for hardware reliability, duplication of program tables and operational programs for failure recovery. Evaluation of costs based on the engineering prototype should be representative of any system with these features. (For a brief discussion of the effect of future hardware component trends on costs see Section 4.6.)

2.6 Communications

The following assumptions about DABS/ATARS communications are applied throughout this study:

a.) All communications between sites, between sites and facilities and between facilities are by voice grade (Series 2000/3000) leased telephone lines. No broad band RM or coaxial links are assumed.

b.) Any point-to-point link consists of a number of 4800 BPS (bits/second) full duplex lines with full backup.

c.) There are no DABS/ATARS communication nodes other than those at the DABS and ATARS processor complexes. That is, no special communication centers are defined.

d.) Relaying of messages through intermediate DABS/ATARS processors is to be minimized. Packet switching is not utilized.

e.) Communication between computers within the same ATC facility is by direct I/O buss. No special modulation is required.

These assumptions are consistent with a desire to put the evaluation of communication costs on a general and realistic future basis, without tying the analysis to the present peculiarities of particular site/facility communication systems.

It has been noted in a recent METREK study [5] that a packet switching network for ER capacity loads is more expensive for a multi-site distributed DABS/Epoch ATARS system than a star network which all links are with and through a common ATC center. The star, in turn, is more expensive than the original distributed dedicated site-site link network design. The cost balance shifts in favor of the star or packet switching for light loads or when Sector ATARS or through-the-transponder coordination is considered. However, we shall not need to analyze this shift or to consider in detail more than a dedicated link network to determine the main tradeoffs between distributed and centralized ATARS.

Further, with an ARTCC as the star center relay point a NADIN switch or similar processor must be used to relay messages. This is, however, a vulnerable failure point without adequate redundancy. Therefore, we omit use of any NADIN star switching in the DABS/ATARS network and allow only relay of noncritical messages through DABS/ATARS processor complexes. (Relaying of surveillance data, conflict table exchanges and uplink proximity warning and intermittent positive control (PWI/IPC) messages is not permitted.)

3.0 DESCRIPTION AND COSTING OF DABS/ATARS SYSTEM COMPONENTS

The following subsections describe and develop costs for the processor and communication requirements for two main systems: distributed ATARS and centralized ATARS. Distributed Epoch ATARS is the baseline system and centralized Epoch ATARS is its alternative, but costs of Sector ATARS, distributed or centralized, are also developed. The effects of through-the-transponder coordination on this analysis are also noted.

The systems are described and evaluated here in a generalized way which does not depend on any precise deployment or configuration. These building blocks are then utilized in succeeding sections to construct entire multisite DABS/ATARS deployments.

The most interesting quantities to be developed here are cost differentials between a centralized ATARS processor complex with its communications and a corresponding distributed ATARS complex. The emphasis is, therefore, on the aspects of DABS/ATARS which differ in these two system architectures.

The ER load capacities (Section 2.2) are applied throughout this analysis as performance constraints. Thus, the various options have similar performance capabilities. In addition to the standard ER loads based on 400 aircraft per site, excursions are also made to 700 and 100 aircraft in order to assess the sensitivity of the results to the load assumptions and to allow a more exact match to individual site capacity needs.

3.1 Distributed ATARS

3.1.1 Processing for Distributed ATARS

DABS and ATARS are implemented in a number of processors with local memory, which are interconnected through a data bus (TILINE) system. The computers are organized in ensembles of up to four each which connect through an ensemble bus. Ensembles connect with each other and with global memory and certain external devices through two global busses. There are supporting power supplies and I/O equipment for operator control and for site/site and site/facility communications. Spare standby computers are provided.

This complex forms the system of Figure 2-1. Figure 3-1 shows the general organization of the multiprocessor equipments and connections at one early stage of the evolving engineering prototype development. Computers (with local memory) are indicated by solid-lined boxes, other equipment by dotted lines. A total of 30 computers arranged in 9 ensembles is depicted; this includes standbys.

Currently, the prototype design has expanded to include a maximum of 36 computers arranged in 10 ensembles. The computers which had originally been assigned to standby have been reassigned to new processing tasks. In order to restore the necessary backup, we shall extend the current prototype design to include 7 spares: one spare ensemble of 4 computers, one spare on the ATCRBS processing ensemble, one spare on the communications ensemble, and one uncommitted spare. This is the distributed ATARS baseline processing system with breakdown illustrated in Table 3-1a. Thus, a total of 43 computers is required to satisfy the current task requirements <u>and</u> provide the desired reliability.

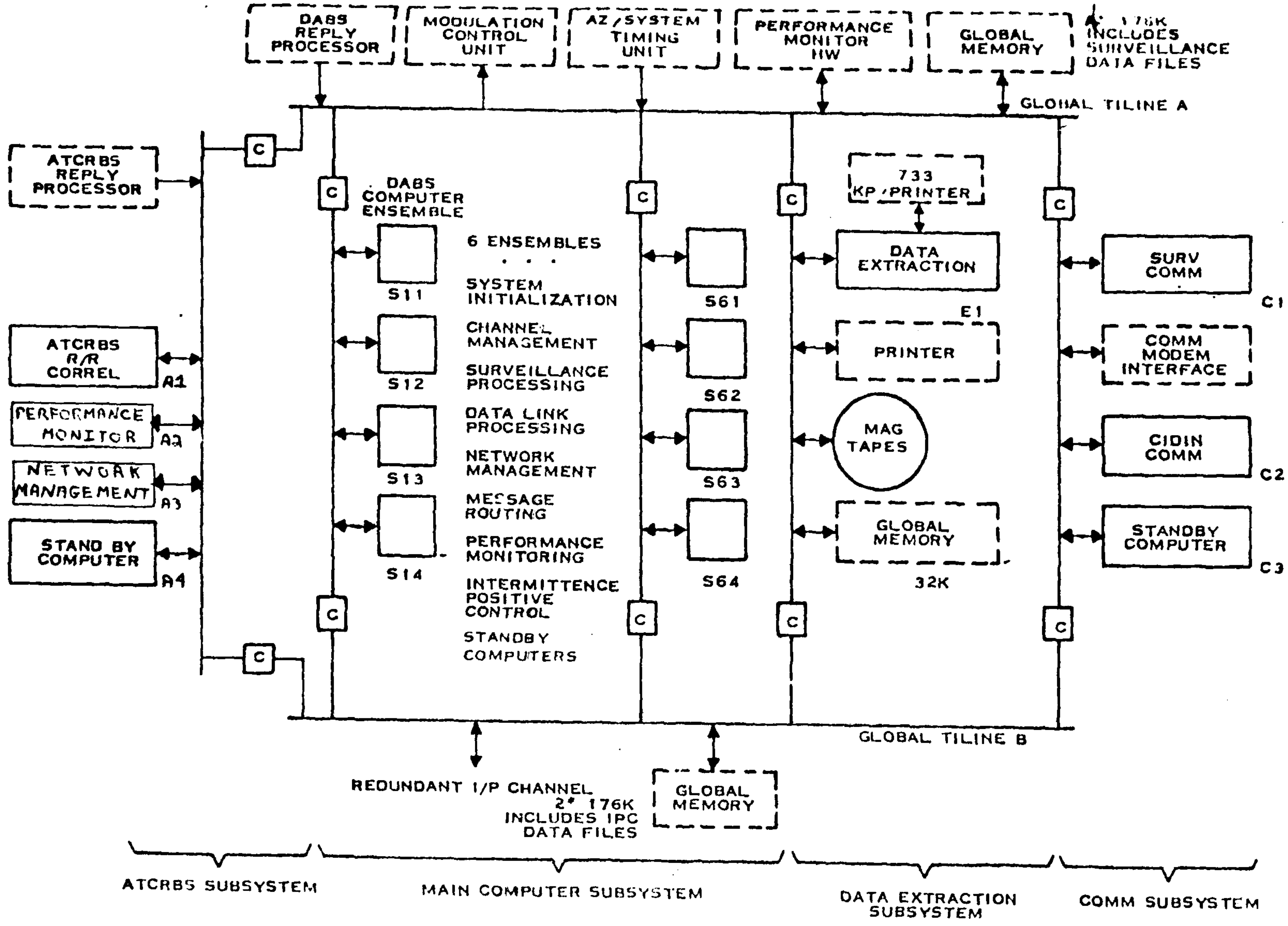


FIGURE 3-1 DABS/ATARS/HARDWARE/SOFTWARE CONFIGURATION (EARLY)

TABLE 3-1a Distributed ATARS Baseline Processors

Number of Processors	Use
25	DABS
5	ATARS & DABS
6	ATARS
7	Standby
43 total	

Table 3-1b Centralized ATARS Processors

Number of Processors	Use
27	DABS
7	Standby
34 total	
14	ATARS
6	Standby
20 total	

Peripheral devices include dual magnetic tapes, printer and keyboard/typewriter.

The prototype system has been designed for the ER loads assumed in this study. Timing studies of the system have not yet been conducted, so that the degree of loading of each computer is not known. However, it is believed that the current prototype will not handle the extended 700 aircraft load without additional processing power.

3.1.2 Processing System Cost Basis

Since differential costs between distributed and centralized processing complexes are of most interest, we shall not be concerned with a full cost model. Only those aspects which are significantly different in the two configurations are emphasized.

In this section a costing basis is developed for the processor systems. The processor system costs have the components listed in Table 3-2.

Computer hardware costs, based on current dollars and the state of microtechnology, are estimated as follows. Using off-the-shelf chips in the special boards required for DABS/ATARS reliability design, a single board computer with the TI9900 microprocessor costs approximately $300. Adding a second computer board, 16K bytes of memory and the requisite 16 bit voting logic (to form a voting computer) costs an additional $1,300. Total cost of the basic computer is, therefore, $1,600.

The cost of 32K bytes of memory is estimated at $960. The necessary power supplies and TILINE busses and couplers to support the additional hardware are costed by adding 25% to final processor and memory costs. Peripherals are estimated at $27,000.

Software costs are incurred whenever additional processors are introduced. The program for a typical processor contains some 1200 FORTRAN instructions. Assume a productivity of 6 FORTRAN instructions/man day (including design and documentation) and a cost of $200/man day. Then, software costs are estimated at $40,000 for the typical processor.

Some processors of the DABS/ATARS complex are spares and require less software in their standby role. A few others require a more detailed, assembly coded software which is more expensive to produce. For the present purposes the average of $40,000 per working (non spare) processor will suffice. This is a one-time cost which becomes greatly diluted for a large deployment (more than 50 DABS sites).

System hardware maintenance is estimated from the ER specification of a 30 day preventative maintenance schedule, a 4 hour maximum time to repair, $40/hour and a 100% overhead for travel. This leads to a monthly cost of about $320/month or $38,000 over 10 years with travel or $19,000 without travel. Software maintenance is assumed to be similar in distributed and centralized architectures under the commonality conditions imposed here (Section 2.1). Therefore, differential costs are negligible and omitted from consideration.

Site rental and services also produce no differential cost under the assumption the centralized ATARS will be located at existing FAA facilities (Section 2.3).

TABLE 3-2 Basis for Processor System Costs

Hardware	
Each computer	$1,600
Memories (32K-bytes)	$ 960
Power supplies and TILINE equipment	(allowance of 25% on computer and memory)
*Set of peripherals	$29,000
Software	
Each computer	$40,000 (one-time cost)
System Maintenance	
**Each site (with travel)	$38,000 (10 years)
(without travel)	$19,000 (10 years)
Site rental, services	
(Provided by FAA—no differential cost)	

*Note peripherals do not include communications interfaces (costed separately) or DABS control/reply devices (no differential cost).

**Maintenance does not include communications maintenance (costed separately).

3.1.3 Communications for Distributed ATARS

Communications for the baseline distributed ATARS consists of three types of links: surveillance data from DABS site to ATC control facility, CIDIN messages to and from the facility and CIDIN messages to and from adjacent sites having overlapping coverage. There are many message types and functions but only a few of these, together with surveillance, are frequent enough to require significantly large communications capacity.

3.1.3.1 Baseline Surveillance Communications

Surveillance communication is direct (without CIDIN formats or protocol). Capacity can be based on the standard 91 bit beacon surveillance report format plus a 13 bit stop character and the ER 400 aircraft load in a 90° sector. Initially, transmission without significant buffering is assumed. Then the surveillance link must accommodate the peak data rate of 400 x 104 bits in (1/4) x 4 second scan for an ASR site. This is 41600 BPS. Additional capacity, say 10%, must be added to allow for strobe, map and timing reports. We then obtain 45750 BPS. For an ASR with 4.7 second scan time this rate would be reduced to a corresponding 38940 BPS.

ARSR scan times are 10 to 12 seconds. Required surveillance capacity is reduced in inverse proportion to from 18300 BPS, to 15250 BPS. These results are summarized in Table 3-3 (rounded).

A modest amount of surveillance buffering can ameliorate these capacity requirements. Since terminal ATC, where the requirement is high, is converting to a noncorrelating user of surveillance data, the tolerable buffering delays are somewhat increased. In any case, a 1.5 sector delay is reasonable, which leads to the capacities given in the second column of the table.

TABLE 3-3 Surveillance Link Capacities for Distributed ATARS

	Link Capacity (BPS)	
Site	Unbuffered	Buffered 1.5 sectors
ASR (4 sec. scan)	45800	37200
ASR (4.7 sec. scan)	38900	31600
ARSR (10 sec. scan)	18300	14900
ARSR (12 sec. scan)	15300	12400

3.1.3.2 Baseline Message Communications

Message communications are conducted using CIDIN compatible message formats and CIDIN protocol. The communications capacities required for message traffic are affected by the overhead imposed by this CIDIN structure. Specifically, each message is imbedded in a 48 bit CIDIN framing sequence for syncronization, message routing and error checking. In addition, about 3% redundant bits are introduced in order to avoid confusing idle characters with part of a message. Finally, if errors of transmission are detected, the programmed protocol requests a message repeat. Correct messages are acknowledged (in blocks).

In order to account for these CIDIN processes, we add 48 bits to each message and, in addition, increase the resulting capacities by 10%.

3.1.3.2.1 Baseline Site-Facility Message Communications

The major components of site-to-facility message traffic for the baseline distributed ATARS are controller alert notices and duplicate IPC (ATARS) message delivery notices. The latter are transmitted to the facility for recording purposes. The number of message bits for each is 80 and 48; respectively, [7]. Adding 48 bits for CIDIN and then 10% more, we obtain effective message lengths of 140 and 106 bits.

