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ARTS-II ENHANCEMENTS COSTS AND BENEFITS

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16. Abstract

This document presents an analysis of benefits and costs expected to accrue from potential enhancement features to the basic ARTS-II terminal automation system. It defines the sources of benefits both quantifiable and nonquantifiable. The study provides information in present value dollars for the equipment life cycle. Further it includes a sensitivity analysis of key assumptions and a deferral analysis.

An examination is first conducted of typical terminal automation enhancement features for their applicability to the ARTS-II system and its environment. Those major features which outwardly appear most desirable are analyzed to determine their quantifiable and nonquantifiable benefits. The major source of benefits in an ARTS-II Enhancement program was found to be improved safety brought about by the Minimum Safe Altitude Warning and the Conflict Alert features. There is also some productivity gain attributable to a radar training simulator capability. Program costs are estimated and converted to present value costs. A comparison of present value benefits to present value cost is made to determine the benefit/cost ratio.

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EXECUTIVE SUMMARY

The purpose of the analysis described in this report is:

1) To identify and measure the benefits provided by the ARTS II Enhancement Program.

2) To develop present value dollar measures of these benefits for the equipment life cycle; and to compare these benefits to present value costs.

3) To determine which assumptions or parameters are most critical to the calculated benefits and costs.

The automation functions which provide the benefits are:

- o Beacon Tracking
- o Minimum Safe Altitude Warning (MSAW)
- o Conflict Alert (CA)
- o Continuous Data Recording
- o Radar Training Simulator
- o Primary Radar Tracking

The major benefits are due to improved safety and increased controller productivity; the results are summarized in Table 1. Significant benefits are calculated for each category, with the total present value benefits exceeding present value costs by a factor of 1.6.

These benefits and costs are based on implementation at 71 ARTS II sites. Three additional systems for support (NAFEC) and training (Oklahoma City) are included in the basic ARTS II procurement.

Table 1

PRESENT VALUE BENEFITS
AND COSTS FOR
ARTS II ENHANCEMENTS

SOURCE OF BENEFITS	VALUE* ($ MILLIONS) (Base Case)	RANGE OF VALUES
SAFETY		
MSAW	12.7	
Conflict Alert	1.5	
PRODUCTIVITY		
Radar Training Simulator	1.2	
Total Benefits	15.4	8.3 - 19.4
Total Costs	9.7	8.0 - 11.8
Benefits/Costs	1.6	.9 - 2.0
"Best" Case Benefits/Costs = 2.4		
"Worst" Case Benefits/Costs = .7		

* 15 year equipment life

Safety related benefits are dominant. The minimum safe altitude warning capability provides 82 percent of the potential benefits. Since there are significantly more ground collisions than midair collisions at ARTS II sites, the number of MSAW preventable accidents is relatively large. The conflict alert capability offers some benefits through the possible prevention of midair collisions. However, the historical incidence of midairs is so low that their prevention does not contribute a significant amount toward quantifiable benefits. The conflict alert function will undoubtedly help the terminal controllers maintain this excellent safety record.

The improvements in training made possible by a radar training simulator would prove valuable by reducing the time spent in direct supervision by an on-the-job (OJT) instructor. This would effectively increase the average productivity of the developmental controller since he could more quickly operate positions under general supervision.

Other Enhancements, such as data recording and primary radar tracking, offer some qualitative improvement in facility operations, but these benefits were not considered quantifiable and are hence not incorporated in the final results.

In summary, the combined package of capabilities discussed in this analysis provides an investment opportunity with a benefits/cost ratio of approximately 1.6. Over 82 percent of the benefits accrue from minimum safe altitude warning. This capability can be inexpensively implemented independently, and therefore MSAW by itself provides a very high (over 4.8) benefits cost ratio. The remaining Enhancements, as a package, provide a lower benefit/cost ratio. These conclusions are relatively insensitive to variations in the basic analysis assumptions, as can be seen from the results in Table 1.

The MSAW and conflict alert capabilities require beacon tracking the function. All three would be available through one addition of computer memory and software only. Therefore, if the full Enhancements are not approved, these capabilities can be procured separately.

1.0 INTRODUCTION

The ARTS II Enhancement program is the primary mechanism for achieving the "Upgraded Third Generation" (UG3RD) level of automation in the lower density terminal air traffic control system. The purpose of this analysis was to determine the benefits and costs of the ARTS II Enhancements. Several other specific programs in the UG3RD ATC System are expected to improve terminal performance. These are:

- ARTS III Enhancements
- Discrete Address Beacon System (data link)
- Wake Vortex Avoidance System
- Microwave Landing System
- Airport Surface Traffic Control

These other UG3RD programs were excluded from this analysis but will be considered in other FAA studies. The major sources of ARTS II Enhancement benefits and the functional capabilities necessary to achieve them are defined in Table 2.

The ARTS II System is currently in the final production engineering phase of development. Installation of 71 sites is planned to begin in 1977. The ARTS II System is a minicomputer based system which displays primary radar and beacon returns on a cathode ray tube display. By associating alphanumeric data through a keyboard input device, the controller can "tag" a particular beacon code return with relevant data. The system is functionally similar to the ARTS III except that no tracking computations are performed.

TABLE 2

ARTS II CAPABILITIES VS BENEFITS MATRIX

Functional Description of Potential Enhancement	Required for other Benefits	Safety	Decreased Training Time	Non-Quantifiable
1) Beacon Tracking	(2)&(3)	X		
2) Minimum Safe Altitude Warning		XX		
3) Conflict Alert		XX		
4) Continuous Data Recording				X
5) Training Simulator			XX	
6) Primary Radar Tracking		X		X

XX = Major Benefit

This means that each radar or beacon return is displayed as received. In ARTS III, the tracking capability smooths the reported returns, computer ground speed, and allows the display to continue when an occasional return is missed. One Enhancement feature considered for ARTS II is the addition of tracking software. Tracking is a prerequisite capability for adding other Enhancement functions such as MSAW and CA.

A prototype ARTS II has been installed at Knoxville, Tennessee, (TRACON), and Wilkes-Barre, Pennsylvania, (TRACAB), for several years. These systems have been well accepted by the professional controllers. This proven base of automation provides an opportunity to augment the basic system with more advanced functions (References 1 and 2). The ARTS II Enhancements are compatible with the overall philosophy of the Upgraded Third Generation Program.

The Enhancement capabilities which yield significant automation benefits will require additional research and development. Since the ARTS II System was originally designed in a modular manner, these functions can be implemented with the addition of new hardware modules and more sophisticated and complex computer software with minimal disruption of the operational system. Most of the Enhancement functions can be implemented separately. The exception is MSAW and CA, which require beacon tracking to be effective.

The inputs to this study consist of research and development documents which describe the systems that would result from the Enhancement program. Data from other analyses which project the performance of these systems also have been included. Considerable experience has been obtained with the ARTS concept and hardware; the Enhancement program is based on this operational experience.

This report develops techniques and models which translate the ARTS II Enhancements functional capabilities into quantitative estimates of increased controller productivity, improved safety, and reduced equipment costs. These benefit calculations are based upon the traffic forecasts for the applicable TRACONs and TRACABs (Reference 3). All of the goals which have been put forth for the program appear to be within the current state-of-the-art computer sciences. However, since the terminal automation program is an integral part of the overall UG3RD ATC System, not all of the advanced Enhancement functions have been developed. There are time and cost risks associated with the program. In addition, some of the interfaces which are postulated are only hypothesized insofar as systems functions and systems costs are concerned.

Section 2.0 briefly describes the ARTS II Enhancements. The uncertainties in defining the advanced functions will be resolved as the development program proceeds. In Section 3.0, each major benefit category (safety and productivity) is analyzed separately. Every effort was made to eliminate overlap in accrual of benefits, and to include all quantifiable sources of benefits. The methodology used for computing present value costs and benefits is that described in OMB Circular A-94, revised 27 March 1972, using a 15-year equipment life cycle.

Section 4.0 presents projected costs of the ARTS II Enhancement Program. Since only R & D costs have been projected by the FAA, other costs are estimated. Section 5.0 presents the results and Section 6.0 the conclusions of the study.

2.0 ARTS ENHANCEMENTS

The basic ARTS II System, as it will be installed in the smaller TRACONs and TRACABs, is an alphanumeric display system utilizing a digital computer. The display subsystem allows broadband radar data to be displayed simultaneously with alphanumeric data. The System reduces the controller's visual and perceptive workload by making radar targets easier to identify and follow. Altitude data are also presented if the aircraft has a Mode C transponder. Some ARTS II terminals will be equipped with IFR room and tower cab displays (TRACON configuration), others with tower cab displays only (TRACAB configuration). The basic ARTS II System design provides for both configurations. A functional prototype of the ARTS II was installed at Knoxville, Tennessee, and the prototype configuration for the TRACAB was installed at Wilkes-Barre, Pennsylvania.

The ARTS III System is currently installed at the larger terminals. This system is similar to ARTS II except that it is capable of tracking target returns. The tracking* capability allows the maintenance of a continuous display of aircraft identifying data even if a few returns are missed by the system. In addition, tracking provides ground speed data and can provide a heading for the aircraft as well. One of the Enhancements considered for ARTS II is a tracking function.

