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U.S. Department
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**Research and
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Volpe Center Report

on

Advanced Automation System

Benefit-Cost Study

Final Report

October 25, 1993

Prepared for:

Committees on Appropriations
United States House of Representatives
United States Senate

Prepared by:

Research and Special Programs Administration
Volpe National Transportation Systems Center

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GLOSSARY

AAP	Advanced Automation Program
AAPO	AAP Office
AAS	Advanced Automation System
ACCC	Area Control Computer Complex
ACF	Area Control Facility
ACF-B	ACF Type B
ACN	(FAA) Engineering, Test and Evaluation Service
ACQ	(FAA) Office of Acquisition Policy and Oversight
ADS	Automated Dependent Surveillance
AERA	Advanced En Route ATC
AF	Airways Facilities
ANS	(FAA) NAS Transition & Implementation Service
AOR	(FAA) Operations Research Service
AOS	(FAA) Operations Support Service
APO	(FAA) Office of Aviation Policy and Plans
ARSR	Air Route Surveillance Radar
ARTCC	Air Route Traffic Control Center
ARTS	Automated Radar Terminal System
ARTSA	Automated Radar Terminal System Assembler
ASM	(FAA) Systems Maintenance Service
ASR	Airport Surveillance Radar
ASTA	Airport Surface Traffic Automation
AT	Air Traffic
ATA	Air Transport Association
ATC	Air Traffic Control
ATIS	Airport Tower Information System
ATOMS	Air Traffic Operations Management System
ATR	(FAA) Air Traffic Requirements Service
BCN	Backup Communications Network
BCP	Backup Control Processor
BRITE	Bright Radar Indicator Tower Equipment
CC	Common Console
CDC	Computer Display Channel
CGW	Communication Ring Gateway
CIP	Capital Investment Plan
CONUS	Continental United States
CP	Central Processor
CPU	Central Processor Unit
CTAS	Center-TRACON Automation System
DARC	Direct Access Radar Channel
D-BRITE	Digital Bright Radar Indicator Tower Equipment
DCC	Display Channel Complex
DCCR	DCC Replacement

DCP	Design Competition Phase
DDF	Development Demonstration Facility
DoD	Department of Defense
DOT	Department of Transportation
DRG	Data Receiver Group
EARTS	En Route ARTS
EDARC	Enhanced DARC
ETMS	Enhanced Traffic Management System
FAA	Federal Aviation Administration
FAAAC	FAA Aeronautical Center
FAALC	FAA Logistics Center
FAATC	FAA Technical Center
FAS	Full AERA Services
FDAD	Full Digital ARTS Display
FDEP	Flight Data Entry and Printout
FDIO	Flight Data Input/Output
FDIOC	FDIO Center
FDIOR	FDIO Remote
FL	Flight Level
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HCS	Host Computer System
IBM	International Business Machines Corporation
ICSS	Integrated Communications Switching System
IFR	Instrument Flight Rules
ISO	International Standards Organization
ISP	Interim Support Program
ISSS	Initial Sector Suite System
KSLOC	Thousands of Source Lines of Code
LCN	Local Communications Network
M&C	Monitor and Control
MBPS	Mega-Bits Per Second
MCF	Metroplex Control Facility
MDC	Main Display Controller
Metroplex	Metropolitan Complex
Mode-S	Mode-Select
MSRDP	Multi-Sensor Radar Data Processing
NADIN	National Airspace Data Interchange Network
NAS	National Airspace System
NRP	National Route Program
OMB	Office of Management and Budget
ORD	Operational Readiness Demonstration
PAM	Peripheral Adapter Module
PAMRI	Peripheral Adapter Module Replacement Item
PDC	Pre-Departure Clearance System
RAPCON	Radar Approach Control
R,E&D	Research, Engineering and Development

RGW	Radar Gateway
RISC	Reduced Instruction Set CPU
RMA	Reliability, Maintainability, and Availability
RMUX	Radar Multiplexor
RSPA	Research and Special Programs Administration
RWP	Radar Weather Processor
SAR	System Analysis Recording
SE	System Engineer
SEIC	System Engineering Integration Contractor
SRAP	Surveillance Radar Data Acquisition Processor
TAAS	Terminal Advanced Automation System
TATCA	Terminal Air Traffic Control Automation
TCCC	Tower Control Computer Complex
TDDS	Tower Data Display System
TIDS	Tower Interim Display System
TML	Television Microwave Link
TMS	Traffic Management System
TPC	TCCC Position Console
TRACON	Terminal Radar Approach Control
TVSR	Terminal Voice Switch Replacement
UPT	User Preferred Trajectory
U.S.	United States
VNTSC	Volpe National Transportation Systems Center
VSCS	Voice Switching and Control System
WECO	Western Electric Corporation

EXECUTIVE SUMMARY

Introduction

The Advanced Automation System (AAS) is a key element of the Federal Aviation Administration's (FAA's) Capital Investment Plan (CIP). It represents the contractual effort to modernize the nation's aging Air Traffic Control (ATC) system infrastructure. Congress has directed that a comprehensive, up-to-date benefit-cost study be performed on the AAS program by the Volpe National Transportation Systems Center (the Volpe Center), which is a part of the Department of Transportation's (DOT) Research and Special Programs Administration (RSPA). The specific language requesting the study was included in House Appropriations Committee Report 102-639 accompanying the Fiscal Year 1993 DOT Bill (Public Law 102-388). The committee report also requested that consideration be given to the impact of other modernization projects implemented or begun since AAS was initiated.

In keeping with the intent of the Congress, the study separately addresses the costs and benefits of each segment of AAS implementation, starting with the Initial Sector Suite System (ISSS); followed by the Terminal Advanced Automation System (TAAS); the Area Control Computer Complex (ACCC); and the Tower Control Computer Complex (TCCC). Advanced En Route ATC, or AERA, which is customarily considered part of the AAS, is viewed in the study as an ATC enhancement function using the AAS as a necessary platform. Terms used in this report are defined in the Glossary preceding the Executive Summary; the AAS is discussed in more detail in Appendix A.

To conduct the study, the Volpe Center assembled a joint government/industry team with appropriate technical and organizational experience. The study was initiated in November 1992. Activities included review of pertinent documents and previous studies, site visits for data collection, as well as interviews with members of the FAA, the Air Transport Association, and several FAA contractors.

Background

The Federal Aviation Administration's basic vision for the upgrade of the Airport/Airway System is twofold. First, new computer hardware, display equipment and operating software will replace existing components. This will create a basic automation foundation -- often referred to as a "platform" -- based on the newest technologies. Second, with this platform in place, the entire air traffic control process can be re-engineered, based on new methods and software tools now being created in the FAA research and development program. These changes will greatly advance the ability of controllers to manage traffic in a more flexible and efficient manner, with benefits to the FAA, air carriers, and passengers.

Current equipment is well past design service lifetime, particularly in the en route centers. This technology, dating from the 1950's and 1960's, represents an increasing support problem due to the unavailability of parts and attrition of the skilled maintenance labor force through retirement.

The logistic support problems are compounded by the inherent design limitations of the current system. The expected future increase in air traffic volume cannot be accommodated without a full modernization effort. The current system has limitations that constrain airspace management and restructuring to accommodate more modern aircraft or more efficient routes.

The AAS is also intended to become a common ATC system used by both the FAA and the military. The TAAS is the selected platform for the Department of Defense (DoD) Radar Approach Control (RAPCON) facilities. This means a common platform and common ATC procedures between the FAA and DoD. This offers the benefit of similar maintenance cost savings for the DoD systems, in addition to those obtained from using common hardware in en route centers and Terminal Radar Approach Control (TRACON) facilities by the FAA. A common basis for training and transition of personnel between FAA and DoD facilities will also be established. Common airspace management procedures will help to maximize efficient cooperative use of airspace.

Study Approach

This study is divided into two distinct parts. The first part examines the implementation of the various segments of the AAS as successive stages of infrastructure modernization to replace aging equipment. It analyzes direct benefits in the form of cost savings to the FAA as the provider of ATC services. The second part examines the potential for implementing new and improved ATC functions on each segment of the AAS in its role as a modernized automation "platform." This phase focuses on the benefits for the users of the ATC service. The users include air carriers, with consideration of general aviation, and their passengers.