One antenna scan generates 80 conflict alerts (from 80 conflict pairs) and 200 delivery notices (from 200 aircraft receiving warnings or commands).

In each case the time frame for transmission is the full scan of 4 seconds for an ASR or the half scan of 10/2=5 seconds for an ARSR (to account for the use of the back-to-back antenna at long range sites).

TABLE 3-4 Site-Facility Link Capacities for Distributed ATARS

Major Component	Message (bits)	Number sent	Time ASR (ARSR) (sec)	Capacity ASR (ARSR) (BPS)
Site-to-Facility:				
Controller alerts	140	80	4 (5)	2800 (2240)
Uplink delivery notices	106	200	4 (5)	7950 (6360)
				10750 (8600)

Facility-to-Site: No major components

The facility-to-site message traffic contains no major components and does not need further consideration.

3.1.3.2.2 Baseline Site-Site Message Communications

The major components of site-site message communications for distributed ATARS is analyzed in [5]. Four major message types are identified: ATARS conflict table messages, DABS aircraft handoff messages, DABS remote surveillance messages and DABS multiple coverage restoration messages. The analysis here is similar, except that CIDIN overhead is added and more current information on conflict message lengths is utilized. Results are summarized in Table 3-5.

One conflict table message is sent for each conflicting cluster of aircraft. The message consists of a 30 bit header, 64 bits for each DABS equipped (128 bits for ATCRBS equipped) aircraft in the cluster and 95 bits for each conflicting pair in the cluster. To this are added 48 CIDIN bits and 10% CIDIN overhead.

We assume that the 13 seam conflict pairs of the ER loads are arranged in 3 isolated pairs and 5 triples consisting of 2 pairs each. This yields a total of 21 aircraft of which 10 are assumed to be DABS equipped.

The total for these 8 conflict messages is 4280 bits (an average of 535 bits/message) as follows:

8 messages:			header bits
10 DABS, 11 ATCRBS:	10 x 64 + 11 x 08 =	2048	a/c bits
13 pairs:	13 x 95 =	1235	pair bits
8 CIDIN frames:	8 x 46 =	368	CIDIN bits
		3891	

CIDIN overhead 3891 x 1.1 = 4280 Total bits

TABLE 3-5 Site-to-Site One-Way Link Capacities
Distributed ATARS

Major Component	Composite Message (bits)	Number Sent	Time (Sec.)	Capacity (BPS)
DABS-to-DABS:				
Aircraft Handoff	355	4	2(2.5)	710 (568)
Remote Surveillance	448	4	2(2.5)	896 (716)
Coverage Restoration	263	3	2(2.5)	394 (316)
				2000 (1600)
ATARS-to-ATARS:				
Conflict Tables				
(Epoch ATARS)	535(avg.)	8	0.3	14270 (14270)
(Sector ATARS)	1360(request/ response)	8	1.8(2.25)	6040 (4840)
(TTC)	(may be neglected)			

Total Site-Site Capacity ASR(ARSR) in BPS:

With Epoch ATARS:	16270	(15870)
With Sector ATARS:	8040	(6440)
With TTC:	2000	(1600)

Aircraft handoff involves three coordination messages with a total of (185 + 3 x 46) x 1.1 = 355 bits. It is assumed the 1% of 400 aircraft require handoff.

Remote surveillance involves four messages with a total of (223 + 4 x 46) x 1.1 = 448 bits. Again 1% of 400 aircraft are assumed to require remote surveillance.

Multiple coverage restoration requires two messages with a total of (147 + 2 x 46) x 1.1 = 263 bits. It is assumed that restoration proceeds at such a rate that 3 aircraft are handled each half scan.

The time available for conflict table transmission in epoch ATARS is a fraction of the 0.5 second dedicated interval for seam processing. Approximately 0.3 seconds is available. On the other hand, the other message transmissions are not time critical and may encompass approximately one-half scan (2 seconds for ASR or 2.5 seconds, effective, for ARSR). The time constraint on adjacent site seam conflict table exchanges causes this component of intersite message traffic to be the dominant one. The remainder accounts for only about 10% of the total peak bit rate.

Total link capacities for site-to-site message communications depend generally both on the sensor (ASR or ARSR) and on the type of ATARS (Epoch, Sector or Sector with Through-the-Transponder Coordination). The estimates of this section are for Epoch ATARS. In the next section estimates for the other ATARS types are determined. Site-to-site link capacity totals are also listed in Table 3-5.

3.1.5 Effect of Sector ATARS and Through-the-Transponder Coordination (TTC) on Baseline Estimates

Sector ATARS algorithms are being developed and planning is under way for a possible replacement of Epoch with Sector algorithms. Therefore, it is necessary to consider the effects of such a replacement on the foregoing baseline (Epoch) estimates.

Although it is not clear at this point how many extra system processors (if any) may be needed to convert to Sector ATARS, it appears that any change will affect the distributed ATARS and centralized ATARS processing systems equally and produce no change in differential processing costs. For purposes of this study, therefore, it is not necessary to modify processing system costs.

A change to Sector ATARS has no essential effect on surveillance or site-facility message communications. There is, however, a major reduction in necessary site-site capacity. Indeed, this is the main motive for the use of Sector ATARS. The reduction occurs mainly because of a relaxed time constraint on the transmission of seam conflict tables (See Table 3-5), although there is also some expansion of the number of message bits transmitted.

The conflict table exchange process has been explained, [6], to involve a request/response protocol for each conflict table. For an ASR site, total available delivery time is 2 seconds of which 0.2 seconds is consumed by processing. The request message contains 85 message bits plus 46 CIDIN bits plus 10% overhead, a total of 144 bits. When added to the average conflict table total of 535 bits, we obtain 679 bits per conflict table transmission. This is doubled to 1360 bits to account for retransmissions which are necessary when simultaneous requests collide. Since 8 tables are exchanged in 1.8 seconds, we obtain 6044 BPS for the required capacity.

For an ARSR the effective scan rate is 5/4ths as great. The time constraint is relaxed to 1.25 x 1.8 = 2.25 seconds, which leads to a capacity of 4835 BPS.

When TTC is added to Sector ATARS the ground transfer of conflict tables is eliminated. Total required site-site capacity is thus reduced to that necessary for transmission of the DABS-to-DABS messages.

3.1.6 Communications Cost Basis

Communications costs are evaluated principally on a 10 year, per line basis (except for backup equipment at each computer complex). The various cost elements are given in Table 3-6 for the standard 4800 BPS voice grade, full duplex line assumed in this study. Line rental charges, adopted from [5], are shown in Table 3-7. Note that modem rental is assumed. Thus, the rental charge includes maintenance of this equipment. *Current dollars are used throughout.*

In order to determine a total cost for a communications link we first determine the number of lines, N, required by dividing the link capacity by 4800.

$$N = \frac{\text{Link Capacity (BPS)}}{4800}$$

Then, 2N full duplex modems and 2N interfaces are required. N additional lines are necessary for full backup. Thus, there are line rentals and drop charges for 2N lines and diversity charges for the N backup lines. Using the estimates of Table 3-6 the costing formula reduces to

$$\text{Link Cost} = 2N\ (120 \text{ month rental per line}) + 2N\ (27300)$$

TABLE 3-6 Basis for Communication Costs

4800 BPS Voice-Grade FDX
10 Year Basis

Line rental	(See Table 3-7)
Diversity	$ 2600 (each backup line)
Station drops	$ 6000 (each line)
Line Conditioning	(Automatic by Modem)
*Modem rental	$16000 (each modem)
Computer interfaces	$ 4000 (each interface)
Link switch	$ 4000 (each computer complex)

*Modem rental, Bell System 208A, includes maintenance.

TABLE 3-7

MULTI-SCHEDULE PRIVATE LINE (MPL) RATES
FOR SERIES 2000 INTEREXCHANGE CHANNELS
QUALIFYING AS SCHEDULE I

Mileage	Line Charge Per Month
1	51.00
2 - 15	51.00 + 1.80 for each mile over 1
16 - 25	76.20 + 1.50 for each mile over 15
26 - 40	91.20 + 1.12 for each mile over 25
41 - 60	108 + 1.12 for each mile over 40
61 - 80	130.40 + 1.00 for each mile over 60
81 - 100	150.40 + 1.00 for each mile over 80
101 - 200	170.40 + .50 for each mile over 100
201 - 1000	220.40 + .40 for each mile over 200
OVER 1000	540.40 + .40 for each mile over 1000

Inspection of the rental schedule, Table 3-7, reveals the following interesting fact. If we try a line length of 50 miles, charges are about \$120 per month. Lengths of from 1 to 140 miles produce a charge of about \$120 ± 70 per month. The link cost formula then becomes

$$\text{Link cost} \simeq N\ (\$83{,}400 \pm \$16{,}800)$$

The following is a somewhat more accurate formula over the same range,

$$\text{Link cost} \simeq N\ [\$81{,}960 + \$240 \times (M - 50)]$$

where M is the length of the line in miles. Thus, as a rule of thumb, we can assume that each line (backed up) in a link costs about \$80K. It is clear, also, that the number of lines in a link is more important in determining costs than the length of the link.

Backup communications equipment at the DABS/ATARS site consists of a spare modem and space computer interfaces (one each for CIDIN, and surveillance) and a link switch. Total cost, based on the standard 10 year base period assumed in this study is \$28,000. This may be charged to the processor complex.

3.1.7 Distributed ATARS Line Assignments

As shown in the previous section, the most important factor of communication costs is the number of telephone lines which link the sites and facilities. This section summarizes the line counts for each baseline distributed ATARS link.

In each case the number of lines is determined by dividing the necessary link capacity in BPS by 4800 BPS, the standard line capacity and remembering that each line has a bidirectional, duplex transmission capability. Surveillance link capacity requirements for 4 second ASR's and 10 second ARSR's (buffered) are utilized.

Results are summarized in Table 3-8.

TABLE 3-8 Link Line Counts for Distributed ATARS Communications

Link		Number of 4800 BPS FDX Lines ASR (ARSR) to each adjacent site or facility	
Site - Facility:			
	Surveillance	8	(4)
	Messages	3	(2)
Site - Site Messages:			
(only one applies)	with Epoch ATARS	4	(4)
	with Sector ATARS	2	(2)
	with TTC	1	(1)

3.2 Centralized ATARS

The DABS/ATARS configuration which is utilized in this study as the building block of a centralized ATARS architecture is illustrated in Figure 2-2. The DABS and ATARS functions are separated and implemented, respectively, in their own computer complexes.

The processing and communications hardware and the computer software is adapted from distributed DABS/ATARS baseline system in a way which makes maximal use of the baseline system development. No radical qualitative changes are introduced. The centralized DABS/ATARS configuration does not require the definition and development of any new major DABS or ATARS functions or the significant restructuring of existing functions. It does, however, result in the reallocation of tasks to computers, since the current baseline DABS/ATARS design allocates both DABS and ATARS tasks to some particular processors.

The two basic configurations (distributed, Figure 2-1 and centralized, Figure 2-2) do differ significantly in the amount of processing equipment and the number and connection of communications links that are required. The major cost impact, therefore, resides in the different hardware complements and required maintenance of the two configurations.

Since new software development is minimized by the approach taken here and since any software costs are spread over the total DABS deployment, software costs should remain of secondary importance into the forseeable future.

Having detached the ATARS functions in their own independent computer complex, we are at liberty to locate ATARS either at a site, side-by-side with DABS, or at a facility where other ATARS units from different sites may be collected (Figure 2-3). These deployments do not differ functionally, but only in the length of the various communications links that are required.

The separation of ATARS from DABS creates an external DABS-ATARS interface which is bridged by new communications links. For an ATARS located remotely from its corresponding DABS, telecommunications are required, which adds an increment of cost. On the other hand, centralization of several remote ATARS at a facility reduces intersite communications to direct computer-computer interfacing which reduces cost.

The following subsections detail the significant processor and communications changes which are produced by adoption of the centralized ATARS configuration and their cost impact.

3.2.1 Processing for Centralized ATARS

The prototype distributed DABS/ATARS design contains 5 computers which perform both DABS and ATARS functions (Table 3-1a). When DABS and ATARS are separated in the centralized configuration, these functions must be reallocated. From an inspection of the tasks performed, it is judged that the ATARS functions in these 5 computers can not be separated and allocated to less than 5 computers. On the other hand the DABS tasks are less demanding, and it is assumed that they can be consolidated in 2 computers.

Therefore, to the original 25 computers solely utilized for DABS processing, we add these 2 computers with the remaining consolidated DABS functions. The 7 computers used as spare backups in the DABS baseline design are retained to provide the required reliability through redundancy (4 in a spare ensemble in case of coupler failure; one communications processor spare and one spare on the reply processing/network management bus because of the especially heavy data traffic to and from these processors, which cannot easily be accommodated except by spares on the same TILINE; and one uncommitted spare). This totals 34 computers for the DABS complex in the separated, centralized configuration.

To the 6 computers solely utilized for the baseline ATARS, we add also the 5 computers from the mixed DABS/ATARS allocation which has been separated. In addition, we require one new ATARS surveillance communications processor and one CIDIN processor to handle communications on the interface created by the DABS-ATARS separation. One ATARS data extraction computer is assumed. The separated ATARS site must then be backed up by spare computers for reliability. 6 additional ATARS computers are required (the same as for the baseline system except that the reply processing/network management spare is not required). This totals 20 computers in the separated ATARS complex.

This processor breakdown is summarized in Table 3-1b. The increase of 11 computers in the combined total of all processors implies that extra power supplies and TILINE equipments are also needed. On the other hand, we judge that the total global memory capacity is only slightly increased (by 64K bytes) because of an efficient separation of files between DABS and ATARS. Additional working computers (non spares) implies additional software programming.

TABLE 3-9 Differential Per Site Processing System Costs for Centralized ATARS Configuration

Element		Cost
11 extra processors x $1,600	=	17.6K
2 extra 32K byte memories x $960	=	1.9K
Subtotal	=	19.5K
Allowance for TILINE equipments and power supplies .25 x 19.5	=	4.9K
Extra set of peripherals	=	27K
Extra set of communications equipment spares	=	28K
Extra maintenance allowance	=	19K
Extra software (per site cost)	=	2K
Total	=	100.4K

The ATARS complex requires its own set of I/O peripherals. A complement of one modem, CIDIN interface and link switch is required for communications backup (See Section 3.1.4). These are in addition to similar equipments already provided for DABS/ATARS and assigned to DABS upon separation of the functions.