*In this study, the term "tracking" refers to the statistical smoothing of several historical returns. Although ARTS II will display data blocks by the moving target, it does not "track" the target in this sense.

ARTS II should provide a reduction in the controller's workload, ARTS II also provides a computerized base, or "platform," upon which more advanced automation can be achieved. The ARTS II Enhancements, which are the subject of this analysis, would exploit this platform by integrating modular hardware and software features which would bring the terminal ATC environment to a higher level of automation.

The Enhancement program has been divided into three "packages." The first package includes beacon tracking, continuous data recording, conflict alert, and minimum safe altitude warning. R & D activities for this group could begin in FY 78. The second package includes interface with the Terminal Information Processing System and the radar training simulator; R & D activities could begin in FY 79. The third package consists of advanced sensor (DABS) interface and radar tracking. This package could be funded in FY 80.

Major functional capabilities of the Enhancement program are analyzed in this report to determine user benefits. Several items in the Enhancement program do not by themselves provide direct user benefits, but are necessary for improving the ARTS II platform so advanced functions can be added. Table 3 provides a brief summary of the major Enhancement items. Figure 1 shows the earliest feasible time phasing of the primary development effort for the Enhancements. For additional descriptive information on these programs, see the Engineering and Development Program Plan - Terminal Tower Control Program (ED-14-2)(Reference 1).

TABLE 3

ARTS II ENHANCEMENT ITEMS

PACKAGE A

Beacon Tracking - This capability would perform tracking computations for all beacon targets, providing a ground velocity readout. The tracking capability will reduce the number of false beacon returns. The current system displays only beacon returns on a scan-by-scan basis.

Minimum Safe Altitude Warning - MSAW provides for the monitoring of altitudes for those aircraft equipped with altitude encoders and Mode C transponders. The controller is alerted if the aircraft is projected to penetrate an unsafe altitude.

Conflict Alert - The Conflict Alert program will project the aircraft tracks using the ground speed and altitude (if available) data to determine if a hazardous circumstance will occur; the controller is warned when appropriate.

Continuous Data Recording - This capability would record the ARTS II System data on a mass storage device, and allow later, selective retrieval of this data.

PACKAGE B

Interface with TIPS - This item will develop an interface with the Terminal Information Processing System (TIPS) capability being developed under a separate program. The activity for ARTS II requires interface and integration with TIPS.

Radar Training Simulator - This item would provide simulated targets in the ARTS II display. A trainer or pseudo pilot can manuever the targets under the trainee's instruction, allowing the ATC environment to be realistically duplicated for training.

PACKAGE C

Radar Tracking - This improvement will allow primary radar targets to be tracked and displayed with alphanumeric tags. Also, when combined with beacon tracking, it improves overall quality of the tracking system.

Advanced Sensor Interface - When the Discrete Address Beacon System replaces the current ATCRBS System, ARTS II Systems may be adapted to use this source of surveillance data. In addition, the DABS System provides a data up-link to the aircraft. This task would develop the necessary DABS interface.

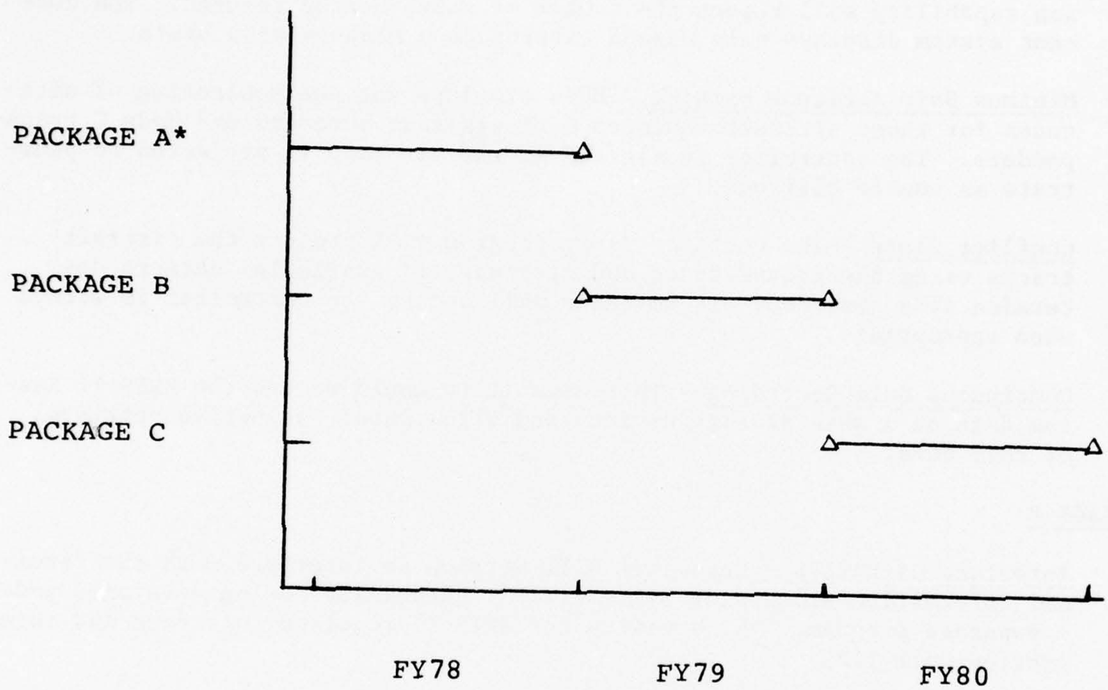

*Table 3 defines R & D Package Items.

Figure 1. ARTS II Enhancement-Earliest Development Schedule

3.0 ANALYSIS OF BENEFITS

3.1 INTRODUCTION

This section describes the analysis techniques used to calculate the benefits that would result from implementing the ARTS II Enhancements. The benefits are determined for the selected 71 ARTS II sites (see Table 4). In addition to the operational sites, systems at NAFEC (support) and at Oklahoma City (training) are planned.

Certain specific items to be procured under the Enhancement program provide a "platform" which is required for other operational improvements. Examples include increased computer capacity and tracking software. These platform benefits are necessary prerequisites to implementing the active functions. Figure 2 illustrates these relationships in a graphic manner. The analysis described in this section focuses on the benefits provided by the following active functions:

- Minimum Safe Altitude Warning
- Conflict Alert
- Radar Training Simulator
- Continuous Data Recording

3.2 SAFETY-RELATED BENEFITS

Maintaining a high level of safety in the National Airspace System is not only a major system goal, but an absolute constraint imposed on any future developments of the System. Two kinds of aircraft accidents can be reduced by improved air traffic control

Table 4

ARTS II Candidate Sites

FAA Academy
NAFEC
Agana RATCC, GU
*Akron, OH
Albrook, Balboa, CZ
Allentown, PA
Atlantic City, NJ
Baer RAPCON, Fort Wayne, IN
Bangor, ME
*Bates RAPCON, Mobile, AL
Beaumont, TX
Bergstrom AFB, Austin, TX
Bristol, TN
Burlington, VT
Casper, WY
Champaign, IL
*Charleston, SC
Chattanooga, TN
*Colorado Springs, CO
Corpus Christi, TX
Daytona Beach, FL
Duluth, MN
Dyess RAPCON, Abilene, TX
Edwards RAPCON, Muroc, CA
Eielson RAPCON, Fairbanks, AK
Elmendorf RAPCON, Anchorage, AK
Evansville, IN
*Fairchild RAPCON, Spokane, WA
Fort Hood, TX
Fort Sill, OK
*Greensboro, NC
Greenville, SC
Griffiss RAPCON, Rome, NY
Gulfport, MS
Harrisburg, PA
*Hill RAPCON, Ogden, UT
*Huntsville, AL
Jackson, MS
Key RAPCON, Meridian, MS
*Knoxville, TN
Lafayette, LA
Lake Charles, LA
Longview, TX
*Lubbock, TX
Malmstrom RAPCON, Great Falls, MT
*Maxwell RAPCON, Montgomery, AL
*McChord RAPCON, Tacoma, WA
Monroe, LA
Muskegon, MI
Otis RAPCON, Falmouth, MA
Palm Springs, CA
Pensacola, FL
Portland, ME
Pueblo, CO
Reno, NV
*Richmond, VA
Roanoke, VA
*Robins AFB, Macon, GA
Rockford, IL
*Savannah, GA
South Bend, IN
Springfield, MO
Tallahassee, FL
*Toledo, OH
Topeka, KS
Waterloo, IA
White Plains, NY
Wichita, KS
Wilkes-Barre, PA
Wilmington, NC
**

*ERS III (Stage III) per Airmans Information Manual, Part 4, July 1974. Thus, approximately 20% of ARTS II sites provide ERS III.