Both quantitative benefits expressed in dollar terms and qualitative benefits expressed in general terms are examined in the study. The applicable period is assumed to be from 1993 to 2020 based on expected equipment life of 25 years. The study considers appropriate costs for new facilities construction and telecommunication costs, as well as personnel relocation costs. The study does not address sunk costs (previous expenditures). In the analysis of quantitative benefits to the provider, the focus is on ATC equipment maintenance cost reductions. Provider benefits are determined using conventional analytical methodology. Examination of qualitative benefits to the FAA (as the provider) considered the AAS segments as enabling platforms for enhanced ATC functionality and controller productivity.

User benefits are assumed to be realized when enhanced software functionality is added to the ATC system. The primary sources of benefits to users were identified as the enhanced ATC functions provided by the Advanced En Route Automation (AERA) and the Center-TRACON Automation System (CTAS). These functional enhancements have positive impacts in the form of reduced airborne delays and the capability for controllers to grant user preferred routes. These, in turn, provide savings in fuel and other direct costs for air carriers and reduced travel times for airline passengers. Qualitative user benefits examined include the ATC system's ability to handle projected traffic increases while reducing travel delays and issues related to national productivity gains.

Originally the FAA planned to implement the complete AAS, except for the TCCC, in 23 consolidated Area Control Facilities (ACFs). The FAA later determined that such a fully consolidated scenario was not operationally feasible. Recent studies by the FAA have concluded that the operationally preferred approach includes limited consolidation, which assumes consolidation of some terminal area facilities into Metroplex Control Facilities (MCFs). The assumption of five MCFs, as used in this study, is consistent with the five currently approved FAA MCFs. The site configuration used in the study is thus fully consistent with official FAA planning as of the time of the analysis.

Basic Findings

The Volpe Center study examined the maintenance costs of the present automation system in detail. The study considered the cost of implementing each segment of the AAS and the effects on system capabilities, maintenance, and operational use. This detailed examination of the present system and its modernization led the analysis team to the following findings and conclusions:

The current ATC system requires upgrade. The current ATC automation system has reached its design life and is maintenance intensive. The costs of maintaining terminal area and tower facilities are the largest because of the number of facilities. The current system is not likely to be supportable or to accommodate future traffic growth.

The AAS segments each reduce recurring maintenance costs. Within the uncertainties calculated (via study sensitivity analyses) for growth in maintenance costs of current automation system elements, implementation of each successive AAS segment was found to justify its capital investment through the reduction of maintenance costs.

The AAS can be viewed as a set of modernized ATC system platforms. The ATC system will undergo significant changes in the next decade. The air traffic control algorithms used in the past will be replaced by new control procedures that provide greater cockpit autonomy and improved operational efficiency for air carriers. The modern platforms provided by the AAS will potentially allow effective use of automated tools and information technology to support re-engineering the entire ATC process.

Additional investment can produce greater benefits. Once platform modernization is achieved, enhanced ATC concepts and procedures have the potential to provide benefits that are substantially larger than the additional investment required to produce them. Technologies, such as CTAS and AERA, appear promising. As the subjects of ongoing research and development activity they are subject to uncertainties of timing, acceptance, and effectiveness.

AAS enables significant savings for air carriers. The largest portion of user benefits accrues from implementing services to support direct, fuel-efficient routes. Air carriers are expected to benefit significantly in terms of fuel savings and reduced crew time. However, the expected saving of a few minutes per flight is likely to be insignificant to most passengers when compared to their total trip time.

AAS and the Benefit-Cost Study

In the early 1980's, the Federal Aviation Administration initiated the multi-billion-dollar National Airspace System Plan (NAS Plan) to modernize the nation's air traffic control (ATC) system. As a major project under the NAS Plan (later replaced by the CIP), the AAS was intended to replace current aging ATC automation systems with improved controller workstations, more powerful computer processors, and modernized software. The modernized equipment and advanced software functions of the AAS are to enable the ATC system to accommodate the increase in traffic volumes projected for the 1990's and early decades of the twenty-first century. This study has viewed AAS as a set of new high-reliability/availability "platforms" for the introduction of a variety of future software-based ATC enhancements.

Driving Forces Behind the AAS Program. The Advanced Automation Program was identified as a future need and goal in 1981. At that time, automation systems were already aging and based on technology from the early 1960's. Initial documentation cited a need for controller productivity and user efficiency gains. A major gain in productivity was promised with the projected consolidation of all TRACON facilities into en route centers (ARTCCs). Long term traffic growth was foreseen, with advanced automation expected to keep pace. The Host Computer System was chosen as the way to satisfy existing urgent computer reliability and capacity needs on an interim basis and was successfully implemented in the mid-1980's. The AAS was intended as a full response to the driving forces just cited. Its design was driven by the goal of consolidating all TRACONs at ARTCCs, and its architecture was strongly influenced by the unprecedented availability goal of .9999999; that is, not more than three seconds of system outage per year.

Influences at Work During AAS Development. In the decade since 1982 several important factors, some unforeseen, have had an influence on the current AAS situation. Detailed analyses and operational decisions have led to the conclusion that full consolidation is not operationally feasible. A form of limited consolidation now seems most likely. It is believed that controller productivity may increase significantly, but verification and quantification of improvements must await the availability of the new platform.

There has been explosive growth in computer capabilities. Concepts of open and distributed architectures have emerged and are maturing. Major reductions in computer costs have been realized by the industry. Satellite navigation and communication systems now offer improved methods of sensing and transmitting information (for example, automatic dependent surveillance) leading to applications not widely envisioned in 1982. Display technology has greatly improved. These, along with other products of a technology revolution, have had major influences on the evolving character of AAS segments.

Because of deregulation, the airline industry has adopted the hub-and-spoke concept of operations. Emphasis has correspondingly shifted from en route to the terminal area. Finally, because of many factors (well-documented elsewhere) there has been cost growth and schedule slippage in the AAS Program. It is this cost growth and schedule slippage that caused the Congress in mid-1992 to direct that the Volpe Center perform the present benefit-cost study.

ATC System Alternatives

With the goal of separately examining the benefits and the costs of the major segments, a set of alternative system configurations was chosen. Each configuration can be viewed as a viable ATC system; that is, it would perform the functions of an ATC automation system. Also, each retains the current basic ATC facility structure. As a basis for comparison, the study defined a baseline configuration using the currently installed ATC system. The modeling alternatives are depicted in Figure E-1 and described below. Note that each successive alternative includes the system equipment from the previous alternative.

	Baseline	**Alternative 1**	**Alternative 2**	**Alternative 3**	**Alternative 4**
283 Towers	Current Systems	Current Systems	Current Systems	Current Systems	Current Systems
152 Towers	Current Systems	Current Systems	Current Systems	Current Systems	TCCC
183 TRACONs	125 ARTS-IIA 58 ARTS-IIIA	125 ARTS-IIA 58 ARTS-IIIA	125 ARTS-IIA 58 ARTS-IIIA	125 ARTS-IIA 58 ARTS-IIIA	183 New Automation Systems
5 MCFs	9 ARTS-IIA 7 ARTS-IIIA 3 ARTS-IIIE	9 ARTS-IIA 7 ARTS-IIIA 3 ARTS-IIIE	5 TAAS 5 VSCS	5 TAAS 5 VSCS	5 TAAS 5 VSCS
En Route Centers	2 EARTS Alaska Hawaii	2 EARTS Alaska Hawaii	2 EARTS Alaska Hawaii	22 ACCC	22 ACCC
	20 Current Systems Host PVDs CDC or DCC	20 ISSS	20 ISSS		
	20 WECO Switches	20 VSCS	20 VSCS	22 VSCS	22 VSCS

Shading indicates new equipment introduced to replace current systems. Only major equipments are listed.

Figure E-1 Summary of Baseline and Alternative Systems

New equipment replaces current equipment assumed under the Baseline. Analysis assumes that each alternative incrementally builds on previous alternatives in conjunction with simultaneous phasing in of new equipment and the phasing out of replaced equipment.

The Baseline reflects the current system. The current fielded NAS ATC system automation and architecture are modeled. Limited capital investment is assumed. The existence of five MCFs equipped with various Automated Radar Terminal Systems (ARTS) is also assumed.

Alternative 1 upgrades 20 ARTCCs with ISSS. ISSS replaces en route equipment in the Baseline. The companion Voice Switching and Control System (VSCS) is included as an integrated and necessary part of the system.

Alternative 2 adds TAAS and VSCS to the five MCFs. This includes all AAS equipment necessary for the establishment of five consolidated terminal area facilities. Previous equipments installed for ISSS also apply.

Alternative 3 replaces the en route Host. The ACCC is introduced into the 20 Continental United States (CONUS) ARTCCs, along with the centers in Hawaii and Alaska. This includes the distributed processing equipment associated with ACCC and re-engineered en route software.