Extra maintenance is necessary because of the increase in equipments.

3.2.2 Differential Processing System Costs

When DABS and ATARS functions are separated in a centralized ATARS configuration, the processing system is expanded in total, as described in the previous section. Therefore, processing system costs increase. Using the cost basis of Table 3-2, the differential cost breakdown per site of centralized ATARS over distributed, baseline ATARS is shown in Table 3-9.

The cost breakdown is self-explanatory except for the following points. The maintenance allowance is calculated on the basis that no extra travel is required. Either the separated ATARS is located at the site, in which case routine maintenance can be combined with maintenance of the DABS complex. Or it is located at the facility, where we assume that no travel is required. Extra per site software costs are based on minimal software changes and cost sharing over the entire deployment of sites. Software for about 5 extra working computers over 100 sites costs approximately 5 x 40000/100 = $2000 per site.

The total per site processing system cost differential of the centralized ATARS configuration over the distributed ATARS configuration is about $100K. It is interesting to note that this is about 1.3 times the cost per line of a standard telephone communications link as developed in Section 3.1.6.

3.2.3 Communications for Centralized ATARS

The organization of communications for the centralized ATARS configuration differs from that of distributed ATARS in several respects. First, surveillance data must be sent to ATARS as well as the facility over external lines. Second, a DABS-ATARS message link is created which also carries substantial traffic. Third, DABS-DABS and DABS-Facility message traffic is relayed through the appropriate ATARS complexes; this means, in particular that ATARS takes over all intersite communications. Finally, the various links can be direct or via telecommunication lines, depending on whether the communicating complexes are located locally or at remote distance.

Seven different one-way communications links are postulated in two categories, surveillance or message communications. The surveillance links consist of the baseline DABS-to-Facility and the new DABS-to-ATARS links. The message links consist of: DABS-to-ATARS and ATARS-to-DABS which handle the DABS-ATARS data interface, exclusive of surveillance reports, and the DABS-DABS and DABS-Facility messages for relay; ATARS-to-Facility and Facility-to-ATARS, which carry the baseline ATARS-Facility plus DABS-Facility traffic; and ATARS-to-ATARS, which carries the same conflict table exchanges and DABS-DABS coordination messages that comprise the intersite baseline traffic.

The existence of these functionally identifiable links does not necessarily imply that separate telephone lines are required for their implementation (where the respective terminals are remote from each). In particular, it is possible to combine DABS-to-ATARS and DABS-to-Facility surveillance and to use the reverse direction of the surveillance lines for some of the ATARS-to-DABS message traffic.

3.2.3.1 Centralized ATARS Surveillance Communications

Surveillance report dissemination for centralized ATARS would be very onerous (on the order of 11 to 17 4800 BPS lines) if it were not possible to combine the DABS-to-Facility and DABS-to-ATARS surveillance links. The costs would make centralized ATARS an obviously poor alternative to distributed ATARS. Therefore, to proceed further we must examine and postulate a satisfactory combined surveillance method.

There are three obstacles to be overcome in order to combine surveillance links:

a.) Facilities are currently correlating users of surveillance reports; ATARS is a noncorrelating user. The DABS ER places requirements for timeliness on reports sent to correlating facility users (less than 3 sectors behind the antenna) so that these users have sufficient time in each scan to complete their correlation and tracking tasks. Because of this time restriction DABS may not be able to complete correlation on every report and, therefore, some may not be sent with the aircraft ID. This is not a problem for correlating users, but becomes one for noncorrelating users like ATARS, which base their report-to-track associations on aircraft ID or track numbers.

b.) The surveillance report data content is different for facility and ATARS users. Reports go to the facility in either the standard 52 bit (radar) or 91 bit (beacon) report formats, [7]. On the other hand, reports are transferred internally for DABS to ATARS in the baseline system by 128 bits. Part of this expansion is due to less attention given to packing and spare bits but some extra information is included: notably track start and stop flags are provided and track numbers are supplied with DABS as well as ATCRBS tracks.

c.) For ARSR sites the connecting facility utilizes only front face surveillance reports; ATARS uses reports from both front and back faces. These two types of reports must be identified and separated so as to minimize the screening problem imposed on the ARTCC facility user.

These difficulties can be addressed in the following manner:

a.) With the current DABS/ATARS design most surveillance reports are expected to complete DABS correlation within the 3 sector time constraint. Only a few reports from ATCRBS aircraft in congested traffic are expected to be delayed. Therefore, if such reports are sent twice, once to meet the time constraint and again when DABS correlation is complete and aircraft IDs (track numbers) are available, the volume of data is only slightly increased. This increase can be covered by the 10% extra report allowance already assumed in the sizing of surveillance capacities (Section 3.1.3.1).

b.) The 128 bit internal DAB/ATARS surveillance report format can be dispensed with if the ATARS surveillance correlation program supplies the missing track numbers for DABS aircraft by means of a track number/DABS ID cross-reference file. The starting and stopping of tracks can be transmitted from DABS to ATARS by special short messages rather than by extra bits in a standard universal report format. (There are already other surveillance message types, such as map, strobe, etc.) We assume that this can be done and that any extra message generation is of sufficiently low volume as to be included in the 10% allowance mentioned above.

We note also that ARTS III is being redesigned, [7], to become a noncorrelating user, but retains the surveillance report formats of the correlating facility. No start/stop messages are postulated or used in this design.

c.) The front/back face sorting problem can be minimized by a natural segregation of front and back report transmissions on different telephone lines. For example, if 7 lines are required, 3 lines can carry front face data, 3 lines back face data and 1 line both types. The facility must then screen out back face reports on only one line. The screening can be performed using the FAA indicator (bit 11) of the standard report format, [8].

Since, therefore, DABS-to-Facility and DABS-to-ATARS surveillance links can be combined, the resulting link will carry the same surveillance reports for both ATARS and the facility in the standard facility surveillance report formats. The facility link can tap off from the link provided from DABS to ATARS. For an ASR site, the facility uses all reports from this link; for an ARSR site, only the front face reports are utilized.

The DABS-to-Facility link requires a capacity of 37200 BPS for an ASR site and 14900 BPS for an ARSR site as shown in Section 3.1.3.1. This requirement is the same for both distributed and centralized configurations.

TABLE 3-10 Surveillance Communications Capacities for Centralized ATARS Configuration

Link Type	Major Component	Required Capacity (BPS)
DABS-to-Facility	Surveillance reports	
(ASR)		37200
(ARSR)		14900
DABS-to-ATARS	Surveillance reports	
(ASR)		37200
(ARSR)		29800
*Combined Surveillance	Surveillance reports	
(ASR)		37200
(ARSR)		29800

*Result of combining both functional surveillance links.

The DABS-to-ATARS link also requires a capacity of 37200 BPS for an ASR site because the same data is utilized. For an ARSR site, the facility data rate must be doubled to 29800 to account for both front and back face data. Here it is assumed that the maximum concentration of 400 aircraft in 90° of coverage, which generates this rate, is distributed as 200 aircraft in each of two diametrically opposite 45° sectors.

The latter DABS-to-ATARS link capacities also applied to the combined surveillance link. These results are indicated in Table 3-10.

3.2.3.2 Centralized ATARS Message Communications

The major components of centralized ATARS message communications are listed in Table 3-11 for each of the message links. Capacities for each component are calculated from the parameters shown. Total capacity requirements for each message link is also listed for ASR (or ARSR) sites and for the various ATARS implementation options.

3.2.3.2.1 DABS-to-ATARS Link

The DABS-to-ATARS link carries the same DABS-to-DABS messages as the distributed ATARS intersite links. However, here messages are exchanged with all adjacent DABS sites through their respective ATARS. Thus, the DABS-to-DABS messages combine traffic for all adjacent sites. In our calculation of bit rates for this component (summarized in Table 3-5) a time constraint of 2 (2.5) seconds was assumed. This constraint means that less than the 4 (5) second scan is used for transmission. Thus transmissions to another adjacent site can occupy the second half of the effective scan time without increasing the peak rate. Since we assume three adjacent sites, this will require double the peak DABS-to-DABS capacities of Table 3-5, i.e. 4000 (3200) BPS.

Uplink delivery notices form the second DABS-to-ATARS component. This component has already been evaluated for the distributed ATARS Site-to-Facility traffic, Section 3.1.3.2.1 and listed in Table 3-4.

The third and final major DABS-to-ATARS traffic component is pilot acknowledgments. For these we assume a message size of 56 bits. (This is larger than the 34 bits in [8] to accommodate a recent redesign of command messages and avionics). Adding 48 CIDIN bits plus 10% we obtain an effective message of 114 bits. In Section 3.1.3.2.1 we assumed that 13 seam conflict pairs were arranged such that a total of 21 aircraft were involved. For 80 conflict pairs in the whole coverage the same arrangements give a total of about 130 aircraft. We assume that all of these are DABS equipped, receive commands and that 25% of them (33) generate pilot acknowledgments in one effective scan, 4 seconds ASR (5 seconds ARSR). The peak rate is thus 940 (750) BPS.

The total capacity required for DABS-to-ATARS for all these components is 12890 (10410) BPS.

3.2.3.2.2 ATARS-to-DABS Link

The main traffic from ATARS-to-DABS consists of ATARS uplink command messages. This is a new type of message created by separating the DABS/ATARS interface. An appropriate number of bits, 104, for this message is provided by analogy with the duplicate uplink command message, [7], whose use has been discontinued. Adding 48 CIDIN bits at 10%, this becomes 167 bits. We assume that an average of 1.5 command messages is sent for each aircraft receiving PWI/ATARS commands. Thus: the effective message length per aircraft is 167x1.5= 251 bits.

Under the Epoch ATARS algorithms the preparation of uplink commands for an aircraft is performed if that aircraft will be scanned by the antenna between 1 and 3 seconds ahead of the time of message formulation. Command messages are expected to be delivered on this scan. The rate at which command messages must be transmitted depends partly on the speed with which the program generates them. A conservative (pessimistic) assumption is that all commands are generated during a brief interval of time during each epoch, beginning just before the .5 second deferred resolution dedicated time slot. At that point there is a minimum of 1 (maximum of 3) seconds to uplink the command. But the ER requires that DABS receive the commands .5 seconds before uplink time to allow the channel management function to prepare the message for uplink. Thus a minimum of .5 seconds is available for transmission from ATARS-to-DABS.

The command messages are not generated by ATARS in any particular order so that the last one may be for the earliest 1 second time point. Thus, if not further sorted, all must be sent in .5 seconds. To reduce the peak bit rate, we assume that the messages are placed in one of two output buffers, one for 1 to 2 seconds ahead and the other for 2 to 3 seconds. Then only the first buffer must be quickly emptied in .5 seconds; the second has more time. Therefore, with an ASR 4 second radar messages for only one quarter of the aircraft receiving commands, 50 messages, must be sent in the short .5 second interval. This yields a rate of 25100 BPS.

For an ARSR site with a slower effective scan time of 5 seconds, 40 aircraft have command messages in the first buffer. This yields 20080 BPS.

TABLE 3-11 Message Link Capacities for Centralized ATARS

Links/Major Components	Message (bits)	Number Sent	Time ASR(ARSR) (Sec.)	Capacity ASR(ARSR) (BPS)	
DABS-to-ATARS:					
DABS-to-DABS (relay)	(From Table 3-5, See text.)			4000	(3200)
Uplink delivery notices	(From Table 3-4)			7950	(6360)
Pilot acknowledgments	114	33	4(5)	940	(750)
	Total			12890	(10410)
ATARS-to-DABS:					
ATARS uplink commands					
If Epoch ATARS	251(avg.)	50(40)	0.5	25100	(20080)
If Sector or TTC ATARS	251(avg.)	200	4(5)	12550	(10040)
DABS-to-DABS(relay)	(From Table 3-5, See text.)			4000	(3200)
	Total	If Epoch ATARS		29100	(23280)
	Total	If Sector or TTC ATARS		16550	(13240)
ATARS-to-ATARS: (From Table 3-5)					
	Total	If Epoch ATARS		16270	(15870)
	Total	If Sector ATARS		8040	(6440)
	Total	If TTC		2000	(2000)
ATARS-to-Facility (Site-to-Facility of Distributed ATARS, Table 3-4)				23300	(18640)
Facility-to-ATARS: (No major components)					

The ATARS uplink command bit rate for Sector ATARS or TTC is based on the fact that for these implementations, uplink message generation on transmission can be spread approximately uniformly over the whole of the radar scan. Thus, 200 aircraft receiving commands in 4 (5) seconds produce the estimates 12550 (10040) BPS.

The second and final component of the ATARS-to-DABS link is the reverse DABS-to-DABS traffic. This is the same as the forward DABS-to-DABS evaluated in the previous section and is tabulated in Table 3-11.

Total ATARS-to-DABS rates for Epoch ATAR and Sector or TTC is also listed.

3.2.3.2.3 Other Links

Three links remain. ATARS-to-ATARS carries the same traffic here as the Site-to-Site link for distributed ATARS and has the same capacity requirements.

Likewise, ATARS-to-Facility and Facility-to-ATARS are identical to the distributed ATARS links, Site-to-Facility and Facility-to-Site.

Borrowing results from Tables 3-5 and 3-4 we list the capacities in Table 3-11.

3.2.4 Centralized ATARS Line Assignments

Table 3-12 shows the line counts for ASR (or ARSR) centralized ATARS configurations determined from the capacities of Tables 3-10 and 3-11. The calculation is a straightforward division by the 4800 BPS standard (and rounding up), except for the following points.

TABLE 3-12 Link Line Counts for Centralized ATARS Communications

Link		Number of 4800 BPS FDX Lines ASR (ARSR)
Surveillance:		
Combined (To Facility & ATARS)		8 (7)
To Facility only		8 (4)
DABS - ATARS		3 (3)
ATARS - Facility		5 (4)
ATARS - ATARS:		
(only one applies)	with Epoch ATARS	4 (4)
	with Sector ATARS	2 (2)
	with TTC	1 (1)

DABS-to-ATARS surveillance is not listed since a remote ATARS will always be located at the facility. Therefore, DABS-to-ATARS surveillance can always be combined with DABS-to-Facility surveillance for a remote ATARS. When the centralized ATARS processor complex is located at the site, the external surveillance lines carry ATARS-to-Facility traffic only.

ATARS-to-DABS capacities are greater than DABS-to-ATARS capacities. However, the DABS-to-ATARS capacities determine the number of message lines required for the ATARS-DABS link. This is because the surveillance lines can carry the excess DABS-to-ATARS message traffic in their reverse direction.