**Three additional sites will be qualified in the future.

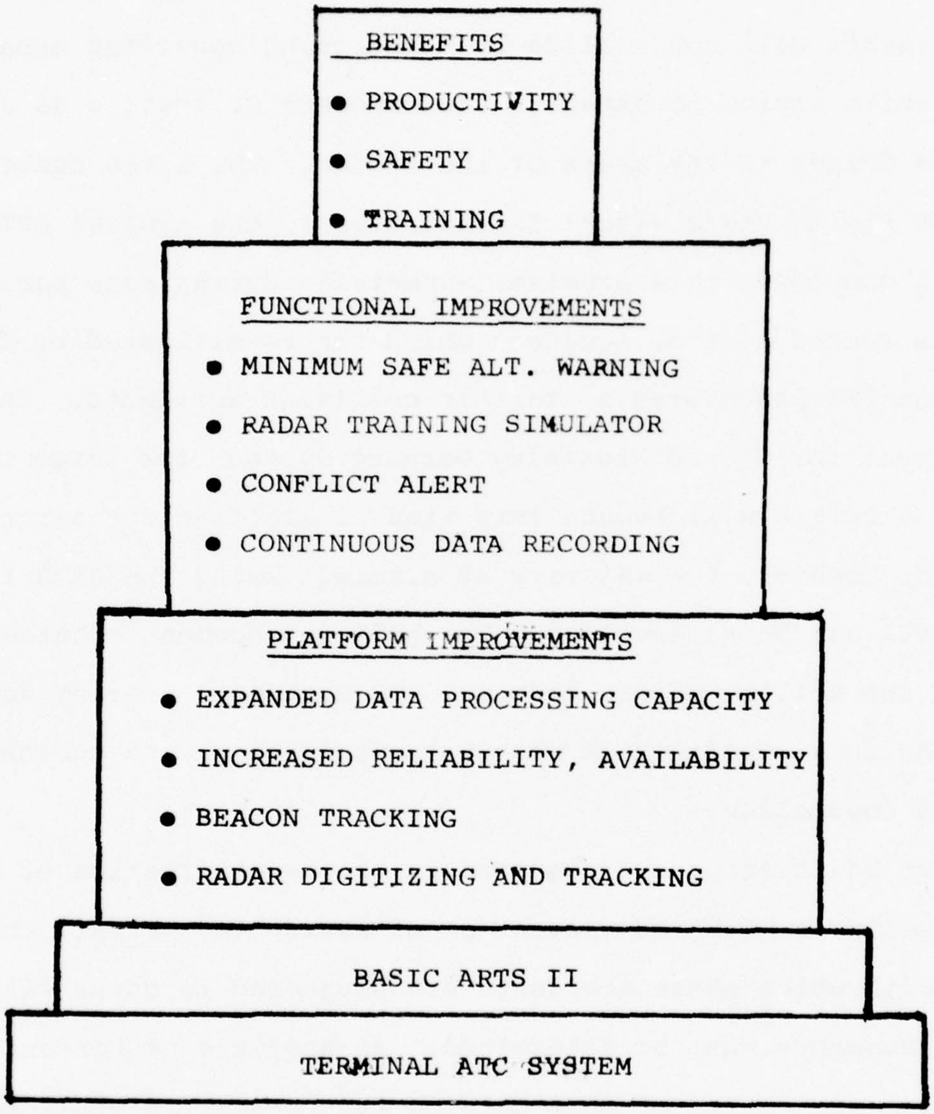

Figure 2. ARTS II Enhancements -- "Building Blocks to Benefits"

systems. First, midair collisions, while not the most common form of accident in the current system, are a major concern of all facets of the air traffic control process. The current ATC System insures that aircraft will not collide by maintaining specified separation minima while trying to expedite the movement of traffic so as to decrease delays to the users of the system. The large number of aircraft flying under visual flight rules in the typical ARTS II terminal compounds this problem, especially during peak periods.

The second kind of accident which can be mitigated by Enhancements and ATC procedures is terrain collision accidents. The recent requirement for Ground Proximity Warning Systems for large turbine-powered aircraft will reduce this kind of accident for aircraft so equipped; however, the majority of aircraft using the ARTS II airports will not be so equipped. The ARTS Enhancement Program should improve the ability of the terminal ATC System to prevent accidents involving an aircraft which was in communication with the ARTS equipped controller.

Four basic steps are required in the quantification of benefits associated with the prevention of accidents. First, the frequency with which these accidents are projected to occur without the Enhancements must be determined. An analysis of historical data and a projection of this data to future traffic environments is the primary mechanism by which this is accomplished. Second, the fraction of these accidents which could have been prevented had the ARTS Enhancements been incorporated must be determined.

Third, the dollar value, expressed in current (1976) dollars, must be developed for the savings projected for those accidents which were preventable. Fourth, the present-value benefits associated with preventable accidents must be calculated using accepted discount factors and equipment life cycle data.

The predominant quantifiable loss associated with aircraft accidents is the loss of life. In order to place a current dollar value common denominator on the loss of life, this study associates a litigated value of $300,000 with the prevention of a death. The next most significant loss is that of equipment. The approximate current market value of the aircraft equipments is used to evaluate this loss.

3.2.1 Safety Related Benefits Analysis

The analysis of aircraft accidents used a series of records for fatal accidents occurring near ARTS II airports. The data was obtained from the FAA, using National Transportation Safety Board computer based accident files. The NTSB accident records were obtained for the time period 1967 through 1972. Due to legal restrictions and NTSB regulations, accident records for 1973 or later were not available.

There were a total of 104 fatal accidents at or near ARTS II sites during this period. Certain accidents were eliminated since there was no likelihood that they could have been prevented by the ARTS II Enhancements. Among the accidents excluded were propeller accidents on the ground, helicopter and glider accidents, engine failure, structural failure, bird strike and uncontrolled descent from various causes. There was also a DC-8 aborted take-off accident with 47 fatalities excluded along with accidents of unknown cause. There were 49 unexcluded accidents remaining with 106 fatalities resulting from those accidents. These were considered potentially "preventable" if ARTS II Enhancements were implemented.

An analysis of the accident records obtained indicated that there were only two midair collisions at or near the proposed ARTS II airports during this period. Both occurred in the terminal pattern or departure climbout areas. There was a total of five fatalities and three general aviation aircraft destroyed. An F105-D received minor damage in one of the collisions.

There were 19 collisions with the terrain or obstructions which were considered potentially preventable by the Minimum Safe Altitude Warning system. Six of these accidents occurred in the cruise phase, three on final approach, one on climbing out, one on descent to the pattern, and eight during other unspecified phases of flight. In this group were 44 fatalities and 19 general aviation aircraft destroyed. It should be noted that no air carrier aircraft was involved in any of the preventable accidents discussed above. Only one military aircraft was involved in one of these accidents, a midair collision. Table 5 summarizes the accident data used for the analysis.

Unfortunately, the NTSB accident data does not include such details as would be provided by the cockpit recording devices used by air carriers. Therefore, the preventability of the subset of

Table 5

AIRCRAFT ACCIDENTS NEAR ARTS II SITES
1967 - 1972*

Category	Number of Accidents	Consequences
Collisions with ground, trees, poles, wires, etc. (1)	19	44 fatalities 19 GA aircraft destroyed
Midair collisions in pattern or departure climbout (2)	2	5 fatalities 3 GA aircraft destroyed 1 F105D damaged
Spin and Stall (3)	18	30 fatalities 18 GA aircraft destroyed
In flight, non-mechanical unknown cause (3)	10	
Miscellaneous; excluded as non-preventable (3)	57	

*Data derived from NTSB files

(1) Preventable by Minimum Safe Altitude Warning

(2) Preventable by Conflict Alert

(3) Not preventable by ARTS II Enhancements

accidents can only be estimated. Since most of the accidents selected for analysis were terrain collisions, some correlation with time of day might be expected.

Thirty-seven percent of the accidents occurred between the hours of 8:00 P.M. and 8:00 A.M. when less than 10 percent of traffic occurs. Assessing the possible causes for this finding is beyond the scope of this investigation. However, darkness markedly reduces visual cues needed for terrain avoidance.

3.2.2 Minimum Safe Altitude Warning Benefits

The present value benefits associated with ARTS II MSAW can now be calculated using the annual cost of preventable terrain collision accidents. The total value of the lives and aircraft lost in the 19 fatal accidents over the six year period (1967-72) was $14.15 million, or $2.358 million per year. This loss is determined from the first category of accident shown in Table 5. The total preventable loss is calculated as follows:

44 fatalities x $300,000	=	$13.2 million
19 GA aircraft x $50,000	=	$ .95 million
Total (6 years)	=	$14.15 million
Total loss per year = $14.15/6	=	$ 2.36 million.

Since all fatal terrain collision accidents at the ARTS II sites involved GA aircraft, MSAW would only be effective if the aircraft were equipped with altitude encoders (Mode C). The preventable loss must be corrected for Mode C population since MSAW does not work without altitude data. Approximately 15 percent of the GA aircraft were estimated to be so equipped. Assuming that the availability of Conflict Alert and MSAW motivates continued purchase of Mode C equipment by the GA community, this population is assumed to start in 1980 when the MSAW capability could become available. Thus, the estimated total population of Mode C equipped traffic at ARTS II sites will range from 40 percent in 1980 to 95 percent in 1995. These populations include air carrier, military, general aviation, and air taxi aircraft.