Alternative 4 modernizes towers and TRACONs. TCCC equipment is installed in 152 towers and a "New TRACON" automation system replaces ARTS in 183 unconsolidated terminal area facilities. The equipment in the New TRACONs is necessary because the planned TCCC cannot communicate with the current ARTS equipments.

Impact of Other Modernization Projects

The Congress requested consideration of the impacts of other modernization projects implemented or begun since AAS was initiated. Some of these systems have affected airspace management and diverted benefits previously attributed uniquely to the AAS. Major projects involved and their respective effects are as follows:

Enhanced Traffic Management System (ETMS). The effect is mainly to reduce in-flight delays, with a resultant increase in ground delays. Since the system also supports some direct routing under the National Route Program (NRP), this was factored into the analysis of benefits.

Interim Support Program (ISP). Three ARTS-IIIE systems are included in the Baseline. Capabilities of these systems were factored into the analysis of benefits in terminal areas.

Voice Switching and Control System (VSCS). This is a necessary adjunct of AAS and is included in the alternatives.

Display Channel Complex Replacement (DCCR). This is a critical en route automation sustainment item and is included as a part of the baseline system. (Note: Since study analysis was completed, this program has been cancelled; costs remain included in results.)

Mode-Select (Mode-S)/Data Link, Global Positioning System/Global Navigation Satellite System (GPS/GNSS), and Automated Dependent Surveillance (ADS). AAS will accommodate these systems as they become available. Additional interface equipment may be required.

Center-TRACON Automation System (CTAS). The technology from this program supports user benefits in the terminal area. The study assumed that CTAS could be implemented in the ARTS-IIIE or TAAS equipment in MCFs.

Advanced En Route ATC (AERA). This is the fundamental technology for efficient future en route air traffic management. Normally embedded within the AAS, the study treated AERA as a software-based enhancement to AAS platform modernization.

Assumptions and Procedures Applied in the Analysis

The analyses carried out during the study were based on carefully defined assumptions, believed to be conservative but realistic. Key assumptions and guiding choices were as follows:

- All cost data, including development, capital, transition, hardware/software maintenance, and controller staffing are obtained from sources within the FAA and their contractors.

- Implementation schedules assumed for the AAS segments, CTAS, and AERA are based on current FAA plans as provided by FAA program managers. No independent assessment of schedule validity was performed.

- Discount rates used in calculating net present values of both provider (FAA) benefits and user benefits are consistent with current Office of Management and Budget (OMB) guidance.

- The maintenance cost growth model used was adapted from DoD experience with the life cycles of comparable types of equipment.

- The study focuses on the costs and benefits of ATC automation equipment and software. Controller staffing levels were not addressed as part of this study since they are subject to future operational scenarios.

- Benefits associated with AERA are assumed to begin only after all en route centers are upgraded to ACCC and the AERA functionality is installed. The modeled transition costs and phase-in time for AERA do not include the effort associated with developing new ATC procedures and redefining airspace.

- Benefits associated with the CTAS program are based on analysis performed by that program. Both the ARTS-IIIE and TAAS were assumed to be capable of supporting benefits from this technology program.

- Benefits to providers in the form of cost savings and benefits to users in the form of time savings were analyzed separately and are presented separately, consistent with current OMB guidance.

Study Results

Cost Effectiveness to Provider. Significant benefits are expected to accrue to the FAA in the modernization of the ATC system, primarily from reduced hardware maintenance costs. The total cost for continued operation of the baseline automation system through the year 2020 is projected to approach $10 billion. The cost for implementation and subsequent maintenance of new automation through 2020 is comparable, particularly within the uncertainties of discount rates and the higher maintenance costs in years beyond the design life of system elements. Although the new system, being software intensive, will incur higher software maintenance costs, equipment maintenance should be far lower than for the Baseline, and stable rather than increasing rapidly with time. There is a strong, though unquantifiable, potential for significant savings in training, maintenance and logistics because of the standardization of system components.

Far more important, however, is the potential for reliability problems in the existing system increasing to the point that ATC system operations are seriously impacted. This is likely to be accompanied by increasing practical inefficiencies and diminished morale and productivity throughout the organization. Indeed, it is unlikely that the present system could be supported through the year 2020.

The results of this analysis are summarized in Figure E-2. The bars in the figure represent system maintenance for software, tower equipment, terminal area equipment and en route equipment. The line for capital costs represents the combination of development, transition and training, capital investment, and facility establishment.

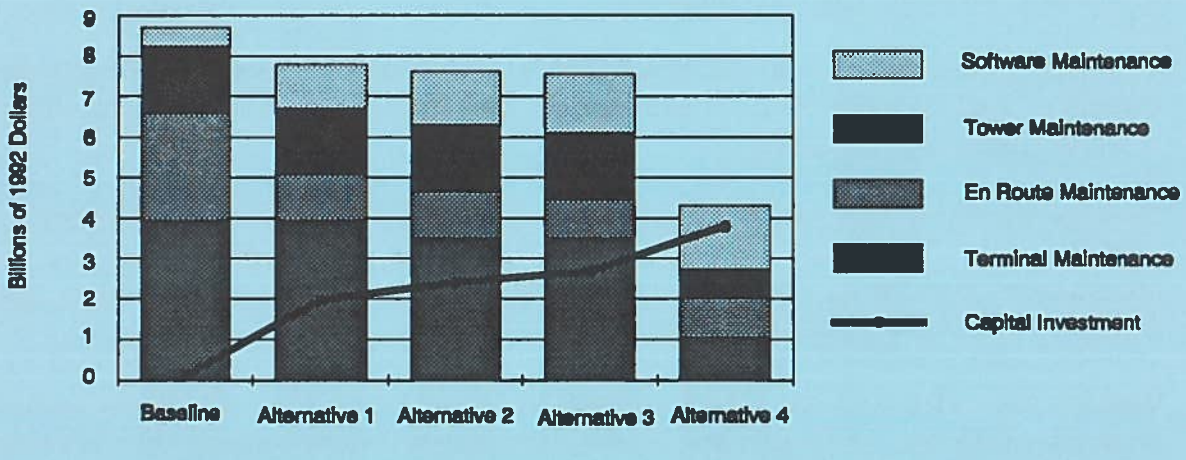

Figure E-2 Total Maintenance Costs and Capital Investment for Each Alternative

The cost results show the following:

- The major expense in the baseline system is maintenance apportioned over software, facilities and equipment (towers, terminal areas, and en route centers). The present value of total maintenance is $8.7 billion representing the expenditures in 1992 dollars to maintain the current ATC automation system (as defined) over the study period of 27 years. There are only very limited capital costs ($130 million) in the Baseline.

- Total maintenance costs for Alternatives 1, 2 and 3 are very similar. Furthermore, the results are within 15% of the baseline system maintenance costs. Each alternative represents an increasing level of capital expenditures; that is, each contains substantially more investment in equipment modernization. Each investment increasingly offsets hardware maintenance costs in the Baseline, but there are corresponding increases in additional software maintenance necessary to maintain the new functionality that each alternative adds. Sensitivity studies discussed later will demonstrate that when a confidence band for study results is taken into account, Alternatives 1, 2 and 3 are also similar in total cost effectiveness based on both capital and maintenance costs.

- Maintenance costs for Alternative 4 drop to $4.3 billion, which is approximately 50% below the Baseline. This alternative requires substantially more capital expenditure because it contains all of the equipment modernization of the preceding alternatives plus modernization of towers and a New TRACON automation system. The substantial additional maintenance savings is attributed primarily to the replacement of aging terminal area equipment by the New TRACON system. This offsets the high costs of maintaining the current ARTS equipments over the period of the study.

Quantifiable Benefits to Users. No user benefits are ascribed to the AAS segments themselves. Rather, the AAS segments are expected to serve as platforms for several future forms of ATC application software (CTAS, AERA and other future functional enhancements) which will provide user benefits. These should enhance the ATC system ability to reduce in-flight delays and provide user preferred routes. The results of this analysis are summarized in Figure E-3. The table shows costs and the value of benefits to air carriers and passengers for Alternatives 2, 3, and 4. Although the ISSS modernizes the en route centers, it does not, of itself, generate quantifiable user savings. However, the ISSS is expected to offset major disbenefits that continue to accrue while the current en route system remains in service.