4.0 ANALYSIS AND COMPARISON OF DABS/ATARS DEPLOYMENTS

In these sections, using the foregoing results, we analyze and compare relative cost, vulnerability and growth potential of various centralized DABS/ATARS deployments relative to a distributed system.

Cost comparisons are treated in the most detail since these are the most quantifiable aspects of the systems. Also, it must be remembered that in this study the properties of performance capability and system reliability are kept roughly equal between distributed and centralized ATARS architectures by assigning sufficient processing and communications with backup for each. These properties are treated as design constraints, and the effect of such constraints is reflected in the relative costs. Maintenance, too, is considered as a design requirement and included as a cost factor.

4.1 Cost Analysis and Comparisons

In order to analyze and compare costs we adopt a building-block approach. Suppose that ATARS is centralized; there are many ways to do this. Using the basic centralized ATARS configuration throughout, we can locate the ATARS complexes for each DABS site either at that site or at some ATC facility as we choose. The consequences of any particular choice for a site will, as we shall see, depend most strongly on: the character of the site (ASR or ARSR), on whether the chosen facility is a terminus for surveillance data from the site for ATC purposes (is the TRACON or ARTCC served by the site) and, if the ATARS is at a facility, on how many of the ATARS from adjacent DABS sites are also at the same facility. Overall, the costs also are affected by the type of ATARS algorithm employed (Epoch, Sector, TTC) and on the traffic load for which the telephone links are sized.

Costs are developed on a per site basis for sites having each possible set of important characteristic. The cost of an entire deployment is the sum of such per site costs according to the character of each site. It will not be necessary to work any very complicated examples of assumed site geometries and deployments because a consideration of the per site costs alone makes the relative cost position of centralized vs. distributed ATARS quite clear. (The results are consistent with the assumption of an ATARS service range of 50-55 nmi. for ASR radars and 100-110 nmi. for ARSR, although these are not explicity used in the analysis.)

The 10-year cost analysis of any DABS/ATARS deployment consists of adding contributions of the two main types of differential costs: processing system costs and communications costs. The differential processing system costs are developed in Section 3.2.2 where, using the costing basis of Section 3.1.2, it is shown that a centralized ATARS deployment costs about $100K more per DABS site in processing costs than a distributed deployment. Processing costs are defined broadly and include maintenance and software development costs. Because of the way in which the basic centralized configuration is defined, one separated ATARS complex for each DABS complex, these differential processing system costs depend only on the number of sites and almost not at all on the geometry of the deployment (location of the sites).

The communications costs are based on the elements developed in Section 3.1.6 and the line counts in Sections 3.1.7 and 3.2.4, which are determined from a load capacity analysis. The communications costs include charges for terminal equipments and maintenance. It is shown in the former section that costs per line are about $80K and that the length of the line has only a secondary effect. This allows us to make an approximate but far reaching cost analysis without considering detailed site deployment geometries.

4.1.1 Differential Cost Formulas

The following differential per site cost formulas are based on the simplicity which is afforded by ignoring two secondary effects, the length of individual telephone lines and the interfacing cost of short bus lines within the facility or site. Then the costing of communications for any configuration reduces to counting the necessary external lines, which has been done in previous sections and listed in Table 3-8 for distributed ATARS and in Table 3-12 for the centralized configuration.

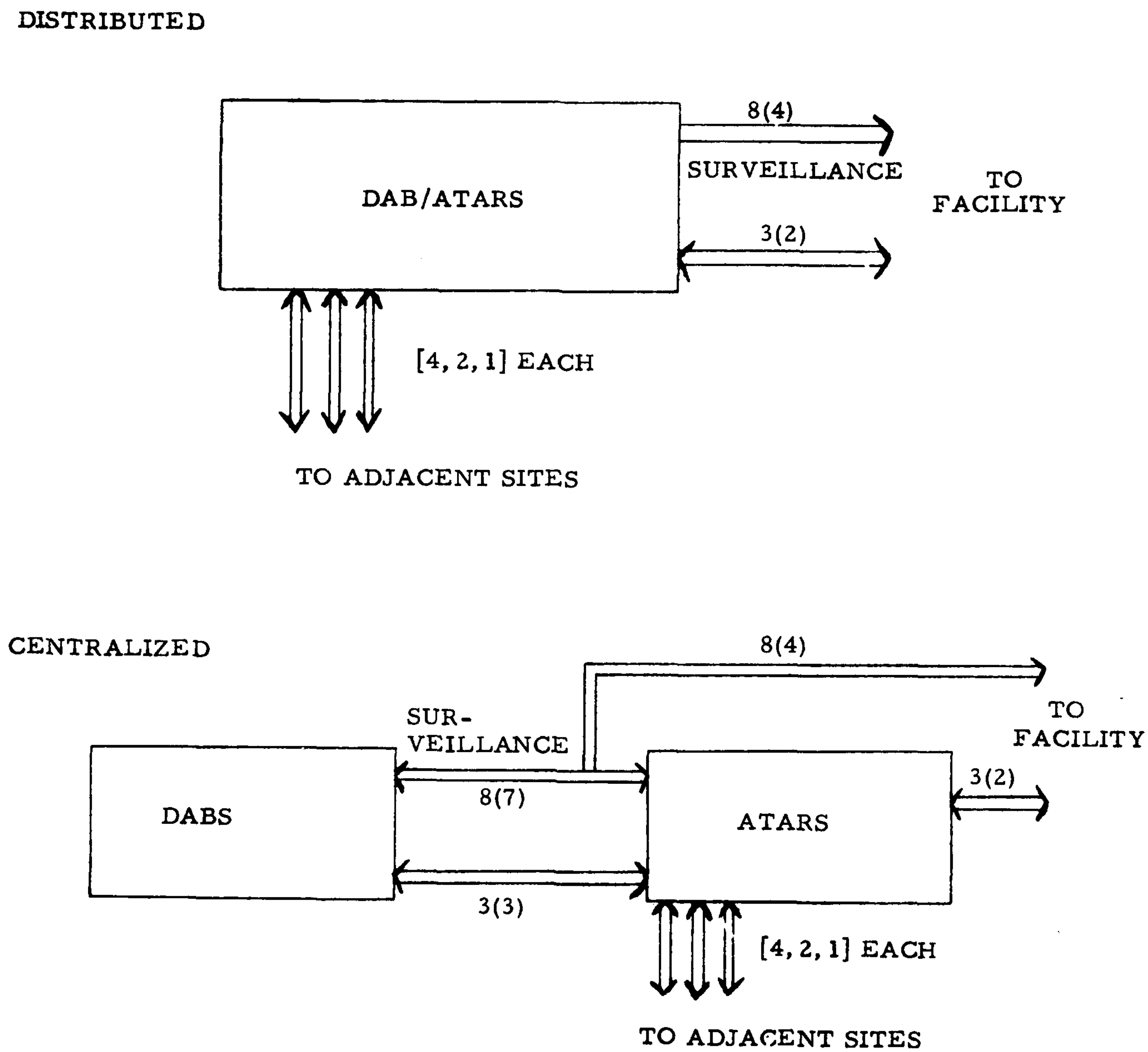
These line counts are presented again for convenience in Figure 4-1. Note that intersite (or inter ATARS) lines are calculated on the bases of three adjacent sites (or ATARS). Thus [12, 6, 3] such lines connect to each site (or ATARS), depending on whether the system design is Epoch, Sector for TTC ATARS. In the figure, line counts are for an ASR site; if different, line counts for an ARSR site are shown in following parentheses.

In order to exhibit the cost formulas, it is convenient to work in units of $80K, since this is the approximate 10-year cost of each communication line. On this scale the increased per site processing system cost for the centralized ATARS configuration is just about 1.3 units. We write

$$\Delta_p = 1.3$$

It is clear from Figure 4-1 that if ATARS is located with DABS at the site in a centralized configuration, the external lines are the same as for the distributed configuration. Thus, the differential communications cost is approximately zero.

$$\Delta_c = 0 \quad \text{(ATARS at site)}$$



LINE COUNTS: ASR(ARSR, IF DIFFERENT)

[EPOCH, SECTOR, TTC ATARS]

FIGURE 4-1 CONFIGURATION OF LINES FOR DISTRIBUTED AND CENTRALIZED ATARS

On the other hand, if a centralized configuration ATARS is located at the facility one can identify the following line differences:

$$\Delta\text{ (Surveillance Lines)} = \begin{cases} \left.\begin{array}{ll} 8 & \text{ASR} \\ 7 & \text{ARSR} \end{array}\right\} & \text{if facility does not already receive surveillance data} \\ \left.\begin{array}{ll} 0 & \text{ASR} \\ 3 & \text{ARSR} \end{array}\right\} & \text{if facility receives surveillance} \end{cases}$$

$$\Delta\text{ (Facility Message Lines)} = \begin{cases} 0 & \text{ASR} \\ 1 & \text{ARSR} \end{cases}$$

$$\Delta\text{ (Inter ATARS Lines)} = \begin{cases} -4N & \text{Epoch ATARS} \\ -2N & \text{Sector ATARS} \\ -1N & \text{TTC} \end{cases}$$

The surveillance line difference depends on whether the site has an ASR or ARSR and whether the facility at which the ATARS is located receives surveillance data from this site for the ATC computers. The inter ATARS lines difference represents external lines which have been eliminated by the centralization (hence, the minus sign). The factor N (N=0, 1, 2, 3) refers to the number of adjacent sites whose ATARS have also been centralized at the same facility. The most optimistic assumption, for centralized ATARS costs, is that N is a maximum, i.e., N=3.

The total differential communications cost per site is determined by adding these contributions, but it must be noted that the cost of inter-site/inter ATARS lines can only be charged 50% to each terminating site or facility (otherwise they would be counted twice when totaling over sites). Also the variable N is replaced by 3F so that F has the range $0 \leq F \leq 1$.

$$\Delta_c = \begin{cases} \left.\begin{matrix} 8 & \text{ASR} \\ 8 & \text{ARSR} \end{matrix}\right\} & \begin{matrix}\text{no ATC} \\ \text{surveillance}\end{matrix} \\ \left.\begin{matrix} 0 & \text{ASR} \\ 4 & \text{ARSR} \end{matrix}\right\} & \begin{matrix}\text{ATC} \\ \text{surveillance}\end{matrix} \end{cases} - \begin{cases} 6F & \text{Epoch ATARS} \\ 3F & \text{Sector ATARS} \\ \frac{3}{2}F & \text{TTC} \end{cases}$$

(ATARS at facility)

The per site differential cost, Δ, is the sum of Δ_p and Δ_c. For a "centralized" ATARS located at the site, Δ=1.3. For a centralized ATARS located at the facility the formula is given in Table 4-1. This formula has been developed for the standard 400 aircraft ER loads.

A similar analysis (Appendix B) can be carried out for other assumed loads. This has been done for 100 and 700 aircraft loads, and the resulting formulas are also exhibited in Table 4-1.

The basis for this analysis is as follows:

a.) The number of seam or total conflicts scale as the square of the basic aircraft load (100, 400, 700).

b.) All other loads scale proportionately to the basic load.

c.) The processing system cost differential is approximately independent of load.

Items a.) and b.) are utilized to revise the communication link capacities, and new line counts result. Item c.) is based on the fact that the additional processors required for the centralized configuration are for backup, data extraction and communications, not for the more basic ATARS tasks which require the same processing in both distributed and centralized systems. Therefore, Δ_p=1.3 also for the new loads.

TABLE 4-1 Differential Per Site Cost Formulas

1 unit = \$80K $\qquad\qquad$ $(0 \leq F \leq 1)$

<u>For ATARS Separate out at site:</u> $\qquad$ $\Delta = 1.3$

<u>For ATARS at facility:</u>

<u>ER load - 400 a/c</u>

$$\Delta = 1.3 + \left\{\begin{array}{ll} \left.\begin{array}{ll} 8 & \text{ASR} \\ 8 & \text{ARSR} \end{array}\right\} & \begin{array}{l} \text{ATC lines} \\ \text{do not exist} \end{array} \\ \left.\begin{array}{ll} 0 & \text{ASR} \\ 4 & \text{ARSR} \end{array}\right\} & \begin{array}{l} \text{ATC lines} \\ \text{do exist} \end{array} \end{array}\right. - \left\{\begin{array}{rl} 6F & \text{Epoch} \\ 3F & \text{Sector} \\ 1.5F & \text{TTC} \end{array}\right.$$

<u>100 a/c load</u>

$$\Delta = 1.3 + \left\{\begin{array}{l} 2 \\ 2 \\ 0 \\ 1 \end{array}\right. - \left\{\begin{array}{l} 1.5F \\ 1.5F \\ 1.5F \end{array}\right.$$

<u>700 a/c load</u>

$$\Delta = 1.3 + \left\{\begin{array}{r} 15 \\ 11 \\ 1 \\ 5 \end{array}\right. - \left\{\begin{array}{l} 15F \\ 7.5F (6F \text{ if ARSR}) \\ 1.5F \end{array}\right.$$

4.1.2 Cost Comparisons

Using the results of the preceding section as summarized in Table 4-1, we can search for the type of sites and deployments for centralized ATARS which produce the best cost advantage. The most advantageous sites for centralization are those which have a negative per site cost differential. A positive differential cost, on the other hand, signifies that the distributed deployment is less costly for that site. Positive differential costs for ATARS at the facility which equal or exceed 1.3 need but slight consideration, since in such cases the centralized ATARS configuration can be located at the DABS site for a lesser or equal cost.

In Table 4-2, we list in order of increasing cost (and decreasing interest) the various types of sites which might be candidates for centralization. The optimistic (for centralization) assumption F=1 is made. That is, when the site's ATARS is located at the facility, all its neighboring adjacent sites are too. Lists for three loads, 400, 100 and 700 aircraft, are presented. Examination of these tabulations and the formulas on which they are based reveals the following points.

The instances in which centralization results in a significant cost reduction for any given site are quite restricted. Generally, the cases favorable to centralization increase with the assumed design traffic load. Further, nearly all cases favorable to centralization are characterized by the assumption of an Epoch ATARS algorithm and the assumption that ATC surveillance lines to the facility already exist.

For a 100 aircraft load centralization produces no significant cost advantage regardless of the type of site. Some cases favorable to centralization appear for the ER load of 400 aircraft. However, these are all restricted to sites where ATC surveillance lines are already in place; the most favorable case is for an ASR site with an Epoch algorithm. For a 700 aircraft load, the favorable cases have more pronounced cost differentials. Again the best costs are again produced by Epoch ATARS algorithms where surveillance lines already exist.