The traffic growth factors are taken from the FAA Terminal Forecasts (Reference 3), and overall traffic growth data are used. The preventable subset of accidents is assumed to grow in proportion to total traffic. All growth factors are linearly interpolated. (See Tables 6 and 7 for aircraft equipment and forecast data.)

Thus, the present value benefits due to MSAW implementation become, for a 15 year life cycle and 10 percent discount rate (assuming benefits begin to accrue in 1980):

$$PVB(MSAW) = \sum_{N=4}^{18} \frac{\$2.36 \text{ million} \times TGF^{*} \times \text{Mode C Factor}}{1.1^{N}}$$

$$= \$12.67 \text{ million}$$

The table on Page 3-12 shows the detailed calculations.

*Target Growth Factor

TABLE 6

ESTIMATED TRANSPONDER BEACON POPULATION
AMONG GENERAL AVIATION AIRCRAFT*
AT ARTS II SITES SURVEYED
(Annual Basis 1974)

	%GA	'74 Annual GA Traffic	Beacon Equipped		Beacon w/Mode C	
			est. %	approx. number	est. %	approx. number
Richmond, VA	56	98,500	60-70	59,000 to 69,000	15-20	15,000 to 20,000
Colorado Spgs., CO	59	115,600	80	92,000	10	11,6000
Knoxville, TN	73	99,300	70	69,500	10-20	10,000 to 20,000
Charleston, SC	35	48,300	70-75	34,000 to 36,000	25-30	12,000 to 15,000
Reno, NV	73	106,500	80	85,300	5-10	5,300 to 10,600
Wilkes-Barre, PA in 1975	60	51,600	60	31,000	5	2,600

*It is assumed that all Air Carrier and Military Aircraft at ARTS II sites have Beacon with Mode C.

Table 7

FAA FORECASTS OF TRANSPONDER
AND MODE C USAGE IN
GENERAL AVIATION

Year	Fleet	Beacon	Percent	Mode C	Percent
1974	164,900	119,453	72.4	9,317	5.6
1977	181,200	136,000	75.	20,000	11.
1981	203,000	162,400	80.	30,450	15.
1986	245,600	196,480	85.	98,240	40.
1995	417,300	375,570	95.	375,570	95.

YEAR	MODE C FACTOR	TGF (TRAFFIC GROWTH FACTOR)	DISCOUNT FACTOR	PRESENT VALUE BENEFITS ($ millions)
1980	.40	1.1125	.751	.789
1981	.44	1.15	.683	.816
1982	.48	1.188	.621	.836
1983	.52	1.225	.564	.848
1984	.56	1.263	.513	.856
1985	.60	1.3	.467	.860
1986	.64	1.356	.424	.868
1987	.68	1.412	.386	.875
1988	.72	1.468	.350	.873
1989	.76	1.524	.319	.872
1990	.80	1.58	.290	.865
1991	.84	1.636	.263	.853
1992	.88	1.692	.289	.840
1993	.92	1.748	.218	.827
1994	.94	1.804	.198	.792
			TOTAL	$12.67 million

3.2.3 Conflict Alert Benefits

This category of benefits results from the prevention of midair collisions. As can be seen from Table 5, there were two fatal midair collisions at ARTS II sites during the six year period studied. These two accidents resulted in the following quantifiable losses:

5 fatalities x $300,000 = $1.5 million

3 GA aircraft x $50,000 = $ .15 million

Total Loss (6 years) = $1.65 million

Loss per year = $1.65 million/6 = $.275 million

In order to achieve tolerable Conflict Alert warning rates, it is necessary to have altitude data as well as radar surveillance data. Hence, this analysis assumes Conflict Alert is effective in proportion to the Mode C population. Thus, applying the same Mode C, traffic growth, and discount factors previously stated yields the following:

YEAR	MODE C FACTOR	TGF (TRAFFIC GROWTH FACTOR)	DISCOUNT FACTOR	PRESENT VALUE BENEFITS ($ millions)
1980	.40	1.1125	.751	.092
1981	.44	1.15	.683	.095
1982	.48	1.188	.621	.097
1983	.52	1.225	.564	.099
1984	.56	1.263	.513	.100
1985	.60	1.3	.467	.100
1986	.64	1.356	.424	.101
1987	.68	1.412	.386	.102
1988	.72	1.468	.350	.102
1989	.76	1.524	.319	.102
1990	.80	1.58	.290	.101
1991	.84	1.636	.263	.099
1992	.88	1.692	.289	.098
1993	.92	1.748	.218	.096
1994	.94	1.804	.198	.092
			TOTAL	$1.48 million

Thus, the total present value benefit due to conflict alert is $1.48 million. Since this number is relatively low, there is little point in speculating about how effective the preventive mechanisms will actually be.

Alth gh the historical analysis indicates relatively low quantifiable benefits from preventing midair collisions, there have been many instances of near midair collisions at the ARTS II sites which reflect the ever-present risk of a costly midair. Air carrier aircraft were involved in approximately 30 percent of such incidents (Reference 4) at all ARTS terminals. This risk will inevitably grow as the airspace densities increase. Since the number of accidents considered in the sample is so low, it is clear that a single air carrier/GA midair could totally dominate the analysis. While no attempt was made to estimate this risk, any system which reduces such risk is clearly of value. The conflict alert function will aid the controller in maintaining the FAA's excellent safety record. As greater reliance on automation equipment occurs in the TRACON, the conflict alert capability will be required to monitor the airspace and alert the controller to potential midair hazards.

3.2.4 Potential IFR/VFR Midairs

A MITRE Study (Reference 4) had previously concluded that IFR/VFR midairs at busy terminal areas represented the prime civil aviation problem to be solved. Since most ARTS II facilities handle a comparatively small percentage of air carrier aircraft and a high percentage of general aviation aircraft, the potential for avoiding IFR/VFR midairs at ARTS II facilities is important, even though no such accident occurred during the six year period analyzed for this study. The MITRE study further concluded that midair collisions at all controlled airports were non-linearly related to operations. That is, when the operations doubled, the number of collisions more than doubled. It may be inferred from this that a higher incidence of midair collisions could occur during peak traffic periods. Thus, as ARTS II sites grow, the risk of an IFR/VFR midair is bound to increase.

Another MITRE study (Reference 5) indicated that the rate of midair collisions is only about 1.4 percent of all airborne accidents and only about 3 percent of the aircraft accidents under normal operating conditions near airports and during the landing phase of flight. Thus, collision with the ground or other obstacles near the airport is likely to remain the predominant hazard at ARTS II sites for the foreseeable future.

3.3 PRODUCTIVITY BENEFITS

Labor costs related to operating and maintaining the National Airspace System comprise a predominant fraction of the current FAA budget, and a large fraction of this labor is required for air traffic control functions. Thus, programs which can significantly improve controller productivity in ATC system operations are good candidates for the necessary capital investment. The ARTS II Enhancement program can offer some benefits in productivity by decreasing the operations staff that would otherwise be required to handle forecast traffic growth.

In assessing the impact of forecast traffic growth on total operations cost, it was necessary to isolate the impact of specific Enhancements on Air Traffic Service staffing at ARTS II installations. It was concluded that while workload at individual positions may be reduced by Enhancements, it is in many cases infeasible to totally eliminate positions. Airspace structure and the small number of positions did not readily permit combination or consolidation. However, with significant traffic growth, it may be possible to take advantage of the increased productivity through the ability to handle more traffic without increasing the existing workforce. (The only exception to this general finding was the possibility of eliminating flight data positions and transferring the remaining few functions to clearance delivery, hand-off and/or coordinator positions through the use of TIPS.)

Staffing requirements are determined by the 90th percentile peak operations rates. Even if peak operations rates occur only during a brief period of each shift, it is necessary to maintain that staffing level for the entire shift. In the analysis, the capability of the system to handle peak operations rates was the criterion for staffing.

3.3.1 Analysis Methodology

Six sites scheduled to receive ARTS II Systems were selected to represent high, medium, and low density sites. These sites, which represent the spectrum of ARTS II terminals, provided the basis for extrapolating productivity improvements to 71 ARTS II sites. The initial study task collected published traffic and statistical data on each site. Then, visits were made to each site except Wilkes-Barre, which had been analyzed during an earlier study (Reference 6). In each case, tower chiefs, shift supervisors, and training officers (where used) were interviewed. Traffic volumes, traffic peaking, airspace structure, operating procedures, staffing, shift manning practices, training and expected ARTS II implementation schedules were discussed and documented. ARTS II

Enhancement possibilities were discussed and comments were obtained regarding expected utility and benefits in the context of future operations.

Following the site visits, an analysis developed productivity, terminal delays, and staffing in the ARTS II context. Productivity was estimated in terms of current sustained workloads, present position staffing and forecasts of future traffic. Current workloads were documented using the SPOTS technique developed during the ARTS III Cost/Benefits Study (Reference 6). SPOTS means Sustained POsition Traffic Estimates for Staffing and is based upon monthly or annual traffic rate information for a two-shift period during the 24-hour day. The third shift is ordinarily deleted due to its very low traffic density.