Assessment Alternative	Functional Enhancement	Implementation Cost	Major Air Carrier Benefits	Passenger Benefits
2	CTAS/TAAS	$32	$85	$208
3	AERA/ACCC	$100	$1,379	$3,352
4	CTAS/New TRACON	$80	$178	$434

(Millions of 1992 Dollars Discounted at 7%)

Figure E-3 ATC Functional Enhancement Costs and Major Air Carrier Benefits

The overall results indicate that the costs of benefits-enabling application technology appear small compared to the benefits realized. The costs listed are incremental costs for the implementation of CTAS and AERA in the AAS platforms already installed. As noted earlier, FAA Research, Engineering and Development (R,E&D) activity needs to be followed by successful implementation before the improvements are considered risk free. The time savings to the passenger resulting from improved automation are generally only a few minutes per flight. This is a small improvement in flight time, and is likely to be insignificant to most passengers when compared to their total trip time. This category, including such small time savings, is included only because it is an item traditionally considered in air travel benefit/cost analysis. The major benefit for the airline passenger is improved adherence to flight arrival schedules due to the introduction of better methods and tools to respond to weather and other special circumstances.

The specific findings can be summarized as follows:

- An investment of $32 million is required to implement CTAS with TAAS within two MCFs not previously established in the Alternative 2 scenario. This provides benefits to air carriers through reductions in terminal area delay estimated at $85 million over the study period. Benefits to passengers from reduced travel time (all of which is less than 15 minutes per flight) are estimated at $208 million. Some benefits are diverted to ARTS-IIIE systems that are assumed under the Baseline.

- The investment cost for implementing full AERA services in 22 ACCC-equipped en route centers in the Alternative 3 scenario is estimated at $100 million. Benefits accrue to air carriers through the granting of user preferred routes. The study assumed AERA will realize 60% of available route improvements (compared to procedural routes), giving air carriers benefits of $1.4 billion. Corresponding AERA benefits of reduced travel time to passengers are estimated to be $3.4 billion. This benefit is attributed almost entirely (99%) to passenger time savings of less than 15 minutes per flight. The benefit estimates for AERA are in addition to direct routing which could be provided under the NRP.

- Implementing CTAS in five additional terminal areas, as defined in Alternative 4, requires a cost of $80 million. The additional benefit to air carriers and passengers is estimated at $178 million and $434 million, respectively. Benefits are greater than for CTAS with TAAS in MCFs because all sites are new; that is, no benefits are diverted to existing ARTS-IIIE systems.

Sensitivity of the Results. A limited sensitivity analysis was performed on the study results. The general results and findings of the study are not substantially modified by the results of the sensitivity analysis. Sensitivity was examined by varying the assumptions in several areas with key results in the following:

- Slip in the AAS implementation schedules
- Cost model growth rates
- Discount rates for user benefits
- Effectiveness of AERA in enabling user benefits

Schedules for the AAS implementation are based on best estimates by the FAA AAS Program Office. Slips of one and two years were applied to segments of the AAS to test schedule sensitivity. Prior year costs were repeated for each additional year. The slips also delay return to the provider from maintenance cost savings. The results showed that the relative magnitude of slip costs, even for the longer two-year slip, is small compared to overall costs.

A key driver in the cost analysis is the high growth rates applied to maintenance parts and labor after systems exceed 15 and 25 years of service. These high rates were varied slightly around the assumed values. The results indicated a confidence band of about 10% around the maintenance cost results. Within the limits of this confidence band, the results show that the combined maintenance and capital costs for Alternatives 1, 2, and 3 are not significantly different from each other or from the Baseline; that is, within the confidence band, they are comparable in cost effectiveness. Alternative 4 continues to demonstrate a significantly lower system cost.

The real discount rate applied in the calculation of user benefits is 7% following OMB guidance. In keeping with OMB guidance, values of 4% and 10% were used for comparison. Reduction in the discount rate (optimistic forecast) has a strong inverse effect on user benefits, substantially increasing the present values. The larger 10% discount rate (pessimistic forecast) reduces the present value of user benefits. Nonetheless, the potential of user benefits remains very large in relation to the additional development costs after the AAS is established as the platform for new ATC functionality.

The effectiveness of AERA services in producing user benefits was calculated for 40% and 80% around the assumed value of 60%. The benefits to users (air carriers and airline passengers) vary linearly with variations in AERA effectiveness. This produces substantial variations, but the lower effectiveness of 40% still predicts substantial benefit to users after AERA is implemented. The higher effectiveness of 80% is regarded as a reasonable objective once AERA services have become fully operational.

Qualitative Assessments

In addition to the quantitative benefits identified, there are other significant benefits associated with the AAS. However, they cannot be quantified with any certainty because of a lack of any operational AAS data, which can only be obtained with operational experience on the new platform. Nevertheless, the beneficial impacts to both providers and users can be characterized qualitatively. Various capabilities and features of the modernized ATC system are expected to translate into benefits for users in the future. The study findings on these unquantifiable benefits are based on extensive discussions with FAA and industry personnel and represents a consensus view among personnel involved in the study.

General Benefits to Provider. The individual segments of the AAS are expected to facilitate both operations and maintenance by using common equipment. The equipment is expected to give a tenfold increase in overall system reliability and availability, virtually eliminating the effects of equipment outages. The ISSS (along with the VSCS) will enhance current en route ATC operations and procedures to potentially reduce delays associated with sector flow volume restrictions and limitations associated with sector-splitting and reconfiguration. The full ACCC in en route centers has the potential to support controller workload balancing through dynamic resectorization across center boundaries.

The consensus view from the current study effort is that the productivity of controllers may increase significantly in the new AAS environment. The AAS segments provide new displays, allowing more flexibility of presentation format. The display also provides a superior work environment with significant potential for lower stress. Electronic presentation of flight plan data promises general improvements in flexibility and controller accuracy throughout the ATC system. But verification and quantification of these effects with certainty, must await measurements and metrics gathered on the new platform when it becomes available.

A modernized system based on the AAS segments provides special advantages as a platform for ATC functionality. The AAS displays can support associated information, such as advanced weather data. Implementation of future ATC improvements will be facilitated by the modular nature of the AAS. Future efforts should be able to use this platform to implement integrated improvements instead of separate stand alone systems. The common equipment in all facilities will improve controller training efficiency. The reliable modern environment should also help to instill controller confidence, thereby smoothing transition to the use of improvements and associated new procedures.

General Benefits to Users. The modernized system will accommodate future growth in overall capacity. The AAS segments support expansion by virtue of modular scaleable architecture. They will handle more sensor inputs -- up to 49 radars versus 15 in the current en route centers, and up to 16 radars versus three in current terminal area facilities. They will have increased capability to process flight plans -- up to 7000 versus the current limit of 2500. The number of aircraft radar tracks increases from the current 940 per en route center up to 6000.

Sector splitting flexibility and higher capacity per sector should enable reduction of user delays associated with current center volume limitations. The AAS enables the creation of additional en route sectors from the current limitation of 60 to some number between 90 and 155. The full ACCC in en route centers will support efficient dynamic resectorization across center boundaries. This should avoid delays associated with unbalanced workloads and communication bottlenecks. ACCC should also support routing preferences tailored to criteria other than efficiency, such as routes to avoid severe weather conditions and increase passenger comfort.

General Benefits to the Nation. A fully modernized ATC system has the potential for benefitting the national interest and helping to achieve national goals. A common system shared by the FAA and the DoD can promote national budgetary cost savings and help to improve flexible and efficient use of all available airspace. There can be gains in national productivity from implementing this new system. Improved airline efficiency clearly fosters American competitiveness in the world aviation market. Improvements in the air transportation infrastructure and in air operations are necessary to the achievement of an integrated, seamless U.S. transportation system.

Summary and General Conclusions

The Volpe Center study of the benefits and costs of the AAS approached the analysis by segments rather than as a whole system. The study concentrated on the automation aspects of the ATC system and applied conservative assumptions to the estimation of benefits to users. Some uncertainties exist in the results for the reasons cited. Within the limits of sensitivity confidence bands, the results suggest that costs are comparable whether the FAA only pursues modernization of the en route centers with ISSS, or if it continues into other phases of the system. The results indicate substantial additional maintenance savings when a New TRACON automation system is installed and associated towers are modernized. The user benefits that accrue from this additional modernization further distinguish the alternatives.

The larger view of these results includes the understanding that each of the system alternatives requires substantial additional expenditures to achieve the next level of modernization. With additional investments in modernized equipment, there are savings in hardware maintenance, although offset by some increases in software maintenance. The shift to a software-based system is a necessary part of modernization. The real source of improved system capacity and flight route efficiency is the introduction of fully modernized software and the advanced operational ATC procedures that it enables.