To interpret these results one should note first that these are <u>per site</u> cost differentials. Not every site in a total deployment has the same character. The individual per site costs must be added over the entire DABS/ATARS system deployment. Since DABS/ATARS is expected to eventually be deployed nationwide at ASR and ARSR sites, we must consider the cost impact of totally deploying a centralized system. Under the commonality assumption of Section 2.1, a centralized ATARS configuration must be used everywhere (either at the DABS site or at the facility). Thus, we cannot select only favorable sites for centralization and ignore the unfavorable ones.

The mixture of sites causes particular difficulty with any attempt to define a single ARTCC facility in a region as a centralization point for all ATARS in that region. As the formulas and tabulations show, such a centralization can be optimum only if the facility receives ATC surveillance data from all sites of the region. The ASR and ARSR sites of the region form one coordinated network for DABS/ATARS operations. The total centralization of ATARS for this network is cost effective only when such surveillance links exist and need not be charged to the centralization. Otherwise, the best centralization is a fragmented one, following the pattern of the existing surveillance data concentrations to the various TRACONs as well as the ARTCC of the region. Those facilities served by only one site are not candidates for an ATARS location; in that case, the separated ATARS is best located with DABS at the site.

Even when some small or large region controlled by a facility contains sites with favorable differential costs according to our approximate computations, we must keep in mind that any such region has boundaries

TABLE 4-2 Most Advantageous Cases of Centralized per Site Cost (1 unit=$80K)

For ER load - 400 a/c

Δ	Site Character
-4.7	ASR, ATC lines exist, Epoch ATARS at facility
-1.7	" " " " Sector " " "
-.7	ARSR, " " " , Epoch " " "
-.2	ASR, " " " , TTC " " "
1.3	Centralized ATARS remains at DABS site

For 100 a/c load

Δ	Site Character
-.2	ASR, ATC lines exist, ATARS at facility
.8	ARSR, " " " " " "
1.3	Centralized ATARS remains at DABS site

For 700 a/c load

Δ	Site Character
-12.7	ASR, ATC lines exist, Epoch ATARS at facility
-8.7	ARSR, " " " , " " " "
-5.2	ASR, " " " , Sector " " "
-2.7	ARSR, ATC lines do not exist, Epoch " "
.3	ARSR, ATC lines exist, Sector " " "
.8	ASR, " " ", TTC " " "
1.3	Centralized ATARS remains at DABS site

where it interfaces with other, perhaps similar, regions. Telephone communications across such boundaries are required for adjacent site coordinations. In a centralized system these take one of three forms: links between site-located ATARS across the boundary, links between facility-located ATARS in one region to boundary site-located ATARS in another and links connecting between facilities-located ATARS in both regions (when the ATARS are from adjacent across boundary sites).

The cost differentials are not as favorable for such boundary sites since such sites are incompatible with the most optimistic assumption, that ATARS is centralized at a facility and that all adjacent site ATARS are too (i.e., F=1 in the formulas). For boundary sites a more realistic assumption is, say, $F=\frac{1}{3}$ to $F=\frac{2}{3}$. This change erases most of any favorable negative cost differential, so that they cannot contribute to an overall system reduction of cost through centralization.

An additional point to remember is that Sector ATARS is a likely successor to Epoch ATARS for any operational DABS/ATARS system. For the current distributed architecture as well as a centralized architecture, Sector ATARS is very desirable to reduce intersite (inter ATARS) peak data rates. The Sector algorithms match naturally with other DABS/ATARS algorithms which keep pace with the site antenna rotation.

There are no per site cost differentials favorable to centralized Sector ATARS for ARSR sites. For ASR sites with existing surveillance lines the favorable differential improves from nearly zero for a 100 aircraft load to -12.7 for a 700 aircraft load. Centralization of TTC ATARS is uniformly unfavorable.

The above considerations clearly show that the only sites which can reasonably be expected to make contributions to cost reductions through centralization are ASR sites of high density terminal areas whose surveillance data is collected to a central TRACON facility. The centralized ATARS complexes would then also be located at this facility.

This description, however, only applies to a handful of TRACON's. Even for those, any cost advantage is diluted by the TRACON boundary sites which add little or nothing to it. So we must expect that the terminal region as a whole will show a significant advantage for centralization only if it is large enough to contain some interior sites.

As an example of a nationwide cost estimate, let us assume that centralized DABS/ATARS is deployed optimally at the following sites:

90 ARSR sites
140 ASR sites of which are counted as
- 90 single-beacon
- 42 in dual-beacon ARTS IIIA
- 8 in four-beacon ARTS IIIA

For ARSR and four-beacon ASR sites we assume $F=1$. For dual-beacon ASR sites we assume $F=\frac{2}{3}$. For single-beacon ASR sites and for ARSR sites with Sector ATARS the optimum centralized deployment consists of placing the separated ATARS at the site with its DABS. Otherwise, the optimum deployment is to centralize at the control facility which receives surveillance data from each site.

The total approximate system differential costs for Epoch ATARS and Sector ATARS under ER loads are computed as follows:

Sites	Epoch	Sector
ARSR	90 x (-.7)	90 x (1.3)
ASR (1-beacon)	90 x (1.3)	90 x (1.3)
ASR (2-beacon)	42 x (-2.7)	42 x (-.7)
ASR (4-beacon)	8 x (-4.7)	8 x (-1.7)
	-97	191

This cost picture for centralization is worsened if we assume that many single-beacon and ARSR sites are sized for communication links under lesser traffic loads. Going to 700 aircraft loads for the dual and 4-beacon sites produces totals of -371 and 80 for Epoch and Sector ATARS, respectively. The breakeven point is not quite reached even then for the Sector ATARS estimate.

It is clear that the deployment of any centralized ATARS system, based on the commonality concept (one universal DABS/ATARS design) and which employs a Sector ATARS algorithm, incurs a cost penalty over a corresponding distributed ATARS deployment. For Epoch ATARS the picture is mixed. High traffic sites produce a cost advantage for centralization; low traffic sites dilute or reverse this advantage.

4.2 Vulnerability Comparison

Vulnerability to catastrophic failure, whether by accidental or deliberate act or by forces of nature, is an important ATC system characteristic. The distributed ATARS system is relatively invulnerable because each site can, if necessary, operate on its own to assist safe separation of traffic. The links to adjacent sites and facility can be severed without disrupting its primary function. There will, in that case, be difficulties with seam conflicts and controller interactions, but the site retains a considerable measure of effectiveness.

For a centralized ATARS, however, where the ATARS complex is located at a facility, an essential DABS/ATARS interface is created. The DABS-ATARS telephone link bridging this interface carries heavy traffic in both directions whose disruption destroys the ATARS operation. Further, a facility outage which includes the ATARS there leaves no ground-based traffic separation services intact. Finally, the concentration of more than one site ATARS at a facility means that control for the whole region thus served can be incapacitated by a general facility outage or break in communications.

Therefore, a centralized ATARS system is inherently more vulnerable than a comparable distributed system.

4.3 Growth Comparison

The current DABS/ATARS prototype is designed for 400 aircraft loads. We have assumed identical ATARS algorithms and similar computer usage for both distributed and centralized ATARS configuration. Therefore, expansion of processor capacity presents essentially the same problems for both architectures. In the cost analysis this is reflected by the fact that differential processing costs are approximately constant with load.

As the cost analysis also indicates, the growth of the necessary communications capacity with increasing design load leads to a progressive advantage for a centralized system. The rate of growth of capacity for distributed ATARS is, however, greatly slowed by adoption of Sector ATARS, and for as many as 700 aircraft there is still only a marginal advantage to be had for some sites. Thus, the conceivable loads are too small to permit centralized Sector ATARS to achieve any overall growth advantage.

The DABS/ATARS system can also grow by accretion of new sites. New sites can be added to distributed or centralized ATARS systems with about equal ease, as we have defined them.

Similarly, the adoption of new DABS or ATARS algorithms is about as easy in one architecture as the other, since the same basic multiprocessor task breakdown is postulated for both.

Thus, in growth by accretion of new DABS sites or improved or expanded DABS/ATARS software, the potentialties of centralized vs. distributed architectures are about equal. In capacity growth to handle increased traffic loads, the centralized system gains a communications cost advantage of the distributed system with Epoch ATARS; but the advantage is not significant for Sector ATARS.

4.4 Hybrid System Possibilities

It may be possible to identify individual sites or groups of sites where ATARS centralization at a common facility is cost-effective. As noted previously, these sites are likely to be part of a multisite TRACON operation at a terminal with dense traffic. (An obvious candidate is the New York TRACON.) If the commonality concept is imposed, the cost advantage of such centralization is reduced or destroyed by dilution with other unfavorable centralized sites. This suggests that we consider a hybrid approach where only those sites exhibiting a strong negative per site cost differential are centralized. The others are left as distributed ATARS sites.

As objections to the hybrid approach, we have the arguments which led to the adoption of the commonality assumption. Most significantly, for hybrid systems there is more than one version of software and more than one on-going software maintenance operation. Although the software differences between distributed and centralized configurations are relatively not very great, their existence is sufficient for one to suspect hidden costs and to be cautious with this approach. This is all the more true when it is noted that the centralization of high density terminal areas does not purport to increase their performance capabilities. It must also be noted that adoption of Sector ATARS removes a great deal of cost pressure for centralization of such sites.

4.5 An Integrated Centralized ATARS

An even more radical suggestion is to merge the centralized ATARS processors at one facility into a more integrated complex whose parts interact in ways not envisaged by the original ATARS multisite design.

For example, ATARS tracking operations from adjacent sites can be merged to effect a more rapid track sample rate. A single track can then be initiated and carried for each aircraft in areas of multiple radar coverage and can be updated using data from all the radars. Compared with single radar tracking, this combined data tracking can produce faster track initiations and faster maneuver detection as well as better tracking generally. Fast maneuver detection is especially critical for an effective ATARS in a congested traffic area.

Similarly, by combining uplink operations for radar overlap areas, joint uplink strategies can be devised so that the sensor which has the earliest opportunity for message delivery can be utilized. Faster message delivery improves the ATARS reaction time.

These functional integrations can be accomplished by processor-to-processor communications via the computer busses rather than through internal communications lines. The multiprocessor concept using microtechnology can, however, be preserved.

Software of a new kind with substantial development and additional maintenance costs will be required. But in this case cost is traded against the improved performance (not so for the hybrid approach of the previous section).

Although this concept of an integrated centralized ATARS is an interesting one, further development or evaluation here is beyond the scope of the present study.

4.6 Future Trends

The future trends in traffic load and system costs will have some effect on the foregoing evaluations.

An increase in traffic loads, as we have seen, shifts the cost balance somewhat in the direction of centralization. However, as loads increase, the consequences of ATARS system failure also increase, so that the lesser vulnerability of the distributed system assumes a greater importance.

The trend of costs of computer and communications hardware is down, while software and maintenance costs trend upward. The processor and communication system costs of DABS/ATARS both contain a blend of hardware and software/maintenance factors. Particularly in communications costs, which are dominant in this study, these trends tend to offset one another. Therefore, we expect in the near future, as in the near past, communications costs will remain relatively stable and the cost analysis of this study will remain valid.

If, farther ahead, communications and processing system costs drop substantially, the cost advantages/disadvantages of the alternatives of this study will become less important and the qualities of relative vulnerability and performance will assume an even greater role than now.

5.0 SENSITIVITY ANALYSIS

5.1 Parametric Approach

The results developed in Chapter 4.0 are expanded parametrically in this chapter. The approach taken starts with those results as given and examines the sensitivity of those results to three key parameters: time, implementation, and discounting.

5.1.1 Sensitivity to Time Horizon

The results developed in Chapter 4.0 are based on a 10-year life cycle cost of the various configurations examined. To determine the sensitivity of those results to changes in time, the O&M cost estimates have been expanded to 20 and then 30 years assuming a linear extrapolation.

5.1.2 Sensitivity to Costs of Implementation

The investment costs aggregated in Chapter 4.0 are based on hardware costs which do not reflect the loading from the implementation phase of system acquisition. To determine the sensitivity of the results to the inclusion of typical categories of implementation costs, the following additions to the basic hardware costs have been postulated:

	Percent
Initial Spares	20
Cables, Connectors	20
Installation	
Placement	5
Connection	10
Initial Adjustment	5

	Percent
Test	
Initial	10
Final	10
Engineering Follow	20
	100

Variations in these percentages may be readily interpreted by interpolating or extrapolating in the graphical presentations.

5.1.3 Sensitivity to Discounting

The life cycle costs developed in Chapter 4.0 represent simple aggregations which have not been discounted. While a formal discussion on the use of discounting is beyond the scope of this study, a short description of the rationale for its use is in order.

Briefly, the technique imposes a constant percentage of reduction each year on a future stream of expenditures according to the following formula:

$$c_t = \sum_{i=1}^{n} c_i \, (1 + r)^{-n} \qquad \text{where}$$

c_t = total system cost at present time (t)

e_i = sum of costs during ith period

n = number of years

This procedure reflects the fact that a delayed expenditure, in effect, is a delayed investment representing a time value of money in terms of a discount function.

Alternatives which have equal or relatively the same time profile of expenditures would not be affected, relatively speaking, by the discounting process. It is only when the time profiles differ, as they do in the present study, that the process then equalizes the alternatives with respect to the time value of money.

The rate of discount used is 10 percent--Office of Management and Budget (OMB) recommended rate for use in economic studies.

5.2 Parametric Analysis of Nationwide Centralized DABS/ATARS

Chapter 4.0, Section 4.1.2, gives an example of a potential nationwide deployment of 230 centralized DABS/ATARS sites, 90 located at ARSR sites and 140 located at ASR sites.

5.2.1 Using Epoch Algorithm

The total system differential cost savings from Chapter 4.0 for nationwide centralized DABS/ATARS using Epoch algorithm, under a load of 400 aircraft, is -97 cost units over 10 years. Those values fix the reference point for the parametric changes in time, cost, and discounting tabulated in Table 5-1 and shown graphically in Figure 5-1.

The derivation of the parametric values used is shown in Table 5-1-1.