Workloads were computed for arrival, departure, and supporting positions, as well as local, ground, and other tower cab positions. The busiest positions of each type in ARTS II facilities were then compared with workloads for comparable positions at ARTS III sites at Atlanta, Denver, and Norfolk (Table 8). The ARTS III workload data was developed in Reference 6. These comparisons indicate that sustained workloads are not especially high for ARTS II facilities (vis-a-vis ARTS III sites). However, two factors significantly impact this finding: First, the variability of traffic, and second, the short duration of heavy traffic periods experienced at ARTS II sites. Traffic variability at ARTS II sites can markedly affect controller workloads. ARTS II sites experience peak traffic

Table 8

COMPARISON OF AVERAGE CONTROLLER LOADING
AT
BUSIEST POSITION OF EACH TYPE

Type Controller Position	Atlanta	Denver	Norfolk	Wilkes-Barre	Charleston	Richmond	Colorado Springs	Knoxville	Reno
TAR/FEEDER	38/hr.	24/hr.	22/hr.		AR+DR 22/hr.				
AR (Final or combined ARs)	38/hr.	48/hr.	22/hr.	10.4/ hr.	PAR 4/hr.	16/hr.	10/hr.	AR+DR 20/hr.	5/hr.
FLT Data	36/hr.	37/hr	n20/hr.	AR+DR 10.4/ hr.	23/hr.	25/hr.	11/hr.	Hand off 12/hr.	
Local	68/hr.	100/ hr.	59/hr.	16.9/ hr.LC+GC	23/hr.	47/hr.	40/hr.	36/hr.	42/hr.
Ground	66/hr.	n96/ hr.	54/hr.		20/hr.	35/hr.	29/hr.	30/hr.	23/hr.
DR	32/hr.	18/hr.	17/hr.			12.1/ hr.	19/hr.		5/hr.
Satellite	13/hr.	(in DR)							
#Clrs/2 shifts	43	30	28	6	18	16	20	18	12
Air Traffic Mix AC/GA/Mil.	85%/ 11%/ 0.2%	50%/ 46%/ 0.3%	28%/ 67%/ 5%	6%/ 60%/ 4%	14%/ 35%/ 50%	16%/ 56%/ 21%	11%/ 59%/ 30%	22%/ 73%/ 4%	18%/ 73%/ 6%
$\overline{X}$ AC/day $\overline{X}$ traffic/day	1210/ day 1421	548/ day 1099	106/ day 640	16/ day	52/ day	69/ day	50/ day	77/ day	68/ day
$\overline{X}$: Peak day ratio $+ 1\sigma$	1.2 $\pm$8%	1.3 $\pm$15%	1.8 $\pm$32%	1.92 $\pm$36%	1.73 $\pm$31%	1.89 $\pm$32%	2.03 $\pm$34%	1.75 $\pm$29%	2.76 $\pm$33%

periods 1.6 to 4.5 times their average traffic. By comparison, the larger ARTS III sites rarely experience peaks more than 1.2 times their average traffic.

For example, assume that the average controller position workload (two shifts) at an ARTS II TRACON was 12 operations per hour. A nominal hourly peaking factor of 1.5 brings a peak hour rate to 18. If peak day traffic also occurred during this period, the controller workload may exceed 40 operations per hour; this is higher than the sustained rate at most ARTS III facilities. This is particularly important if highly structured airspace is essential to enable ARTS III controllers to sustain such traffic rates. For the most part, ARTS II facilities have not found it necessary or desirable to implement a high degree of airspace structuring. Thus, what appears to be a relatively light workload for the ARTS II controller does peak on occasion to a relatively high demand. This peaking can be especially taxing due to the mixture of aircraft performance and less structured airspace.

In order to assess productivity impacts of the Enhancements, the workloads for each position were projected to 1981 traffic levels. In most cases, it appeared that the current staff, equipped with the basic ARTS II, could handle the increase. The workloads are generally below ARTS III workloads for comparable positions. A sample of the form in which the data was generated and analyzed is presented for Colorado Springs (Table 9), Knoxville (Table 10), and Charleston (Table 11). Table 12 shows the current staffing at these sites.

TABLE 9

SPOTS Data for Colorado Springs, CO

		1974			1981 PROJECTED		
TOTALS 2 SHIFTS		AVG	$+1\sigma$	Peak	AVG	$+1\sigma$	Peak
AR North	2	10/hr	13/hr	20/hr	15/hr	20/hr	30/hr
AR South	2	10/hr	13/hr	20/hr	15/hr	20/hr	30/hr
Flight Data (Coor AR)	2	11/hr	14/hr	22/hr	17/hr	22/hr	34/hr
Supv IFR	2	40/hr	54/hr	81/hr	60/hr	81/hr	123/hr
Local Clr	2	40/hr	54/hr	81/hr	60/hr	81/hr	123/hr
Gnd Clr	2	29/hr	39/hr	59/hr	44/hr	59/hr	89/hr
Supv Cab	2	40/hr	54/hr	81/hr	60/hr	81/hr	123/hr
Coor Cab Flt Data Cab	2	14/hr	19/hr	28/hr	21/hr	28/hr	32/hr
Coor IFR	2	40/hr	54/hr	81/hr	60/hr	81/hr	123/hr
DR Clr	2	19/hr	25/hr	39/hr	29/hr	38/hr	58/hr

Traffic Mix = 11% AC, 59% GA, 30% MIL

TABLE 10

SPOTS Data for Knoxville, TN

		1974			1981 PROJECTED		
TOTALS 2 SHIFTS		AVG	$+1\sigma$	Peak	AVG	$+1\sigma$	Peak
AR-DR West	2	20.0/hr	25.8/hr	35.0/hr	33.4/hr	43.1/hr	58.45/hr
AR-DR East	2	20.0/hr	25.8/hr	35.0/hr	33.4/hr	43.1/hr	58.45/hr
Supv IFR	2	40.0/hr	51.6/hr	70.0/hr	66.8/hr	86.2/hr	116.9/hr
Local Clr	2	35.8/hr	46.2/hr	62.6/hr	54.1/hr	69.8/hr	94.7/hr
Gnd Clr	2	30.5/hr	39.3/hr	53.4/hr	46.1/hr	54.5/hr	80.7/hr
Coor Cab Flt Data Cab	2	11.1/hr	14.3/hr	19.4/hr	16.8/hr	21.6/hr	29.3/hr
Coor IFR	2	40.0/hr	51.6/hr	70.0/hr	66.8/hr	86.2/hr	116.9/hr
Clr/HO_W	2	12.0/hr	15.5/hr	21.0/hr	20.0/hr	25.8/hr	35.0/hr
Clr/HO_E	2	12.0/hr	15.5/hr	21.0/hr	20.0/hr	25.8/hr	35.0/hr

Traffic Mix = 22% AC, 73% GA, 4% MIL 1974 basis E:W=50:50

TABLE 11

SPOTS Data for Charleston, SC

		1974			1981 PROJECTED		
TOTALS 2 SHIFTS		AVG	+1σ	Peak	AVG	+1σ	Peak
AR-DR West	2	21.9/hr	28.8/hr	37.9/hr	33.1/hr	43.7/hr	57.2/hr
AR-DR East	2	11.8/hr	15.5/hr	20.4/hr	17.8/hr	23.5/hr	30.8/hr
PAR (Final)	2	3.7/hr	4.9/hr	6.4/hr	5.8/hr	7.6/hr	10.0/hr
Flight Data (Coor AR)	2	23.3/hr	30.6/hr	40.3/hr	35.2/hr	46.5/hr	60.9/hr
Supv IFR	2	33.7/hr	44.3/hr	58.3/hr	50.9/hr	67.2/hr	88.0/hr
Local Clr	2	22.5/hr	29.6/hr	38.9/hr	34.0/hr	44.9/hr	58.8/hr
Gnd Clr	2	19.9/hr	26.3/hr	34.4/hr	30.0/hr	39.7/hr	52.0/hr
Coor Cab Flt Data Cab	2	10.0/hr	13.2/hr	17.3/hr	15.1/hr	19.9/hr	26.1/hr
Coor IFR	2	33.7/hr	44.3/hr	58.3/hr	50.9/hr	67.2/hr	88.0/hr
Stg III DR Clr + Overflts	2	7.7/hr	10.1/hr	13.3/hr	11.6/hr	15.3/hr	20.0/hr

Traffic Mix = 13.5% AC, 34.5% GA, 50.5% MIL

Table 12

ATC STAFFING AT ARTS II SITES SURVEYED

	Total Staff	** FPL	Developmental (not certified FPL)	Trainees	Day/Evening Shift Staffing	Flt Data Position Staffing 2 shifts
Richmond, VA	32	21	7	4	8/8	2
Colorado Springs, CO	43	23	9	0	10/10	2* (coord.)
Knoxville, TN	32	28	3	0	9/9	4* (Hand off)
Charleston, SC	52	30	11	0	10/10	4
Reno, NV	28	22	0	0	6/6	6* (AR, DR or Coord)
Wilkes-Barre, PA (in 1975)	21	13	2	2	4/4	2* (coord.)