1 INTRODUCTION

The Advanced Automation System (AAS) Project

The current air traffic control (ATC) automation equipment has reached its design service lifetime, particularly in the en route centers. The technology in these facilities, dating from the 1950's and 1960's, suffers from increasing support problems because of unavailability of parts and attrition of skilled maintenance labor through retirement. An additional issue with the current system design is its limited traffic handling capacity. The expected future increase in air traffic volume cannot be accommodated without implementing a major ATC system modernization effort.

The Federal Aviation Administration (FAA) is pursuing a two-stage upgrade to the infrastructure of the ATC automation system. First, new computer hardware, display equipment and operating software will replace existing system components. This will create a basic automation foundation -- referred to as a *modern platform* -- based on the newest computer, display and communication technology. With this equipment platform in place, the second stage will be the re-engineering of the entire air traffic control process based on new ATC techniques and software tools now being developed. These changes will enhance controllers' ability to manage traffic in a more flexible and efficient manner, yielding new benefits to the FAA, air carriers, and passengers.

The AAS program is the key element of the ATC automation system modernization program. AAS will provide improved controller work stations, a modern voice communication system, distributed processing, and software. AAS will be implemented in stages starting with the Initial Sector Suite System (ISSS) in the en route centers. This will be succeeded by the Terminal Area Automation System (TAAS) in consolidated terminal area facilities. The Area Computer Control Complex (ACCC) will complete the en route center modernization. The AAS program is completed with the Tower Computer Control Complex (TCCC) in airport towers.

Terms used in this report are defined in the Glossary at the front of this report. The AAS is described in more detail in Appendix A.

Previous Benefit/Cost Studies of the AAS

The MITRE Corporation completed AAS benefit/cost studies first in 1985[1] and more comprehensively in 1988[2]. The MITRE study approach was to treat the AAS and its applications as one program. The quoted AAS benefits include both provider and user benefits.

In 1991 the Martin-Marietta Corporation, as the FAA's System Engineering and Integration Contractor (SEIC), updated the MITRE study. The SEIC study was an "economic update" which refreshed the numerical assumptions used to derive the benefits, such as the value of passenger time and average aircraft direct operating costs. Expenditures up to this point were considered sunk. This update did not alter the basic assumptions of sources of benefits.

This Study

The Volpe Center's approach to the performance of this benefit/cost study was distinctly different from previous AAS studies. It did not follow the usual form for this type of assessment of a system's costs and benefits. The Center's study was tailored to answer the specific questions posed by Congress in mandating this effort, and provide better insight into the individual sources of provider and user benefits. To this end, the study approach differs from previous studies in several ways:

- Each AAS segment was examined individually as opposed to simply treating the AAS as a whole.
- Benefits to the provider (FAA) and the system users (air carriers and passengers) were derived separately for each AAS segment.
- Emphasis was on the detailed examination of the provider benefits; this entailed a thorough examination of the present system's maintenance costs and the effect of AAS segment deployment on these costs.
- User benefits were examined with the intent of separately determining each AAS segment's benefits to air carriers and passengers.
- The AAS was treated as a modernized platform that can support new ATC applications, such as Advanced En Route ATC (AERA) and the Center-TRACON Automation System (CTAS); user benefits from these applications were derived separately from provider benefits.

Previous studies included benefits achievable through reductions in en route delays associated with sector splitting limitations and improvements in controller productivity. Within the present study, these benefit sources were not quantified for two reasons. First, the advent of the Traffic Management System (TMS) has added a strategic approach to ATC, enabling balancing of airspace demand against available capacity. The effect of this is to reduce in-flight delays, with a resultant increase in ground delays (also viewed as expensive by users). En route delays in the centers have been reduced to about 1% of total flight delay. Second, benefits from improved controller productivity are expected from AAS and the use of Common Consoles as the controller interface, but a time/motion study to evaluate this effect was beyond the scope of this assessment.

Sector splitting flexibility and higher capacity per sector should however, enable additional reduction of user delays associated with current center volume limitations. The AAS enables the creation of additional en route sectors from the current limitation of 60 to between 90 and 155 sectors. Full ACCC in centers will support dynamic resectorization across center boundaries, avoiding delays associated with unbalanced workloads and communications bottlenecks. ACCC also supports preferences tailored to criteria other than efficiency, such as routes to avoid severe weather conditions and increase passenger comfort.

The Volpe Center assessment took a conservative approach to the derivation of provider and user benefits. This involved an examination of potential benefit sources and quantitatively estimating only those benefits that were unambiguous and could be defended. Sensitivity analysis was performed against parameters considered critical to the derivation of costs and benefits. This final step served to enhance the confidence level in the results and the overall conclusions. Benefits that were considered speculative were treated as qualitative effects which could not be quantified at this time. The overall result of this approach is a better insight into AAS segment costs and a better understanding of the sources of provider and user benefits.

To conduct the study, the Volpe Center assembled a joint government/industry team with appropriate technical and organizational experience. Primary industry support was provided by Intermetrics, Inc. Additional help was provided by Booz, Allen, and Hamilton, Inc.; The Analytic Sciences Corporation; Hickling Corporation; and Jerry Thompson and Associates, Inc. The study was initiated in November 1992. Activities included review of pertinent documents and previous studies, and site visits for data collection, as well as interviews with members of the FAA, the Air Transport Association, and several FAA contractors.

2 ASSESSING BENEFITS AND COSTS

Data and General Procedures

Primary data for the performance of this study were obtained from sources within the FAA and their contractors. Cost data, including development, capital, transition, and hardware/software maintenance of the AAS program elements and related programs were obtained from FAA program managers and their contractors.

Projected future aircraft traffic volume is fundamental to the analysis. It determines the assumed size of the ATC system in the future and the number of users receiving benefits. Forecasts of National Airspace System (NAS) traffic volume, aircraft fleet mix, and passenger loads were based on FAA Office of Aviation Policy and Plans (APO) traffic projections[3].

Some of the data and assumptions applied in the estimation of user benefits were arrived at by consultation with experienced air traffic personnel. An expert panel was convened to focus on issues relating to en route and terminal area operations and the impact of the AAS segments on operational efficiencies.

Procedures and guidelines for the determination of costs and benefits were based on Office of Management and Budget (OMB) guidelines[4] and FAA system evaluation guidance[5]. Several areas identified in previous studies as sources of monetary benefits for providers and users could not be supported analytically. These were assessed qualitatively.

Analysis Structure

Baseline -- The Current ATC System. The framework for the analyses in this assessment is the configuration of the ATC system. A baseline system configuration was defined using the currently installed ATC system as a basis of comparison for the costs and benefits of the AAS modernization program. The assessment defined four incremental levels of modernization based on the AAS segments. Each modernization level forms an *alternative*. Each alternative is a representation of the total assets of ATC facilities and automation equipment after modernization is applied.

Structure of Alternatives -- Increments of AAS Modernization. All systems were modeled under the current NAS architecture of ATC facilities that includes 22 en route centers or air route traffic control centers (ARTCCs), five consolidated terminal area metroplex control facilities (MCFs), 183 TRACONs, and 435 airport towers. The alternatives add AAS modernization in increments within this facility mix. The basic composition (facilities and equipment) of the baseline system and the four AAS alternatives is shown in Figure 1. The en route facilities include the 20 en route centers in the Continental United States (CONUS) and the centers in Alaska and Hawaii. The 435 air traffic control towers in the NAS are divided into 152 major facilities that are scheduled to receive AAS upgrades and 283 that may receive other equipment (not considered in this study).

	Baseline	Alternative 1	Alternative 2	Alternative 3	Alternative 4
283 Towers	Current Systems	Current Systems	Current Systems	Current Systems	Current Systems
152 Towers	Current Systems	Current Systems	Current Systems	Current Systems	TCCC
183 TRACONs	125 ARTS-IIA 58 ARTS-IIIA	125 ARTS-IIA 58 ARTS-IIIA	125 ARTS-IIA 58 ARTS-IIIA	125 ARTS-IIA 58 ARTS-IIIA	183 New Automation Systems
5 MCFs	9 ARTS-IIA 7 ARTS-IIIA 3 ARTS-IIIE	9 ARTS-IIA 7 ARTS-IIIA 3 ARTS-IIIE	5 TAAS 5 VSCS	5 TAAS 5 VSCS	5 TAAS 5 VSCS
En Route Centers	2 EARTS Alaska Hawaii	2 EARTS Alaska Hawaii	2 EARTS Alaska Hawaii	22 ACCC	22 ACCC
	20 Current Systems Host PVDs CDC or DCC	20 ISSS	20 ISSS		
	20 WECO Switches	20 VSCS	20 VSCS	22 VSCS	22 VSCS

Shading indicates new equipment introduced to replace current systems. Only major equipments are listed.