TABLE 5-1 Tabulation of Parametric Analysis of Nationwide Centralized DABS/ATARS Using Epoch Algorithm

Parametric Change	Total Cost Units 10 Years	20 Years	30 Years
Extend Time	-97*	-189	-212
Include Implementation	18	-143	-189
Discount @ 10%/yr.	7	-21	-11

* Chapter 4.0 Result

Parametric Analysis of Nationwide Centralized DABS/ATARS:
Epoch Algorithm

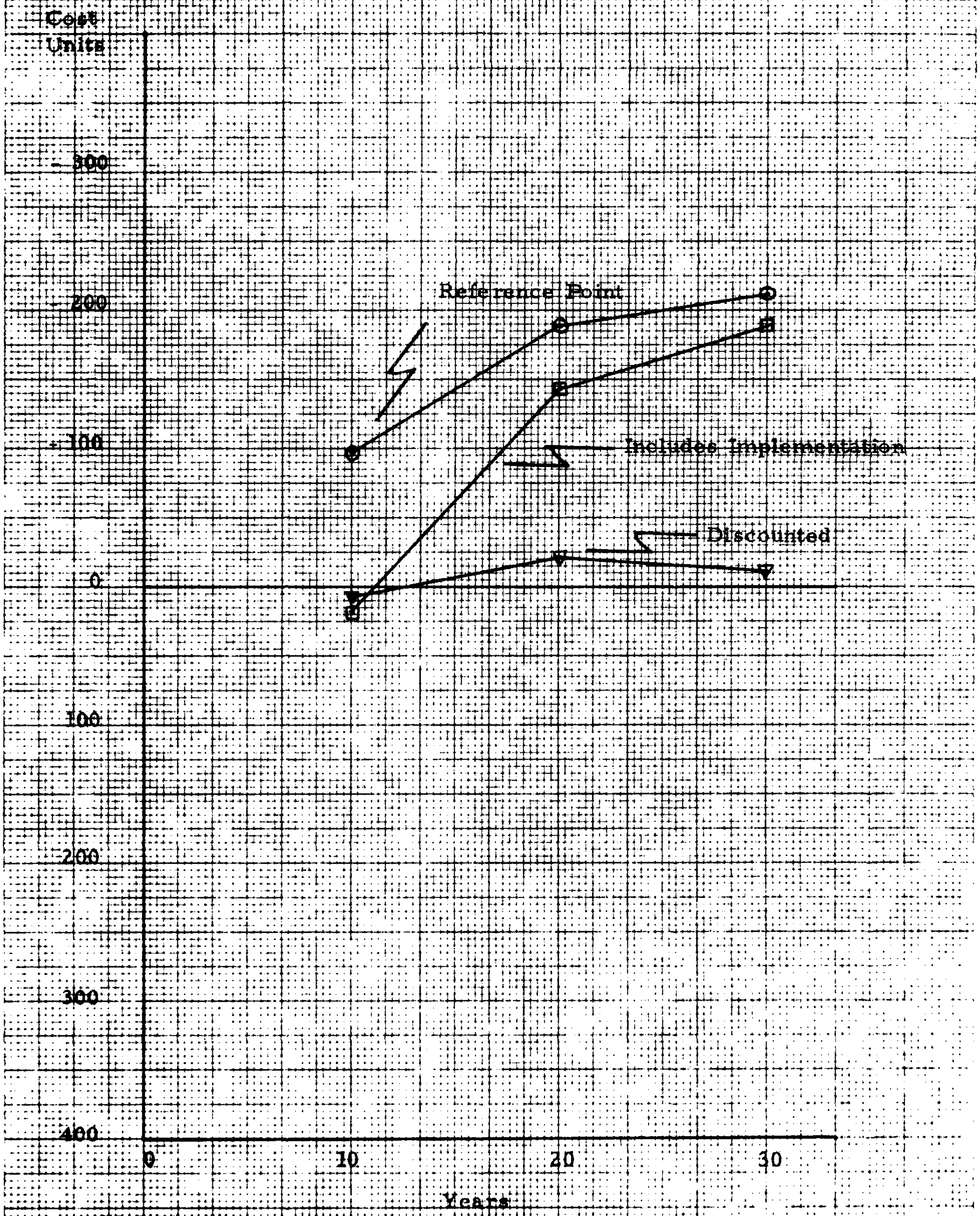


FIGURE 5-1

TABLE 5-1-1 Total System Differential Costs for Nationwide Centralized DABS/ATARS Using Epoch Algorithm

Sites	Qty.	Years 10	20	30
ARSR	90	(- .7)	(-1.1)	(-1.2)
ASR (1-beacon)	90	(1.3)	(.9)	(.8)
ASR (2-beacon)	42	(-2.7)	(-3.1)	(-3.2)
ASR (4-beacon)	8	(-4.7)	(-5.1)	(-5.2)
	230	-97	-189	-212

Total System Differential Costs for Nationwide Centralized DABS/ATARS Using Epoch Algorithm (Including Implementation Costs and Discounting)

Sites	Qty.	Years 10	20	30
ARSR	90	(- .2)	(- .9)	(-1.1)
ASR (1-beacon)	90	(1.8)	(1.1)	(.9)
ASR (2-beacon)	42	(-2.2)	(-2.9)	(-3.1)
ASR (4-beacon)	8	(-4.2)	(-4.9)	(-5.1)
	230	18	-143	-189
Discount Factor		.39	.15	.06
Discounted Cost		7	-21	-11

5.2.2 Using Sector Algorithm

The total system differential cost penalty from Chapter 4.0 for nationwide centralized DABS/ATARS using Sector Algorithm, under a load of 400 aircraft, is 197 cost units over 10 years. Those values fix the reference point for the parametric changes in time, cost, and discounting tabulated in Table 5-2 and shown graphically in Figure 5-2.

The derivation of the parametric values used is shown in Table 5-2-1.

5.3 Parametric Analysis of Centralization on a Per Site Basis

Chapter 4.0, Table 4-2, shows five cases of centralized ATARS on a per site basis ranging from the least advantageous (greatest cost penalty) to the most advantageous (greatest cost savings). In this section only the extreme cases are chosen for parameterization: the most advantageous Epoch and Sector algorithms at ASR sites and the least advantageous ATARS at DABS sites case.

5.3.1 ASR Site Using Epoch Algorithm

The total system differential cost savings from Chapter 4.0 for Epoch ATARS at an ASR site where ATC lines exist, under a load of 400 aircraft, is -4.7 cost units over 10 years. Those values fix the reference point for the parametric changes in time, cost, and discounting tabulated in Table 5-3 and shown graphically in Figure 5-3.

TABLE 5-2 Tabulation of Parametric Analysis of Nationwide Centralized DABS/ATARS Using Sector Algorithm

	Total Cost Units		
Parametric Change	10 years	20 years	30 years
Extend Time	191*	99	76
Include Implementation	306	145	99
Discount @ 10%/yr.	119	22	6

* Chapter 4.0 Result

Parametric Analysis of Nationwide Centralized DABS/ATARS:
Sector Algorithm

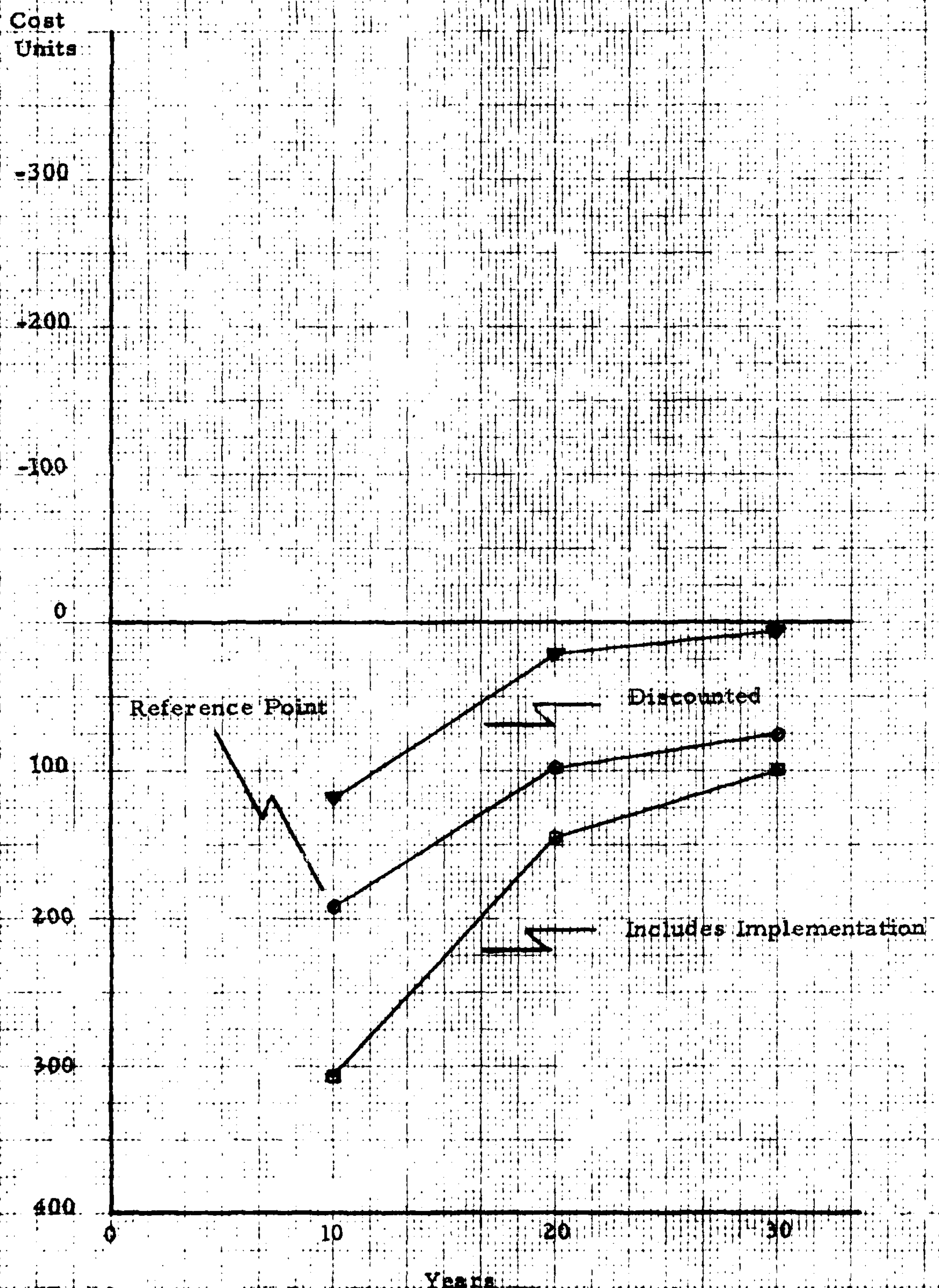


FIGURE 5-2

TABLE 5-2-1 Total System Differential Costs for Nationwide Centralized DABS/ATARS Using Sector Algorithm

Sites	Qty.	Years 10	20	30
ARSR	90	(1. 3)	(.9)	(.8)
ASR (1-beacon)	90	(1. 3)	(.9)	(.8)
ASR (2-beacon)	42	(- .7)	(-1. 1)	(-1. 2)
ASR (4-beacon)	8	(-1. 7)	(-2. 1)	(-2. 2)
	230	191	99	76

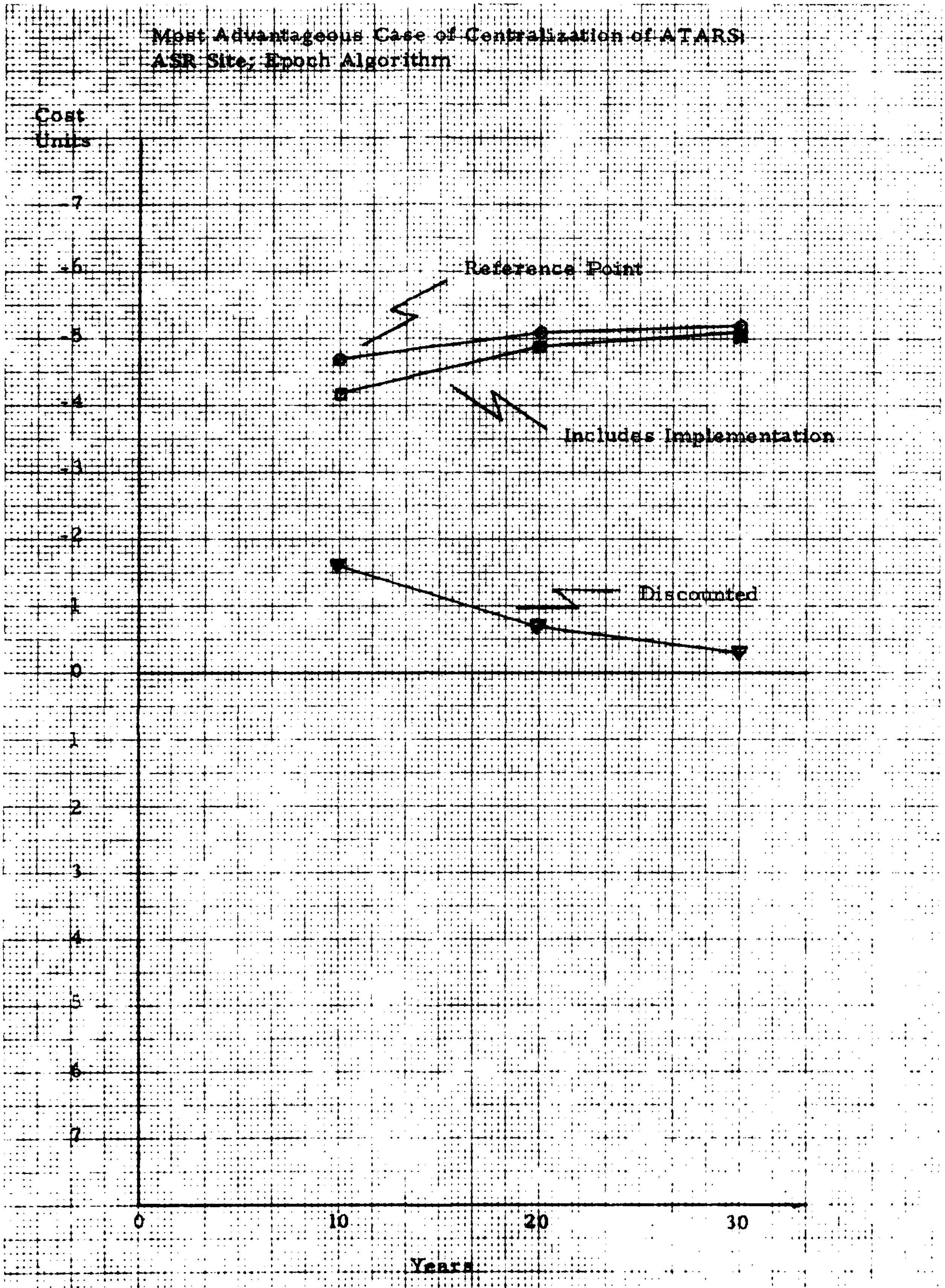
Total System Differential Costs for Nationwide Centralized DABS/ATARS Using Sector Algorithm (Including Implementation Costs and Discounting)

Sites	Qty.	Years 10	20	30
ARSR	90	(1. 8)	(1. 1)	(.9)
ASR (1-beacon)	90	(1. 8)	(1. 1)	(.9)
ASR (2-beacon)	42	(- .2)	(- .9)	(-1. 1)
ASR (4-beacon)	8	(-1. 2)	(-1. 9)	(-2. 1)
	230	306	145	99
Discount Factor		.39	.15	.06
Discounted Cost		119	22	6

TABLE 5-3 Tabulation of Parametric Analysis on a Per Site Basis of Centralized ATARS Using Epoch Algorithm

Parametric Change	Total Cost Units 10 years	20 years	30 years
Extend Time	-4.7*	-5.1	-5.2
Include Implementation	-4.2	-4.9	-5.1
Discount @ 10%/yr.	-1.6	- .7	- .3

* Chapter 4.0 Result



Most Advantageous Case of Centralization of ATARS:
ASR Site; Epoch Algorithm
Cost
Units
Reference Point
Includes Implementation
Discounted
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
0
10
20
30
Years

FIGURE 5-3

The parametric values used are derived by extrapolation from the data in Table 4-1.