*Flight data distribution shared with other duties (i.e., coordinator or handoff)

**FPL - Full Proficiency Level Controllers

From AT Manpower Systems Branch data: ARTS II sites, system-wide have an average of 24 controllers (range 8 to 47), with an average of 13 FPL (range 3-30) and an average grade 9 of step 4, and an average of 6 developmental and trainee controllers (range 0-13).

Due to the difficulty of eliminating any one position in the relatively small ARTS II staff, it was concluded that potential productivity gains would be difficult to realize for the projected traffic. Those Enhancements which directly assist the radar controller, such as Beacon Tracking and Conflict Alert, are unlikely to have any observable impact on staffing. There simply is no portion of his current activity which can be significantly reduced by these functions. Their principal benefit is safety, as analyzed in the preceding section.

The one exception to achieving staff reductions is the Terminal Information Processing System. The flight data positions could be eliminated entirely when not combined with other positions. The productivity gains from automated flight data handling are not credited to ARTS II Enhancements since the Terminal Information Processing System is being developed under a separate program.

The principal productivity gain is due to reduced on-the-job training time required to certify for the radar positions. The productivity benefits which can be realized from the use of a simulator are calculated in Section 3.3.3.

3.3.2 Delay Benefits

Delay information collected from facilities visited indicated no appreciable annual delay. A previous study had determined that where the percentage of air carrier traffic was less than 50 percent, sites did not routinely experience significant flight delays. None of the facilities that were visited in this study had more than 33 percent air carrier traffic. The busiest ARTS II sites handle from 5 to 15 percent air carrier traffic, from 0 to 50 percent military traffic, and the remainder general aviation. It was also determined that significant delays were not being experienced either by the general aviation community or military aviation. Thus, no significant delays were observed for any traffic category at current or projected activity.

3.3.3 Radar Training Simulator Benefits

An analysis of the ARTS II sites surveyed indicated that reductions in the time required for radar training and certification of developmental controllers to full proficiency level are possible by using a radar training simulator. ARTS II facilities spend a substantial amount of time training developmental controllers. In addition, due to the nature of the traffic situation, there are four to six hours each day during which light traffic would permit devoting extensive periods of time to radar training for developmental controllers using the "guaranteed" traffic provided by simulation, without interference to normal traffic.

A radar training simulator could permit systematic presentation of a wide variety of traffic situations of varying difficulty to developmental controllers without risk to live traffic. The simulator would be of value both in radar and non-radar training. In non-radar training, the simulator could provide immediate graphic illustration of the effects of non-radar instructions given by developmental controllers and the opportunity to correct errors immediately. In addition, a radar training simulator could present various emergency situations seldom encountered in live traffic.

The typical career path of an ARTS II developmental controller will include one year each in grades GS-7, 9, and 11. During this three year period, he will require an average of 341 hours (Reference 7, page 223) of on-the-job (OJT) instruction in radar training per year. (The exact number depends on the facility and the student.) During these OJT hours, he is under the direct supervision of an FPL controller and therefore, the developmental's time is non-productive in staffing active positions. Any acceleration of this OJT instruction will result in a direct savings in the developmental's salary which is expended on non-productive activity. In other words, the developmental becomes certified on the radar positions sooner and can operate those positions under general supervision only, without requiring the OJT instructor's time.

Although it is difficult to estimate the precise effect of a simulator on radar training savings, the estimates provided by training officers ranged from 25 percent to 50 percent reduction in OJT instruction (no reduction in classroom savings could be expected, with minimal reductions in non-radar training time). In order to provide a conservative estimate of simulator benefits, it is assumed here that the OJT instruction will be reduced by 25 percent before position certification.

The Whitten Amendment restriction requires the controller to spend at least one year in grade before promotion. This restriction will not allow significant acceleration in overall time to achieve FPL status. However, if the time required to qualify for the radar positions is reduced, there will be a savings in OJT instruction which, in effect, ties up two controllers per position.

Thus, the simulator would reduce the OJT radar instruction time by 85 hours (341 hours total x 25 percent savings) per year per developmental. The ARTS II facilities visited had an average of 5.33 developmentals each (Table 12). Thus, the total savings in OJT radar instruction per facility per year becomes 453 hours (=85 hours/developmental x 5.33 developmentals). This translates into a savings of approximately $3600 per facility per year, or $257,000 per year for all facilities involved.

Assuming the benefits begin to accrue in 1982, the Present Value Benefit becomes:

$$\text{PVB (Training)} = \sum_{N=6}^{20} \frac{.26}{1.1^N} = \$1.22 \text{ million}$$

The realization of these savings, which amount to a fraction of a man-year per facility, is possible through overall reductions in levels of recruiting. An Advanced Recruitment Model is used to calculate total new hires needed for each region. A major factor in projecting future manpower needs is the productivity of the developmentals as a function of their time in training. If productivity growth is accelerated by use of a simulator, and properly reflected in the model, then fewer developmentals would be necessary to perform the equivalent full proficiency level workload.

Radar simulators can also assist in accelerating the identification of trainees who will washout later in the training cycle. However, the use of a radar simulator for this purpose is best accomplished at the Academy. A major procurement is currently in process to provide a radar simulator training laboratory at Oklahoma City; one of the justifications for this procurement was that earlier washouts could be accomplished, thereby saving salaries of trainees and keeping the pipeline full of those who would ultimately qualify as controllers. No evidence has yet been collected to indicate that radar simulators will reduce the washout rate; but strong evidence does suggest that the washouts can be identified earlier in the training cycle. Since the Academy simulator will be available before the facility simulator, it is hoped that relatively few of those passing through the Academy screen will washout in the facilities. Those that do could undoubtedly be identified earlier with a radar simulator at the facility. A study (Reference 7) found that the cumulative washout rate in 1974 for the terminal option developmental was 38 percent. Any reduction in this rate, or accelerating the occurrence of the washouts at the Academy, will save salary costs.

The availability of a facility simulator could increase the maximum rate at which controllers can pass through the training process. This factor is relatively moot since the Whitten Amendment requires that controllers stay in grade for one year, and controllers at the GS-7, 9, 11 grades are allowed to train on and certify only for certain limited positions. It is clearly the case that the faster trainees could progress at a more rapid pace. A major cost of facility training is the time required by the direct supervision of an OJT instructor. Therefore, the optimum time for controller training is the shortest possible time which imparts the necessary skills to perform the job. If automation programs such as TIPS eliminate the less skilled positions such as flight data and clearance delivery, it is more important that the trainee progress more rapidly into the radar control positions since he will have no other useful tasks to be assigned to in the facility until he has certified on these more advanced positions. The larger number of positions for which a trainee is certified in a given facility, the greater flexibility the management staff has in assigning him to a productive function in a manner which is compatible with other staffing constraints. As long as the developmental is certified on enough positions to allow effective utilization of the entire staff, his total time in training is of little consequence, since he can be assigned productive tasks a larger fraction of the time.

Each level of facility has a maximum ratio of trainees to FPL controllers which can reasonably be accommodated without inefficient assignment of staff. As the trainee progresses through the certification process at a particular facility, he sequentially becomes qualified on progressively more difficult positions in the facility. As he becomes qualified on each position, he can operate that position under only general supervision just as an FPL controller would operate that position. The major obstacle presented by a large fraction of trainees on a facility staff is, other than the classroom training time of the instructor, the inability to flexibly assign available staff to cover all positions during all time periods. In other words, if one-third of a facility's staff is qualified to operate only flight data, clearance delivery, and ground control positions, it is extremely difficult for the facility management to assign and rotate the remaining two-thirds of the FPL controllers so as to cover the other positions during all the necessary time. Likewise, since the flight data and lower level positions must be covered, it also makes it difficult to rotate the trainees into other positions and provide OJT instruction while maintaining adequate assignments in the rest of the facility. The exact ratio of trainees to FPL controllers which can be accommodated is clearly a function of the level of facility and the distribution of positions.

3.4 OTHER BENEFITS

Two Enhancement functions offer identifiable, but unquantifiable, benefits for the efficient operation of the ARTS II facility. These benefits are briefly described in this section. They are not included in the analysis since quantifiable gains in safety or productivity could not be identified and measured.

The continuous data recording (CDR) Enhancement option is intended to provide historical records of the ARTS II terminal traffic environment. The CDR also provides data for administrative reports and a positive record of operational transactions in the event of safety related incidents. The primary interest in CDR by ARTS II tower chiefs and staffs is to provide an automated operations count which will provide greater accuracy and allow personnel who would otherwise count operations manually to spend time at more productive tasks.

As far as any improvements in productivity are concerned, the CDR capability would ease the workload at each position by some small amount, but would not allow any consolidation or reduction in staff. The assurance that operations counts were accurate would assist in accurate classification of facilities. The CDR function would not impact safety.

Another non-quantifiable benefit is available from primary radar tracking. Since the predominant fraction of all aircraft will be beacon equipped by the time this Enhancement would become available, there is little, if any, quantifiable improvement measurable in being able to track non-beacon targets. Since midair collision rates are quite low now (without ARTS II), the added refinement of radar tracking would be insignificant. Of course, MSAW is ineffective without MODE C, and would be unaffected by this situation. The one identifiable benefit is the overall improvement in track quality. With radar plus beacon returns available, a more accurate track can be computed and fewer tracks lost due to beacon shielding, etc. At the lower traffic densities of the ARTS II sites, this is not anticipated to measurably affect safety.