Figure 1 - Summary of Baseline and Alternative Systems

A fundamental requirement for each AAS alternative was to define the system in a way that would support the examination of costs and benefits of each of the major AAS segments as if they were implemented separately. In addition, each configuration was required to be a viable ATC system. That is, it could be expected to perform the functions of an ATC automation system over the time frame of the study.

Each successive alternative is defined to add another segment of the AAS and to be incremental to the previous one. Alternative 1 includes all of the equipment in the Baseline, and replaces the en route center equipment with the ISSS. Alternative 2 is an incremental extension of Alternative 1, modernizing the five defined MCFs with the TAAS technology. Alternative 3 completes the modernization of the en route centers with the ACCC. Alternative 4 completes the AAS modernization adding the TCCC technology to the busiest towers. This alternative also modernizes the unconsolidated terminal area facilities with a "New TRACON" automation system, currently in the planning stage. The New TRACON system was treated as a necessary adjunct to the AAS because the Automated Radar Terminal Systems (ARTS) cannot communicate effectively with the TCCC. The Voice Switching and Control System (VSCS) is similarly included with the ISSS modernization of the en route centers and the TAAS in the MCFs.

Provider Cost Reductions Versus User Benefits. The approach to benefit/cost analysis in this study is different from previous treatments of the AAS. As requested by Congress, each segment of the AAS was examined as a separate stage of an infrastructure modernization program, replacing aging ATC automation equipment. This focused study attention on the cost-reductions of modernization as the primary benefit to the FAA as the provider of ATC services. Benefits to the provider accrue from recurring direct cost reductions in the maintenance and operation of existing equipment and improved functionality and operational efficiencies. Analyzing provider and user benefits separately emphasizes the value of equipment modernization to offset increasing maintenance costs.

Quantitative Versus Qualitative Assessments. Well-defined provider and user benefits which were analytically supportable were estimated quantitatively in this study. Analysis of potential cost savings to the provider is strongly dependent upon underlying assumptions. Some key assumptions, such as the growth rates for maintenance costs, may be subject to interpretation. These assumptions were examined for sensitivity and this is discussed in Section 8. Other provider benefits such as controller productivity, were examined but were not quantifiable; these are discussed qualitatively in later sections.

Although the new ATC technologies can provide substantial user benefits, they are currently research and development activities and subject to uncertainties of timing, acceptance, and effectiveness. Estimation of user benefits is subject to more flexible assumptions than those applied in the cost analysis of provider benefits. This places some uncertainty on the estimates of return to users. Some of this uncertainty is also addressed in the sensitivity analyses of Section 8. The study did not estimate benefits where reasonable assumptions could not be formulated. In particular, en route congestion delays associated with limitations in the splitting of sectors could not be estimated. The benefit of the AAS technology in this area is recognized, but a quantitative assessment was not possible. Other benefits qualitatively assessed included AAS impacts on NAS capacity to handle future traffic volume and general impacts on the national transportation system.

Analysis of Costs

The study focuses on maintenance costs of current and new equipment and appropriate costs for development, implementation, and transition costs of new equipment. Costs of new facilities and personnel relocation are also considered. Sunk costs (previous expenditures) prior to the base year (1993) are not considered. Provider benefits are determined primarily by estimating ATC equipment maintenance cost reductions. Categories of costs included:

- **Development Costs,** representing the total remaining development costs for a given AAS segment.
- **Capital Costs,** representing the cost of a unit of each given equipment type. Totals are based on the number of units procured in the alternative.
- **Transition Costs,** representing the total FAA costs for transition (test and checkout, training, and so on) for a given equipment item.
- **Facility Costs,** representing the total new, non-recurring facility costs to support all new equipment items included in the alternative.
- **Maintenance Costs,** representing maintenance labor, spare parts, and contract maintenance (as applicable) for each equipment item.

Figure 2 depicts the process used to derive the costs of the Baseline and each alternative.

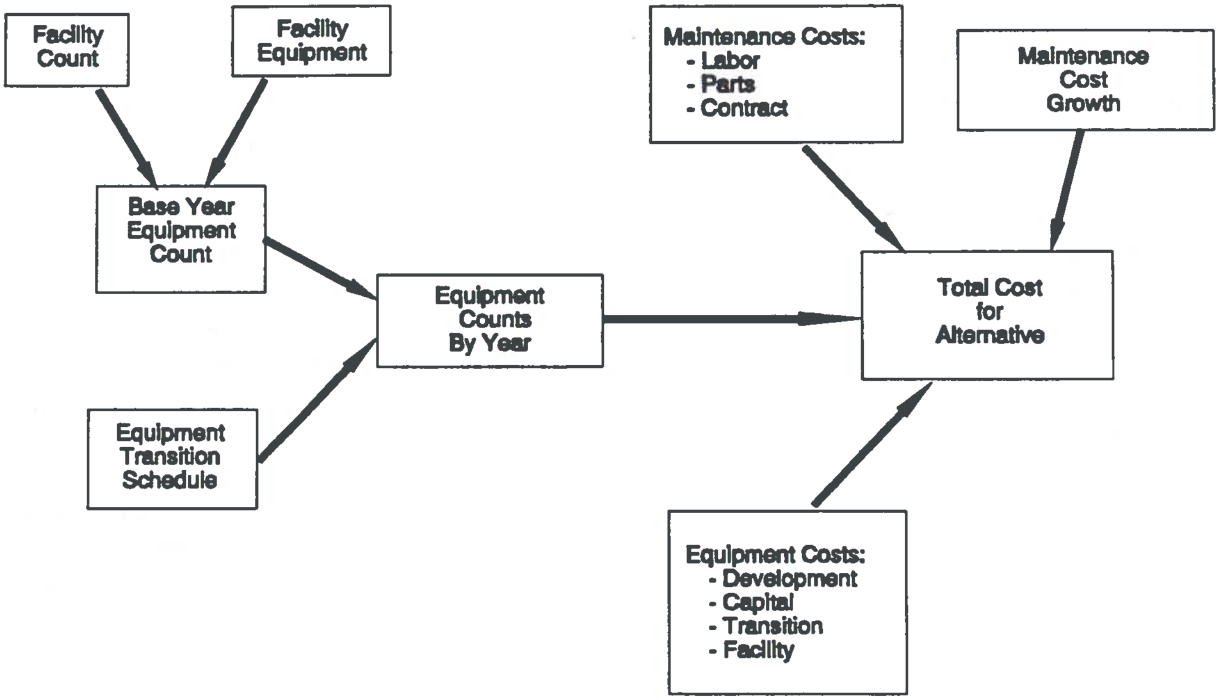

Figure 2 - - Cost Analysis Process

__Primary Cost Data and Growth Models.__ Most facility building and modernization costs are already sunk under the limited consolidation scenario of five MCFs. This includes the expansion of en route centers to accommodate the AAS and the establishment of MCFs. Development, capital and transition costs apply primarily to the AAS equipment. Primary cost data for the AAS and VSCS were developed from detailed analysis of associated contract data.

Since the assumed facility mix in this study does not exactly match these contracts, the contract data were scaled to the facility sizes and equipment counts in the study scenarios.

Maintenance costs were based on both Airways Facilities (AF) staffing standards and contract maintenance. If both were applicable in an allocated maintenance scenario, they were applied in combination. The staffing standards used for hardware and software in the Baseline and all of the alternative systems were provided by the SEIC and the FAA Systems Maintenance Service (ASM), and are appropriately scaled for budget considerations and indirect cost burden. The average salary for AF labor was also provided by the SEIC. Contract maintenance values were obtained from the various FAA program offices.

The cost model distributes costs of current equipment and AAS replacements over the years covered by the study, driven by the data in the various cost categories. The categories invoke the applicable models:

- A model of initial parts costs was developed using the ratio of system labor costs to total labor for all FAA equipment. In this model, the fraction for each equipment is applied to the total parts expenditures for the latest year for which data are available (1992). This model implicitly bases parts costs on system complexity, assuming that the complexity is correctly measured by the staffing standard labor. Systems covered by contract maintenance are assumed to include parts coverage.

- The hardware maintenance cost growth model used was adapted from the Department of Defense (DoD) experience with the life cycles of comparable types of equipment. This model is based on complete long-term maintenance histories of electronic and electro-mechanical systems similar to FAA automation systems. The growth model is applied both to equipment maintenance labor and to parts. For equipment under contract maintenance, the contract costs are applied for covered years. Later covered years are escalated according to the growth model.