5.3.2 ASR Site Using Sector Algorithm

The total system differential cost savings from Chapter 4.0 for Sector ATARS at an ASR site where ATC lines exist, under a load of 400 aircraft, is -1.7 cost units over 10 years. Those values fix the reference point for the parametric changes in time, cost, and discounting tabulated in Table 5-4 and shown graphically in Figure 5-4.

The parametric values used are derived by extrapolation from the data in Table 4-1.

5.3.3 DABS Site Using DABS/ATARS Algorithm

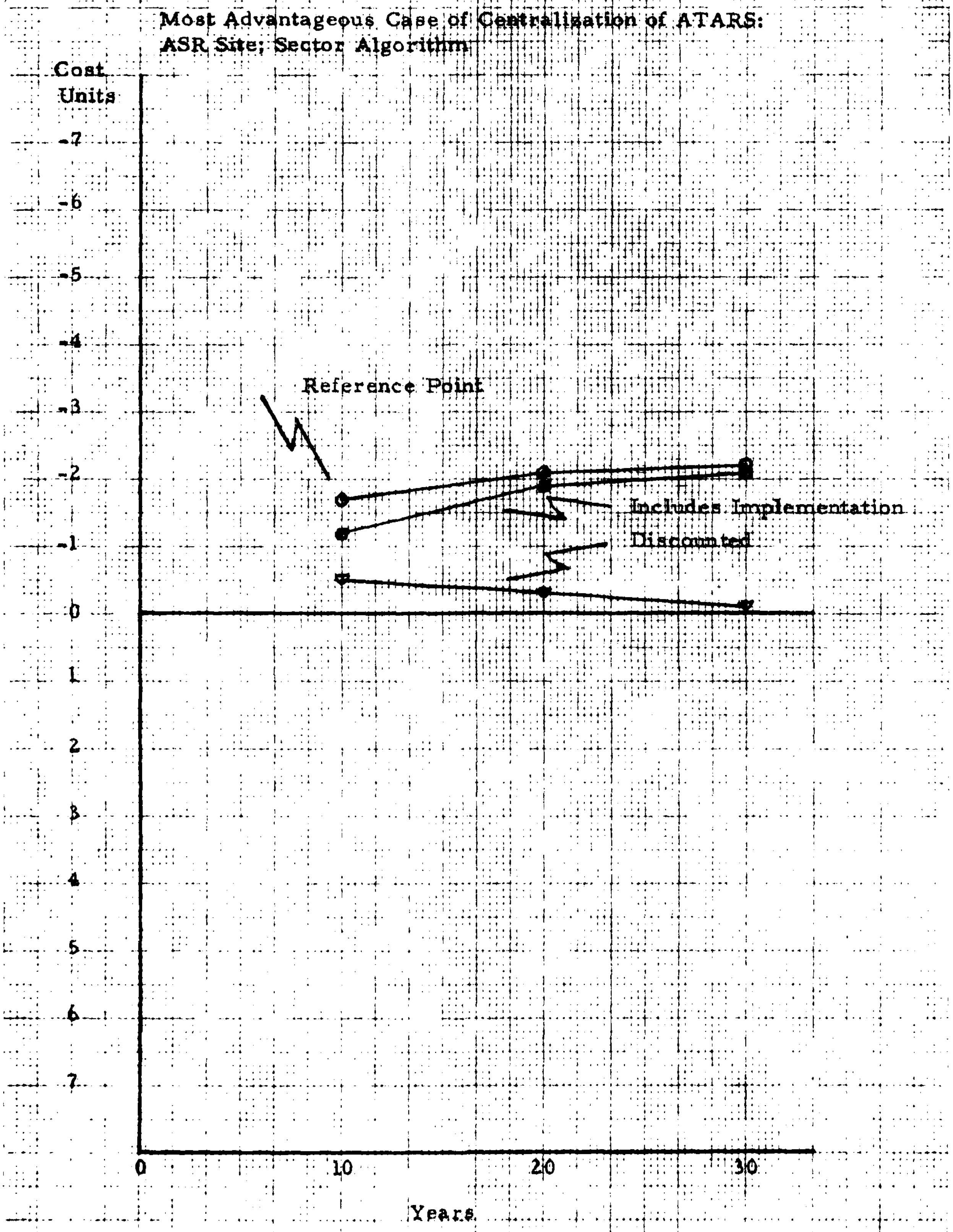
The total system differential cost penalty from Chapter 4.0 for DABS/ATARS algorithm at a DABS site where ATC lines exist, under a load of 400 aircraft, is 1.3 cost units over 10 years. These values fix the reference point for the parametric changes in time, cost, and discounting tabulated in Table 5-5 and shown graphically in Figure 5-5.

The parametric values used are derived by extrapolation from the data in Table 4-1.

TABLE 5-4 Tabulation of Parametric Analysis on a Per Site Basis of Centralized ATARS Using Sector Algorithm (ASR Site)

Parametric Change	Total Cost Units 10 years	20 years	30 years
Extend Time	-1.7*	-2.1	-2.2
Include Implementation	-1.2	-1.9	-2.1
Discount @ 10%/yr.	-.5	-.3	-.1

* Chapter 4.0 Result



Most Advantageous Case of Centralization of ATARS:
ASR Site; Sector Algorithm
Cost
Units
-7
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
7
Reference Point
Includes Implementation
Discounted
0
10
20
30
Years

FIGURE 5-4

TABLE 5-5 Tabulation of Parametric Analysis on a Per Site Basis of Centralized ATARS Using DABS/ATARS Algorithm (DABS Site)

Parametric Change	Total Cost Units 10 years	20 years	30 years
Extend Time	1.3*	.9	.8
Include Implementation	1.8	1.1	.9
Discount @ 10%/yr.	.7	.2	.1

*Chapter 4.0 Result

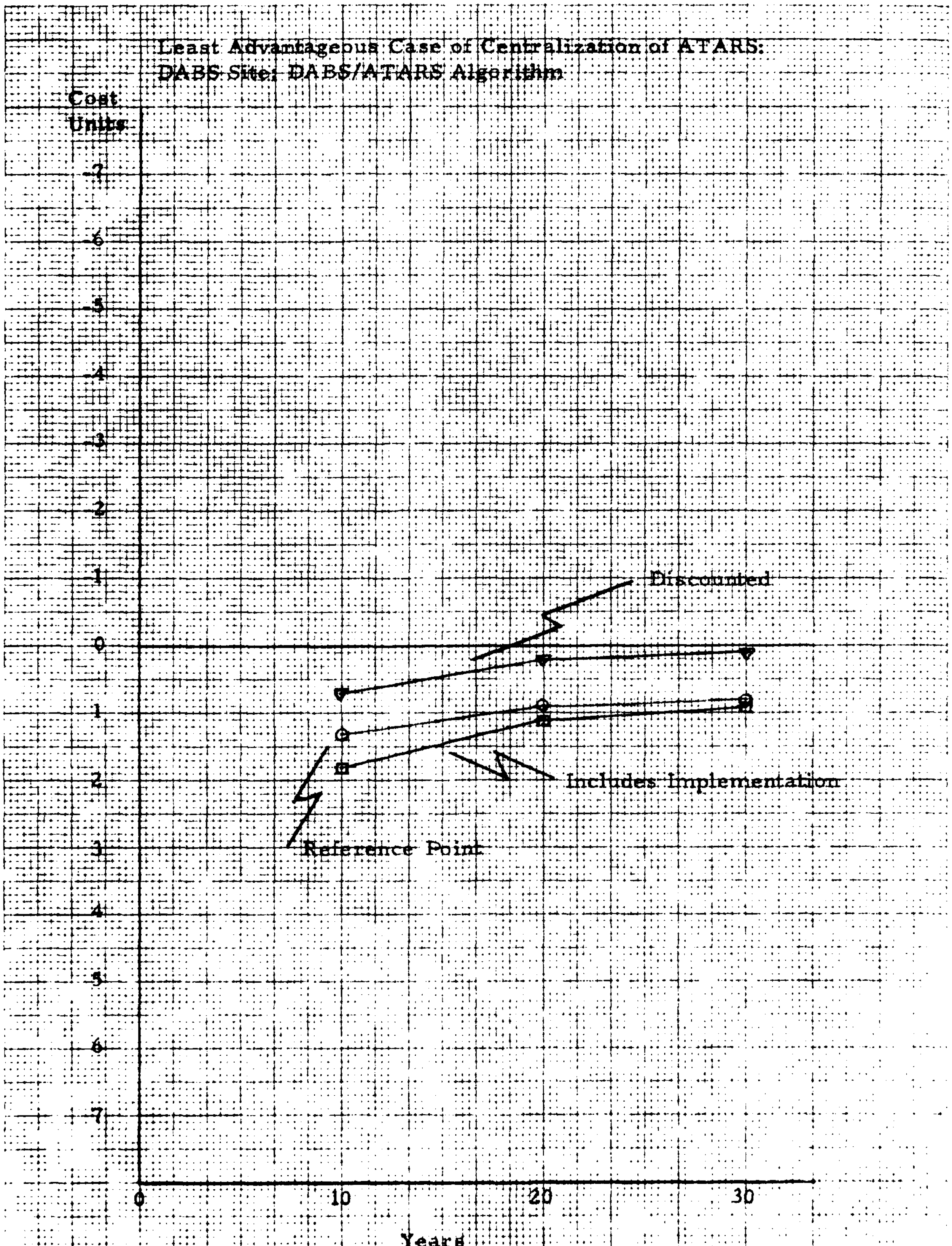

Least Advantageous Case of Centralization of ATARS:
DABS Site: DABS/ATARS Algorithm
Cost
Units
7
6
5
4
3
2
1
0
1
2
3
4
5
6
7
Discounted
Includes Implementation
Reference Point
0
10
20
30
Years

FIGURE 5-5

6.0 SUMMARY AND CONCLUSIONS

This study compares implementation of a multisite DABS/ATARS system with two competing architectures: distributed ATARS and centralized ATARS. The properties of interest are: cost, performance, reliability, vulnerability, maintainability and growth potential.

Vulnerability is a particularly important criterion for selecting an ATARS architecture. Because of the trend towards increasing air traffic, the consequences of system failure are certain to become more grave. It is clear that a centralized ATARS system is inherently more vulnerable than a distributed system because of its concentration of processing and communications and its dependence on report surveillance inputs. Thus, the centralized system is prone to catastrophic failure, and its failsoft properties are inferior.

The performance and reliability of the current multiprocessor DABS/ATARS design are treated as constraints to be matched by any proposed centralized architecture. A specific centralized configuration building-block is chosen to meet these requirements and to minimize the impact of any redesign from a distributed to a centralized system.

Maintainability is treated as a cost problem and is factored into cost estimates.

Costs are analyzed in detail in two main categories: processing system costs and communications costs. Per site centralized vs. distributed costs are determined as a function of the type of radar (ASR or ARSR), the location of the centralized ATARS complex, the a priori presence or absence of surveillance data from the site at this location and the type of ATARS algorithm used (Epoch, Sector or Sector with TTC). Costs are calculated for site designs accommodating 100, 400 and 700 aircraft loads.

The costing formulas are developed in a manner which resolves uncertainties and secondary effects to the favor of centralization. Nevertheless, conclusions of the cost analysis are mostly unfavorable for centralization:

a.) For 100 aircraft loads a centralized architecture is almost always more costly at each site than a distributed architecture (slight cost advantage for centralized ASR site with lines to facility already existing).

b.) For ER loads of 400 aircraft the only type of site where a significant cost saving can be demonstrated for centralized architecture is an ASR site which is part of a multi-site TRACON operation with ATARS at the TRACON facility. A lesser cost saving applied to ARSR sites centralized at the enroute facility when Epoch ATARS is used.

c.) For ER loads the use of Sector ATARS greatly reduces any per site cost advantage for centralization.

d.) For 700 aircraft loads there are more types of individual sites favorable for centralization. However, when a total mix of sites and loads over an entire deployment is considered, any advantage for a centralized deployment is greatly diluted by the unfavorable sites.

Centralized ATARS incurs unacceptable cost penalties in cases where the ATARS of a site is located at a facility which does not receive ATC surveillance data from a site. Therefore, the centralization of ATARS can only follow the pattern of centralization of ATC surveillance.

Larger networks cannot be arbitrarily defined for DABS/ATAR use alone without prohibitive cost. In particular, ASR sites over a large region cannot be combined and ASR sites cannot be centralized with ARSR sites (unless the ARTCC already receives the ASR data). Thus an optimum centralization (for cost) is fragmented at best.

Both distributed and centralized architectures, as defined, have equal evolutionary growth potential.