In addition to benefits discussed above, there are non-quantifiable benefits which accrue to the radar training simulator by permitting regular training on irregular (e.g., emergency) events. Such events require immediate and appropriate control responses and the simulator would permit systematic development and refreshment of such skills. Since real circumstances of such events are rare, the FPL controller would be better equipped should they occur.

4.0 COSTS

4.1 INTRODUCTION

The ARTS II System will be installed at 71 operational sites. This program represents a substantial investment in automation equipment and provides a base upon which the Enhancements can be built. Since these costs have been committed, they are not included in the cost/benefits analysis of the Enhancements. In addition to the basic ARTS II, a research and development effort must be undertaken, as well as an F & E program of field modifications to install the Enhancement hardware and software.

In projecting the additional costs for research and development (R&D), facilities and equipment (F&E), and operations and maintenance (O&M) budgets, previous experience with existing ARTS III hardware has been considered. Part of the cost presented here is from FAA sources while the remainder was estimated.

The potential cost reductions for operating the system, due to increased controller productivity, are treated as a benefit. A previous section (3.3) calculated these productivity benefits in terms of operating cost reductions made possible by the radar training simulator. This section calculates the present value cost of the projected R&D, F&E, maintenance, and site expansion. The costs and benefits are derived for 71 candidate operational sites.

All calculations assume the R&D program is successful. A sensitivity analysis in Section 5.3 examines the impact of

R&D cost and time overruns. Differences in technical risk were considered only in terms of delays in R&D or in increased program costs.

4.2 R & D COSTS

A preliminary acquisition paper prepared by the FAA for the ARTS II Enhancement Program (E&D Subprogram 142-175) was used to assist in estimating R&D costs. The several R&D programs were costed at $2.4 million distributed over a three year period; FY 78-80. These costs include interfaces with TIPS and DABS.*

4.3 F & E COSTS

The total costs for procuring and installing the Enhancements are shown for a typical site in Table 13. These costs would not be incurred simultaneously, and are assumed to be distributed over three years and to lag the R&D costs by two years.

Thus, the schedule** for incurring the F&E costs is as follows:

FY 1980	$6.67 million
FY 1981	$ .852 million
FY 1982	$3.408 million

* No F&E costs for DABS or TIPS interface were included since no decision to deploy DABS or TIPS at ARTS II sites has been made and no benefits were taken for these programs.

**A deferral analysis (Section 5.4) considers a two-year delay in program implementation.

TABLE 13

ESTIMATED ARTS II F & E COSTS

FUNCTION	EQUIPMENT	COST/SITE (000)	INSTALLATION AND SPARES (000)
1. Beacon Tracking	ONE CPU + 32K Memory	$40	$8
2. MSAW			
3. Conflict Alert			
4. Data Recording	Tape Drive	$30	$6
5. TIPS Interface	Not Included	--	--
6. Training Simulator	Pilot Consoles + 16K Memory	$10	$2
7. Primary Radar Tracking	Digitizer + 16K Memory	$40	$8
8. DABS Interface	Not Included	--	--
9. Site Expansion	---	$10	--
TOTAL		$130	$24

TOTAL COST - 71 Sites = $10.93 million

4.4 MAINTENANCE COSTS

Incremental maintenance costs also must be included for the additional hardware that would be installed if the Enhancements were procured. The cost of the additional maintenance was estimated from the most recent Airway Facilities Maintenance Staffing Criteria and Standards (1380.9) (Reference 8). This order utilizes a point count system for determining the category of a particular facility. Each kind of equipment has associated with it a specified number of points. The points are accumulated linearly for any particular configuration, and the total point count then is used to determine into which class the installation falls. All candidate ARTS II sites require maintenance coverage for the basic equipment. What is relevant for this analysis is the additional staff that would be required because of the increased point count accumulated from the new Enhancement equipments.

The point counts associated with the ARTS II type facility are summarized in Table 14.

The listing in Table 15 gives examples of the point counts associated with the ARTS II Enhancement type of equipments. The ARTS III data are used since ARTS II equipment has not been added to 1380.9. Since the point count of the added Enhancement hardware does not bring the total beyond the minimum count for a Class N facility, no additional maintenance costs should accrue by adding the Enhancements.

TABLE 14

COSTS OF MAINTENANCE

- Based upon Airway Facilities Maintenance Staffing Criteria and Standards (1380.9), it is estimated that maintenance staffing necessary for ARTS II Enhancements will not exceed the threshold manning for a Class N facility.

- Class N facilities range in automation point count from 11,441 to 13,520 and call for 5.91 Man-Years of maintenance (i.e., one man per watch as a minimum).

- The estimated point count for ARTS II Enhancements is as follows:

32K Memory	600
32K Memory	600
Radar Data Acquisition System	500
System Configuration Control Unit	150
Memory Multiplexer	310
Processor Cabinet	100
CPU (IOM + DPO)	620
16K Memory	300
Continuous Record Tape Unit	450
Software Maintenance (ARTS III)	1,500
Enhancement Total	5,130

- The point count for the basic ARTS II System must exceed 8240 automation points before any additional maintenance support is required for ARTS II Enhancements. The ARTS II System is not expected to exceed that point count.

TABLE 15

Maintenance Staffing for ARTS Facilities

Point Count	Class	Man-Years
11,441 - 13,520	N	5.91
13,521 - 15,600	O	6.70
15,601 - 17,680	P	7.83
17,681 - 19,760	Q	8.57
19,761 - 21,840	R	9.52
21,841 - 23,920	S	10.57
23,921 - 26,000	T	12.35
26,001 - 28,080	U	13.87
28,081 - 30,160	V	15.15
30,161 - 32,240	W	16.00
32,241 - 34,320	X	17.00
34,321 - 36,400	Y	18.00
36,401 - 38,380	Z	19.00
38,381 - 40,560	1	20.00
40,561 - 42,640	2	21.00
42,641 - 44,720	3	22.00
44,721 - 46,800	4	23.00
46,801 - 48,880	5	24.00
48,881 - 50,960	6	25.00
50,961 - 53,040	7	26.00
53,041 - 55,120	8	27.00
55,121 - 57,200	9	28.00

4.5 PRESENT VALUE LIFE CYCLE COSTS

The next step in the cost analysis is to calculate a present value cost for the entire Enhancement Program over the equipment life cycle. In accordance with OMB Circular A-94, revised 27 March 1972, the present value cost is equal to (using a 10 percent discount factor):

$$\text{Present Value Cost} = \sum_{N} \frac{(\text{Year N Cost})}{1.1^N}$$

Table 16 summarizes this calculation. The R&D and F&E costs are broken out in the table. Thus, the total present value costs of the ARTS II Enhancements described in Table 13 are $9.7 million.

TABLE 16

Present Value ARTS II Enhancement Costs

($ Millions)

FY	Discount Factor	R&D	F&E	Present Value Cost
78	.909	.8		.727
79	.826	.8		.661
80	.751	.8	6.67	5.610
81	.683		.85	.581
82	.621		3.41	2.118
				MILLION

TOTAL PRESENT VALUE COST = $9.70 MILLION

5.0 RESULTS

5.1 INTRODUCTION

This section summarizes and graphically presents the final benefits and cost calculations. In addition, a sensitivity analysis is provided in order that the impact of changes in the basic parameters can be assessed. A deferral analysis calculates the impact on present value benefits and costs if the entire Enhancement program is delayed one or two years.

5.2 MAJOR RESULTS

In each category of benefits, the rate of accrual varies depending on the time the capability becomes available and the dependence of the benefit accumulation on traffic growth factors. Table 17 summarizes the accumulation of benefits to 15 and 20 years, and Figure 3 presents the results graphically. These results are for the "base case"; variations on the base case assumptions are treated in the following sections. The quantifiable sources of benefits derive from safety improvements and controller productivity gains. Safety related benefits grow in proportion to traffic growth and other factors such as the prevalence of altitude encoders in the fleet. Productivity gains are, within a broad range of traffic growth, relatively independent of traffic counts for the ARTS II facility.