- Software maintenance at operational sites is also based on staffing standards and contract allocations. However, the general scenario for AAS and VSCS software maintenance requires centralization at the FAA Technical Center (FAATC). The contractor staffing requirements projected by the FAATC are based on projected lines of code for the AAS software and their experience on the Host Computer System software. The total software staff at the FAATC will be allocated between FAA and contractor personnel. The split is based generally on FAATC experience with similar programs.

- Software maintenance staffing is modeled as level for the first five years after implementation, followed by a decline in the second five years. After that, it continues level (although labor costs are subject to growth). Parts of this model are based on FAATC experience with large programs such as the en route Host Computer System.

User Benefits Framework

<u>Derivation of User Benefits</u>. User benefits were analyzed under the assumption that they are supported primarily by software implemented on the modernized ATC platforms. Under this view, user benefits are not necessarily unique to the planned AAS architecture. While planned modernization is primarily AAS technology, it includes other initiatives, particularly in terminal area facilities, such as ARTS-IIIE systems and the New TRACON automation system. The increasing use of "outboard" processors to enable new automation functions also reinforces this assumption of non-uniqueness.

The primary sources of benefits to users were identified as the enhanced ATC functions provided by Advanced En Route ATC (AERA) and the CTAS. These enhancements have positive impacts in the form of more efficient flight routes and reduced airborne delays. These, in turn, provide savings in fuel and other direct costs for air carriers and reduced travel times for airline passengers. Qualitative user benefits include the ATC system's ability to handle projected traffic increases while reducing travel delays and issues related to national productivity gains. Figure 3 diagrams the overall process of the benefits analysis.

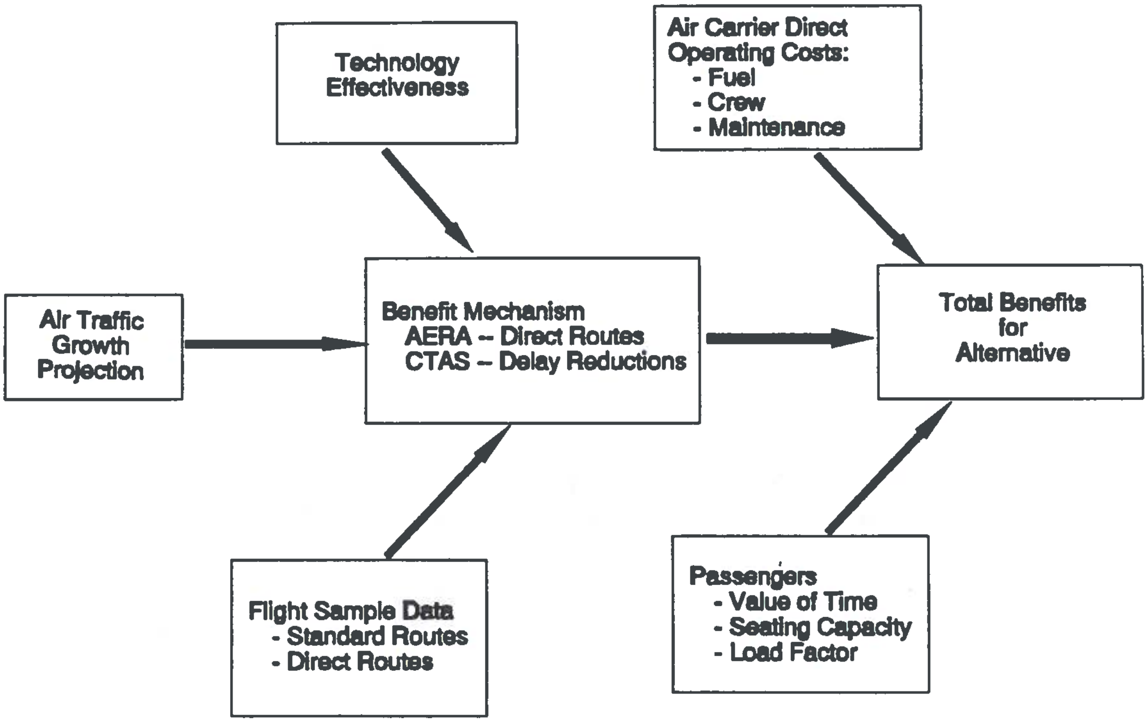

Figure 3 - - Benefits Analysis Process

No direct benefits to users were developed based on platform modernization alone. Benefits were accrued to users when airspace management procedures were changed because of enhanced ATC functions. The study accounted for the costs of implementing new ATC functions that enabled benefits as additional to platform modernization. That is, benefit enabling technology was implemented and costed on the ATC platform after modernization. AERA, customarily considered part of the AAS, is viewed in this study as an ATC enhancement which operates in the AAS ACCC as the available automation platform.

User benefits accrue after new technology (primarily software) is inserted into the ATC automation platforms and becomes operational. In general, benefits to users accrue as direct cost savings to the airlines and time savings to airline passengers. Savings depend upon reducing time in flight by more efficient routing or smoother flow. Direct cost savings to the airlines include reduced operating costs for fuel, crew, and aircraft maintenance. Benefits to passengers result from reductions in travel time. User benefits depend upon common values for air carrier operating costs, aircraft capacity and occupancy, and the value of passenger time. In any given year the number of users eligible for benefits depends on projected traffic volume.

Air Carrier Direct Operating Cost. A value of $1652 per hour was established for the direct operating costs of major air carriers and $171.50 per hour for non-major air carriers through analysis of historical data for the aircraft fleet[6].

Average Passenger Load. An average value of 95.6 passengers per major air carrier flight was established from published FAA data[7]. The average for non-major air carriers was estimated at approximately 2.5 per flight[8].

Value of Passenger Time. The value of passenger time is set at $42 per hour, based on FAA guidance and practice. (This value is used in other current FAA studies to facilitate comparisons between studies and programs.) For the non-major air carrier category, the value of passenger time is based on averages for business trips and was estimated at $82.60 per hour[9].

Savings of even a few minutes per flight can be beneficial to airlines because the associated cost savings are cumulative. Small time savings to passengers are of less tangible value, particularly if the savings are only a few minutes per flight. Passenger benefits, including small time savings, are included in the analyses because they are a customary measure of benefits used in evaluating transportation programs.

Derivation of CTAS Benefits. The CTAS program provides automation tools to terminal area controllers to meter and control aircraft at arrival runways. The technology can be hosted on ARTS-IIIE systems, TAAS, or the New TRACON automation system (planned to replace ARTS). Since the ARTS-IIIE can support the technology, some benefits could be realized under the Baseline scenario. The effect is to erode some benefits that might otherwise be uniquely attributable to TAAS.

CTAS technology attacks the problem of delay caused by congestion in terminal area airspace. Delay of flights arriving at a particular airport is caused by many factors, such as available runway capacity, number of defined instrument approaches, and terminal area congestion (the amount of traffic in the terminal area airspace around the airport). Of key importance in the analysis is the relationship between air traffic growth and delay caused by terminal area congestion.

Prediction of Airport Delay. The analysis relied on an established method for predicting delay at airports as a function of growth in traffic. Weighted regression equations based on historical data are used to predict delay as function of traffic for specific airports. The equations are used with the predicted traffic growth rate, assumed at 2% for all air carriers, no distinction being made in this analysis between major and non-major air carriers. Delays were calculated for all airports receiving CTAS. Since the forecast delays cover all sources of delay experienced by aircraft, it was necessary to separate the portion associated with the terminal area airspace.

Terminal Area Delay. Delay at airports includes: weather, terminal volume, center volume, closed runways/taxiways, NAS equipment interruptions and other causes. The relative share attributed to congestion in the terminal area airspace (terminal volume) is the largest source of delay after weather and has grown in recent years. An estimated average over recent years for terminal volume is 27%. That is, for the average delay experienced at a particular airport, 27% of that delay is assumed to be airborne within the terminal area airspace.

CTAS Effectiveness. The effectiveness of CTAS in reducing airborne delay is assumed at the level estimated in studies under the program. Overall effectiveness of CTAS has been estimated at 10.12%[10]. This means that the terminal area portion of airborne delay would be reduced by 10.12% in a CTAS-equipped terminal area. Given the average 27% of forecast delay assumed for airborne delay within the terminal area airspace, the effect of CTAS will be to reduce the total delay at an airport by 2.73%.