A major assumption of this study is that a system cannot be deployed part distributed and part centralized. Therefore, occasional sites which might be profitably centralized are swamped by the forced centralization of those which cannot. Even if the assumption is relaxed, the number of favorable sites (very high density, multisite, terminal areas) for unique centralization is so restricted that the additional cost of special hardware and software development and maintenance would probably not be worthwhile—especially since no performance improvement is claimed.

A distinct improvement in ATARS performance might be obtained by nonevolutionary, gross changes in ATARS architecture. This requires centralization of ATARS from several adjacent sites at a common facility, merging the ATARS tracking, detection and resolution, and uplink command generation into one hardware/software system. This would be a new development to exploit the data rate increase produced by overlapping site coverages. However, it would also be costly and could only be cost-effective for high density areas.

The general conclusion of this study is that centralization of ATARS does not yield significant advantage, is typically inferior to a corresponding distributed deployment in most major system criteria and is likely to remain so in the foreseeable future.

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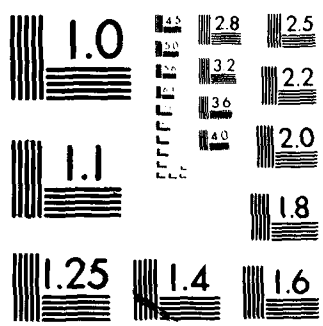

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The sensitivity analysis in Chapter 5.0 does not alter any of the conclusions reached above; rather, it significantly reinforces them. Specifically, in the case of the nationwide centralized DABS/ATARS example using the Epoch algorithm:

a) extending the time horizon to 30 years increases the savings by 120%;

b) including the costs of implementation reduces the savings by more than 100% in 10 years;

c) including the costs of implementation and then discounting reduces the savings by 100% in 10 years.

The total effects in the above case and in the other four cases examined are summarized in Table 6-1.

TABLE 6-1

Parametric Change	Nationwide Example Epoch Algorithm	Nationwide Example Sector Algorithm	Most Advantageous ASR Site Case Epoch Algorithm	Most Advantageous ASR Site Case Sector Algorithm	Least Advantageous DABS Site Case DABS/ATARS Algorithm
Extend Time From 10 yrs. to:	Increases Savings	Increases Cost	Increases Savings	Increases Savings	Decreases Cost
20 yrs.	95%	48%	9%	24%	31%
30 yrs.	120%	60%	11%	29%	38%
+					
Include Implementation	Reduces Savings	Increases Cost	Reduces Savings	Reduces Savings	Increases Cost
10 yrs.	over 100%	60%	11%	29%	38%
30 yrs.	11%	30%	2%	5%	13%
+					
Discount @ 10%/yr.	Reduces Savings	Reduces Cost	Reduces Savings	Reduces Savings	Reduces Cost
10 yrs.	over 100%	38%	66%	71%	46%
30 yrs.	95%	92%	94%	95%	87%

APPENDIX A - DABS/ATARS General Description

The following brief description of the DABS/ATARS system will facilitate further discussion of important features in this report and will introduce the necessary terminology.

A.1 Sensors and Airborne Equipment

DABS receives aircraft radar and beacon target reports from the site radar and its associated signal processors. The site radar may be either an ASR (Airport Surveillance Radar) or ARSR (Air Route Surveillance Radar). Range and scan times are approximately:

ASR:	55 nmi.	4-4.7 sec.
ARSR:	140 nmi.	10-12 sec.

Aircraft equipped with the new DABS transponder can receive and transmit messages over data-link as well as reply to beacon position interrogations. These messages and replies carry a unique (among aircraft) 24 bit identity code. This identity is maintained and utilized throughout the DABS/ATARS system.

Aircraft equipped with the old ATCRBS (Air Traffic Control Radar Beacon Subsystem) transponders do not have data-link or a unique identity capability. When ATCRBS equipped aircraft are tracked, a track number is assigned by the DABS processor (12 bits), which serves as an identifier throughout the system.

A.2 DABS

The DABS ground processor must maintain reliable tracks on all aircraft within the service area of its site. An important part of this processing is the careful management of beacon interrogations (channel management) in order to provide reliable position reports with a minimum of interrogations. This intimate interaction with the radar/beacon transmitter/receiver implies that DABS processing is best located in close physical proximity to the radar site.

Channel management is supported by a scan-to-scan tracking system whose purpose is to: 1) predict aircraft positions in order to selectively interrogate them on future scans, 2) maintain track identity on ATCRBS equipped aircraft and 3) reduce acceptance of false reports by allowing scan-to-scan comparisons (correlations). This last consideration is of increased importance in DABS because a decrease in beacon interrogation rate is a feature of DABS design. In particular, ATCRBS targets receive fewer bits per scan and the target detection process is less sure.

DABS communicates with aircraft (uplink and downlink data-link messages), with adjacent DABS sites, with its central ATC control facilities and internally with its associated ATARS. In the current design it also serves as a conduit for all intersite and site-facility ATARS as well as aircraft-ATARS message traffic.

DABS communications are of two types: surveillance data and messages. Surveillance data (target reports) are disseminated by DABS to its assigned ATC facility (or facilities)—an enroute center (ARTEC) or terminal area center (TRACON) for use in the NAS-Stage A or ARTS systems located there. Surveillance data are also transferred internally to the ATARS function associated with DABS at the site. Surveillance data traffic is direct, one-way and is relatively heavy and steady in volume.

DABS message communications (excluding data-link) are more sporadic in character. They are handled by a handshake CIDIN protocol (Common ICAO Data Interchange Network), which is a two-way process.

Message communications between DABS functions at adjacent sites is required to coordinate interrogations of and data link for aircraft seen by both sites, to assist in providing fill-in reports for aircraft temporarily not reported at one site and to allow for reconfiguration in case of failure at an adjacent site. Message traffic between DABS functions and the facilities also assists in maintaining a consistency of air surveillance between DABS and NAS-Stage A or ARTS, and provides a communications channel through data-link to DABS transponder equipped aircraft.

DABS intersite and facility message traffic (not including traffic generated by the ATARS function) is generally light and may be accommodated through one voice-grade telephone line.

A.3 ATARS

ATARS accepts surveillance reports from its associated DAB and retracks them. The DABS track identities are accepted by ATARS, but ATARS produces new track position and velocity estimates more suitable for conflict detection and resolution. Therefore, a new ATARS track data base is formed and ATARS is described as a "noncorrelating" user of surveillance reports. (A noncorrelating user makes primary use of supplied track ID's rather than track position, velocity for scan-to-scan report-to-track association).

The set of ATARS algorithms which implement the ATARS function is separated into two classes, sector algorithms and epoch algorithms. Sector algorithms are executed in synchrony with the rotation of the site radar/beacon antenna. Sector processing operations are performed on data or tracks corresponding to one sector of radar azimuth ($11\frac{1}{4}°$) and are sequenced to keep pace with the antenna. Epoch algorithms, on the other hand, are controlled by a real time clock which is maintained in synchrony with adjacent site clocks. Epoch tasks are executed within a fixed two-second epoch frame which bears no precise relation to the radar scan.

In the current ATARS design the basic tasks of conflict detection, resolution and intersite ATARS coordination are all part of the epoch structure. For that reason it is called Epoch ATARS. Only the support tasks of tracking and data communications with aircraft are performed in the sector mode.

ATARS conflict detection and resolution algorithms prepare a data base describing conflicts among all aircraft in the service area. This data base consists of conflict tables, one for each aircraft cluster in conflict. It contains complete information on the state of each conflict and is the master file for ATARS management of the conflict.

Message communications between ATARS functions in a multisite environment take place via DABS and consist principally of conflict table exchanges for conflict clusters which lie in seam areas between adjacent sites. Careful coordination of actions must be made to resolve problems of jurisdiction of control (advisories) and compatibility of resolution commands to the various aircraft.

ATARS message communication with the facility consists mostly of control alerts and command notices so that the requisite controller can be kept abreast of conflicts detected and actions taken by ATARS.

ATARS communication via DABS data-link to aircraft under its service consists principally of warnings and commands to aircraft (from ATARS) and uplink delivery notices and pilot acknowledgements (to ATARS).

A.4 Epoch ATARS Seam Processing

Epoch ATARS handles the problem of intersite jurisdiction and coordination of conflict resolution in seam areas by assigning a particular 0.5 second subinterval of the 2 second epoch for seam conflict processing and coordination. Four nonoverlapping time slots are defined and assigned to sites so that no two adjacent sites use the same slot. *Transmission of seam conflict* tables to adjacent ATARS takes place within the dedicated time slot of each local ATARS. Since adjacent site time slots do not overlap, simultaneous transmissions concerning the same conflicts cannot occur between sites. Thus, a first-come-first-served policy resolves jurisdiction for each conflict pair and a coordination of commands for the cluster can be sequentially effected without confusion. (See Reference 1 for more details).

Inter-ATARS exchange of seam conflict tables forms the dominant part of intersite DABS/ATARS communications. Although the amount of conflict table information to be transmitted is rather modest, the requirement to complete transmission within the 0.5 second slot (actually only about 0.3 seconds is available) leads to a large peak rate (bits per second).

A.5 Sector ATARS

Recent attention has been given to the redesign of ATARS conflict detection and resolution algorithms so that they too operate in the sector mode. This redesigned ATARS system is called Sector ATARS. At the same time, development of an airborne Beacon Collision Avoidance System (BCAS) is progressing, which will provide protection in areas not covered by DABS/ATARS.

The problem of jurisdiction for seam conflicts, solved by the dedicated time slot in Epoch ATARS, is resolved in Sector ATARS by utilizing the airborne Conflict Information Register (CIR) which is part of the airborne BCAS equipment. Conflict table exchanges for Sector ATARS can then be conducted at a more leisurely pace than for Epoch ATARS. Message request/response protocol is used to achieve non-ambiguous coordination. Thus, Sector ATARS reduces the peak rate of information exchange between adjacent, overlapping DABS/ATARS sites.

A.6 Through-the-Transponder Coordination

A further reduction in DABS/ATARS intersite ground communication capacity for Sector ATARS can be achieved by employing the BCAS CIR for exchange of conflict tables between adjacent sites. Unfortunately, the coordination, so achieved, is not foolproof under all circumstances. Hence, this method of coordination may only be suitable for sites with light air traffic.

A. 7 The Facility

The ATC facility connected to DABS/ATARS receives surveillance reports from and conducts message communications with the site through telephone lines or over RM (Radio-Microwave) links or coaxial cable. If the facility is an enroute center (ARTCC, Air Route Traffic Control Center) the data is handled by the IBM 9020 computers which constitute the NAS-Stage A ATC system. If the facility is a terminal area TRACON (Terminal Radar Control) center with automatic tracking capability, the data is handled by ARTS III (Airport Radar Tracking System) using UNIVAC IOP computers. Terminal areas with light traffic may use the ARTS II system in which surveillance data is displayed but not tracked.

ARTS III and NAS-Stage A are "correlating" users of surveillance data. That is, tracks are initiated upon and correlated scan-by-scan with arriving reports primarily on the basis of continuity of position. However, ARTS III (and the newer, multiprocessor ARTS III A) and, perhaps, eventually NAS-Stage A are evolving toward systems integrated with DABS/ATARS which are "noncorrelating" users of surveillance data. A "noncorrelating" user accepts the unique track identify attached by the DABS correlator to each target report and uses this identity as the primary matching criterion. Since ATARS is also a noncorrelating user of surveillance data, ARTS III and ATARS automatic tracking functions are converging in design.

Communications at an ARTCC may be eventually enhanced by employment there of a NADIN switch (National Airspace Data Interchange Network). This would allow the ARTCC to be a node in a star-configured message network without direct involvement of the ATC program.

APPENDIX B Communications for 100 and 700 Aircraft Loads

This appendix summarizes the calculations of link capacities (in BPS) and lines for ASR(ARSR) sites under 100 and 700 aircraft loads and of the resulting cost formulas.

Capacity / Lines

Distributed ATARS Link	100 a/c	700 a/c
Surveillance	9300(3725) / 2 (1)	65100(26800 / 14 (6)
Site-Facility	2700(2150) / 1 (1)	18810(15050) / 4 (4)
DABS-DABS	500(400)	3500(2800)
ATARS-ATARS	890(890)	42810(42810)
	380(300)	18120(14520)
	-	-
Total Intersite (Epoch)	1390(1290) / 1 (1)	46310(45610) / 10 (10)
(Sector)	880(700) / 1 (1)	21620(17320) / 5 (4)
(TTC)	500(400) / 1 (1)	3500(2800) / 1 (1)

Centralized ATARS Link	100 a/c	700 a/c
Combined Surveillance	$\dfrac{9300(7450)}{2\ (2)}$	$\dfrac{65100(52150)}{14\ (11)}$
DABS-ATARS	$\dfrac{3220(2600)}{1\ (1)}$	$\dfrac{22560(18220)}{5\ (4)}$

Inter ATARS (Same as Distributed Intersite)

ATARS-Facility (Same as Distributed Site-Facility)

For 100 aircraft:

$$\Delta_p = 1.3$$

$$\Delta(\text{Surveillance Lines}) = \begin{cases} \left.\begin{array}{l} 2 \ \text{ASR} \\ 2 \ \text{ARSR} \end{array}\right\} \text{facility gets ATC surveillance} \\ \left.\begin{array}{l} 0 \ \text{ASR} \\ 1 \ \text{ARSR} \end{array}\right\} \text{no ATC Surveillance} \end{cases}$$

$$\Delta(\text{Facility Message Lines}) = \begin{cases} 0 \ \text{ASR} \\ 0 \ \text{ARSR} \end{cases}$$

$$\Delta(\text{Inter ATARS Lines}) = -\frac{3}{2}F \begin{cases} 1 \ \text{(Epoch ATARS)} \\ 1 \ \text{(Sector ATARS)} \\ 1 \ \text{(TTC)} \end{cases}$$

Adding these, we get the cost formula for 100 a/c in Table 4-1.

For 700 a/c:

$$\Delta_p = 1.3$$

$$\Delta(\text{Surveillance Lines}) = \begin{cases} 14 \\ 11 \\ 0 \\ 5 \end{cases}$$

$$\Delta(\text{Facility Message Lines}) = \begin{cases} 1 \ \text{ASR} \\ 0 \ \text{ARSR} \end{cases}$$

$$\Delta(\text{Inter ATARS Lines}) = -\frac{3}{2}F \begin{cases} 10 \\ 5 \text{(4 if ARSR)} \\ 1 \end{cases}$$

Combining these, we get the cost formula for 700 a/c in Table 4-1.

APPENDIX C

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