5.3 SENSITIVITY ANALYSES

The calculations which produced the benefits/cost ratio presented in Sections 3 and 4 involved several assumptions which are

TABLE 17

CUMULATIVE PRESENT VALUE BENEFITS AND COSTS - ARTS II ENHANCEMENTS

YEAR	SAFETY BENEFITS ($ million)	PRODUCTIVITY BENEFITS ($ million)	CUMULATIVE PVB ($ million)	CUMULATIVE COST ($ million)
1977	0	0	0	0
1978	0	0	0	.73
1979	0	0	0	1.39
1980	.88	0	.88	7.00
1981	.91	0	1.79	7.58
1982	.93	.15	2.87	9.70
1983	.95	.13	3.95	
1984	.96	.12	5.03	
1985	.96	.11	6.10	
1986	.97	.10	7.17	
1987	.98	.09	8.24	
1988	.98	.08	9.3	
1989	.97	.08	10.35	
1990	.97	.07	11.39	
1991	.95	.06	12.40	
1992	.94	.06	13.40	
1993	.92	.05	14.37	
1994	.89	.05	15.31	
1995	.85	.04	16.20	
1996	.81	.04	17.05	

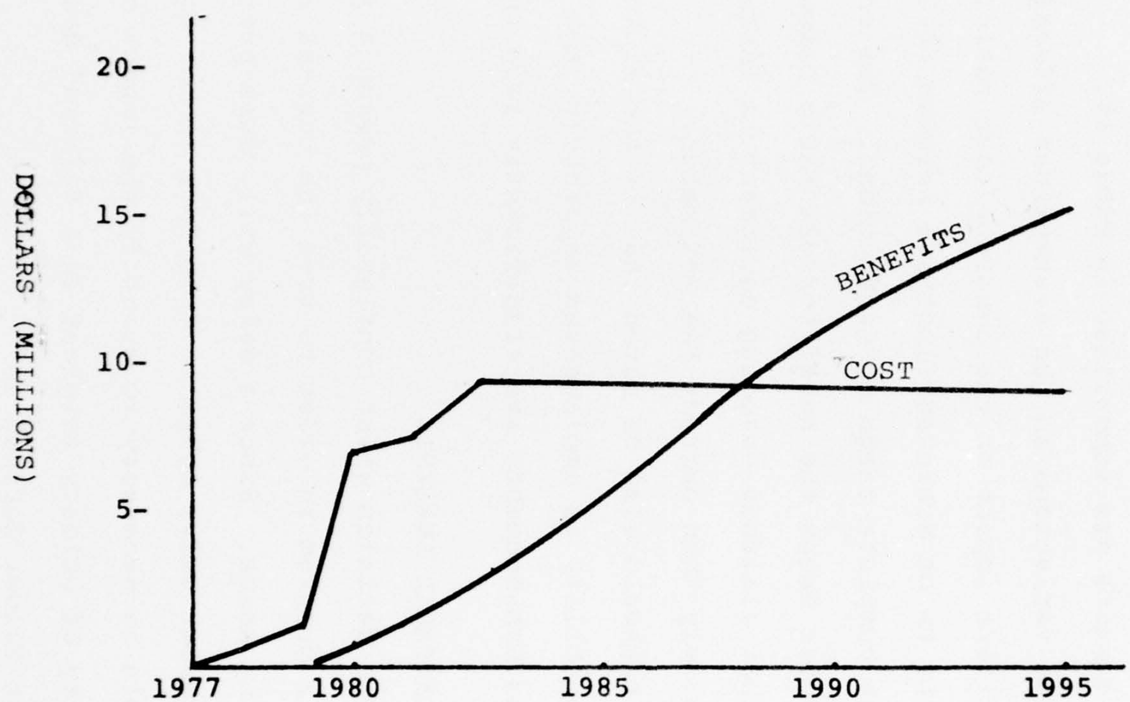

Figure 3. Cumulative Present Value Benefits and Costs - ARTS II Enhancements

subject to uncertainties. In general, these uncertainties do not significantly alter the basic conclusions of the study. Results of several calculations are presented here which determine the sensitivity of benefits and costs to the more significant assumptions. These results are summarized in Table 18.

The variations in the assumptions affecting benefits have significant impact on the benefits/cost ratio. The present value benefits to be achieved fluctuate between $8.3 and $19.4 million for the complete range of assumptions. The only sensitivity variation which drops the benefits/cost ratio below 1.0 is the assumption that altitude encoding equipment is installed in the GA fleet more slowly than current FAA estimates.

It should also be noted that if the Minimum Safe Altitude Warning capability is implemented separately, the benefits of the remaining Enhancements are significantly less than the costs.

5.4 DEFERRAL ANALYSIS

One decision which continually presents itself is whether to delay a program in order to free the current resources for more pressing needs. Since a delay will cause present value benefits and present value costs to drop (due to the discount factor), an analysis is necessary to quantify the impact of a delay. The quantity of primary interest in a deferral decision is the Net Present Value, defined as:

Net Present Value (NPV) = Present Value Benefit (PVB) -- Present Value Cost (PVC)

TABLE 18

RESULTS OF SENSITIVITY CALCULATIONS

PARAMETER CHANGE	PVB ($ million)	PVC ($ million)	PVB/PVC
Base Case	15.4	9.7	1.6
Traffic Growth + 25%	18.95	9.7	2.0
Traffic Growth - 25%	11.85	9.7	1.2
R & D Cost Doubles	15.4	11.8	1.3
20-Year Life Cycle	19.4	9.7	2.0
2-Year Program Deferral	12.7	8.0	1.6
Altitude Encoders Implemented 50% slower	8.3	9.7	.9
"Best" Case	19.4	8.0	2.4
"Worst" Case	8.3	11.8	.7

The change in NPV with program delay is a direct measure of the resulting loss (or gain). This section calculates the change in NPV for a one and two-year delay in continuing the ARTS Enhancement program.

This change in NPV (ΔNPV) is calculated from the following equation:

$$\Delta NPV = NPV_o - NPV_n$$

where

$$NPV_o = PVB_o - PVC_o \quad \text{and}$$

$$NPV_n = PVB_n - PVC_n.$$

The subscript in the above equations refers to the number of years the program is deferred.

If the entire program is deferred two years, then the discount factors applied, as required by the OMB guidelines, result in a reduction in present value benefits and present value costs. The net present value, which is a direct measure of the value of the program, also changes. In summary, the two year deferral results in a reduction of approximately $1.0 million in the net present value of the ARTS II Enhancement program. In other words, each day's delay in making a decision to implement reduces the NPV by about $1,400.

Assuming a 10% discount rate, then

$$PVB_n = PVB_o/1.1^n$$

and hence, if all benefits and costs are delayed, the total reduction in benefits or costs for one year is 9.1% and the total reduction for two years is 17.4%. For the base case of the Enhancements, then, the following results are obtained:

	BASE CASE	ONE YEAR DEFERRAL	TWO YEAR DEFERRAL
BENEFITS	$15.4 million	$14.0 million	$12.7 million
COSTS	$ 9.7 million	$ 8.8 million	$ 8.0 million
NET PRESENT VALUE	$ 5.7 million	$ 5.2 million	$ 4.7 million
BENEFITS/COSTS	1.6	1.6	1.6

5.5 REDUCED DEPLOYMENT

The candidate ARTS II Sites (Table 4) have annual operations which fall in a rather narrow band; most in the 100,000 - 200,000 per year range. Therefore, those safety benefits which are related to traffic do not vary widely over the range of sites. The basic conclusion regarding the cost-effectiveness of MSAW and CA holds at the lowest level facility. The other (non-safety related) Enhancements contribute primarily to productivity gains. However, the productivity benefits do not exceed the costs even at the largest ARTS II candidate sites.

5.6 MSAW AND CA BENEFITS/COST

Based on the preceeding analysis, it is clear that the safety related functions provide the most benefits and cost the least. In this section, the Benefit/Cost ratio is computed for MSAW and CA only. Since Beacon Tracking is also required for these functions, the Package A R&D costs must be incurred. Thus, the present value cost (PVC) of MSAW and CA is:

R & D - $.8 million in 1978; PVC = $.66 million

F & E - $3.41 million in 1980; PVC=$2.33 million

Total PVC of MSAW & CA= $2.99 million

Total PVB of MSAW & CA (Table 1) = $14.2 million

PVB/PVC = 4.8

Because of this high benefit/cost ratio, the development and implementation of MSAW and CA should occur at the earliest possible time. All other ARTS II Enhancements can be deferred and reevaluated at a later date.

6.0 CONCLUSIONS

6.1 The ARTS II Enhancement Program, upon implementation, will produce a present value benefits/cost ratio of 1.6.

6.2 Safety-related benefits would be $14 million for a 15-year equipment life. These benefits derive predominantly from the MSAW function which helps prevent altitude management accidents in the terminal environment. The conflict alert function which supports the controller in achieving aircraft separation has low quantifiable benefits (under $2 million) since the historical frequency of such accidents in the candidate Enhancement sites is so low. Therefore, over 82 percent of the benefits are achieved with MSAW. If MSAW and CA are implemented separately (Beacon Tracking must be included), the benefit/cost ratio equals 4.8.

6.3 Present value costs of the ARTS II Enhancements at 71 sites, including development, equipment, maintenance, and site expansion, are expected to be approximately $9.7 million. All costs which have been appropriated and expended are excluded from this figure.

6.4 The major conclusions stated above were relatively insensitive to the variations in parameters included in the sensitivity analyses. Sensitivity analyses were performed for variations in traffic growth, program delays, increased R & D costs and a longer life cycle. The maximum variation in the benefits/cost ratio was .7 to 2.4. The major impact on the sensitivity analyses is reduced altitude encoder purchases by the GA community. This reduces MSAW effectiveness and, therefore, overall benefits, significantly.

6.5 This report is based on information available at early stages of ARTS II Enhancement developments. Further studies may be desired as the research and development progresses and more specific parameters and information are known.

6.6 A deferral analysis was performed to determine the impact of delaying the Enhancement program two years. This delay results in a reduction of the net present value of $1.0 million.

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