Benefits accruing from CTAS depend upon the number of aircraft that experience a reduction in delay within the equipped terminal areas. This is driven by the traffic growth rates, assumed at 2% in this analysis, no distinction being made between major and non-major air carriers. Monetary benefits are scaled from time savings based on air carrier direct operating costs and passenger value of time.

Derivation of AERA Benefits. ACCC automation will replace the en route center Host Computer System and software, and it is designed as a platform to support the AERA functionality. The AERA technology is designed to provide controllers with software and displays to calculate and grant direct fuel efficient routes and/or user preferred trajectories (UPTs). Past studies have identified this as the largest source of user benefits. The Enhanced Traffic Management System (ETMS) also addresses en route flow and direct routing currently. User benefits from AERA were analyzed quantitatively with consideration of the impact of the ETMS.

Flight Route Data. The benefit provided by AERA depends on flying direct routes in place of standard routes. Access to the ETMS at the Volpe Center provided a unique opportunity to sample actual ATC system flight data to support this study. The ETMS receives flight plan and surveillance data for every aircraft in the NAS. The study collected data over a period of three days for a sample of 11,420 flights from which to analyze typical activity and identify Continental U.S. airports with high activity. The three-day sample was taken over a period in February and reflects any inherent biases normally present at this time of year compared to a long-term annualized sample.

UPTs were assumed to be great circle routes that, on average, will maximize fuel savings. While greater savings may be possible for specific flights based on altitude, winds, and direction of travel, assuming great circle routes enabled a timely analysis of the problem. The ETMS data extraction process was also used to calculate the difference between the predicted time to fly a standard route and time for direct routes. The ETMS-determined direct route time is the time for flying a great circle experiencing the same winds aloft as the standard route. The difference is a prediction of the AERA improvement. The standard route rather than the actual flight time is used as the basis of improvement to assess benefits. The ETMS calculation of standard route time represents the current ATC system in optimal operation.

The ETMS data sample of 11,420 flights was segregated by *major air carriers* and *non-major air carriers* as per Research and Special Program Administration (RSPA) classification for the most recently reported quarter of Form 41[11]. A major air carrier is defined as one who achieves more than $1 billion in annual revenues. Major carriers constituted 9,770 of the flights or about 85% of the sample. The remainder of the sample includes a mix of commuter and air taxi carriers, business jet aircraft, and other piston engine general aviation users. These flights were grouped under the aggregate category of non-major aircraft carriers. The non-major category is approximately representative of general aviation users of the ATC system.

AERA Effectiveness. The AERA technology can not always grant the most efficient routes to all users of the ATC system. It is also likely that some users will prefer routes that are optimized for other factors such as passenger comfort or maximum speed. The study assumed an effectiveness of 60% for the AERA services in granting efficient routes. This is the same value assumed in previous benefit/cost analysis. Under this assumed effectiveness, only 60% of the available savings could be achieved on average. The assumption is conservative -- some proponents of AERA suggest 100% effectiveness as a realistic goal within a few years after services are introduced. The 60% assumption was adopted for the purposes of comparative analysis.

Major Air Carriers. The major air carrier flights in the ETMS sample were scaled to the annual national figure of 6,203,950 major air carrier departures recorded in FY 1992. Initially, flights of less than 500 nautical miles were not considered for AERA benefits. Discussions with FAA Air Traffic (AT) personnel indicated that it is not clear how UPTs could be granted within terminal airspace that typically extends 200 miles around airports. For airport pairs closer than 500 miles it may be possible for benefits to be achieved in the future using AERA technology if revised ATC procedures and airspace partitioning are introduced. AERA benefits reflecting a possible reduction in flight length are considered as a sensitivity analysis in Section 8.

The Central Flow Control organization at the FAA ATC System Command Center uses the ETMS to provide a service known as the National Route Program (NRP). This grants between 100 and 200 direct flights each day for long routes typically over 1500 nautical miles and above Flight Level (FL) 390. Discussions with experienced AT personnel indicate that the NRP should be expandable to shorter flights and more flight levels. The study assumed that this expansion could accommodate as many as 1000 flights per day. These routes are essentially UPTs which could be granted under the baseline system. So as not to attribute this level of benefit uniquely to the AERA services, the annualized estimate of major air carrier flights over 500 miles in length was reduced by 1,000 flights per day (365,000 per year) to 2,361,565 for the base year. This is about 38% of all flights in this category.

The sample set of major air carrier flights was then analyzed for the average time savings per flight. To estimate the potential savings for the base year, the annualized total number of departures over 500 nautical miles is multiplied by the average number of minutes of time saving. The total potential for savings in air carrier operating hours and passenger hours translates into dollars for the base year assuming aircraft direct operating costs. Passenger time savings are computed from average seating and average load factor. The calculation is also scaled by the assumed AERA effectiveness. Assumed traffic growth rate and the discount rate drive the annual benefits stream. Results are discussed in Section 6.

__Non-Major Air Carriers.__ Analysis of UPT benefits to non-major air carriers was conducted in a similar fashion to the major carriers. Analysis and results in this category were not briefed before the release of this report. As in the analysis of the major air carrier data, the sample was also scaled to the annual departure total of 23,100,000 for this category of flights. The figure reflects the much larger fraction of aircraft in this category that operate primarily on short trips in terminal airspace (commuters, air taxis, and other instrument flight rules general aviation). There is no adjustment of this part of the sample for participation in the NRP -- it was assumed that those routes apply only to major air carriers because they fly many more scheduled long routes. An estimated 1,386,000 flights over 500 nautical miles in length were calculated for the base year. Remaining calculations are the same as for the major carrier category. Results for this category are also discussed in Section 6.

Major Assumptions

Several assumptions were applied in the study to achieve necessary analytical simplifications. Some assumptions apply generally within the overall framework of the study while others apply more specifically to the provider or user benefits calculations. The assumptions were carefully considered and chosen to be conservative but realistic. They also embody necessary simplifications to enable successful and timely analysis of the entire ATC automation system. High level assumptions and guiding choices are described briefly.

__Costing Guidelines.__ Discount rates are applied per OMB Circular A-94. Provider benefits are discounted at 4.5%. User benefits are discounted at a real rate of 7%.

__NAS Architecture.__ At the time of this study, the FAA was in the process of defining the future NAS architecture. The level of terminal area consolidation assumed in this study is based on discussion with the FAA at the time of the study. Originally, the FAA planned to implement the complete AAS, except for the TCCC, in 23 consolidated Area Control Facilities (ACFs). The FAA subsequently determined that such a fully consolidated scenario was not operationally feasible. Recent studies by the FAA have concluded that the operationally preferred approach includes limited consolidation. Limited consolidation assumes consolidation of terminal area facilities into MCFs. The site configuration of five MCFs used in the study is consistent with FAA planning as of the time of the analysis.

The current and approved field configuration of the NAS is comprised of 22 en route centers and 170 - 190 TRACONs. For the purposes of analysis, 183 unconsolidated TRACONs are assumed. Additional MCF scenarios, expanding from five to nine MCFs, were performed as part of the sensitivity analysis. The TCCC was assumed to be installed in 152 towers while the remaining 283 towers are candidates for non-AAS improvements (not considered in this study). Consideration was also given to ATC equipment installed at the FAA Technical Center and the FAA Aeronautical Center.

The AAS equipment in each facility is sized for projected traffic in the year 2005. This results in some differences from the AAS contract in the way the segments are assumed to be implemented. The Baseline, however, assumes no growth in capacity.

Study Time Period. The study covers the years 1993 - 2020 based on an expected 25-year life for most equipment. AAS equipment is installed beginning in 1995. The base year is 1993, with all prior costs assumed to be sunk.

AAS Implementation Schedule. Implementation schedules assumed for the AAS segments, CTAS, and AERA are based on current FAA plans as provided by FAA program managers. No independent assessments of schedule validity were performed. New AAS equipment is introduced within each alternative according to the planned schedule. When introduced, it replaces current equipment in the Baseline. Replacement is modeled as the phasing in of new equipment and subsequent phasing out of the replaced equipment.

Traffic Growth. Air traffic growth was projected at 2% annually over the study time frame. This value was selected after consultation with the FAA and applied to facility sizing and to benefits for major air carriers. A lower value of 1.9% is published by the FAA[12] for small air carriers and general aviation through the year 2004; constant growth is assumed thereafter. This was used in the analysis of benefits to non-major air carriers.

Growth in air traffic affects the calculation of benefits to the provider and users. On the provider side, the application of this growth affects the sizing of AAS-equipment within facilities in each of the alternatives. The sizing is based on projections for required system capacity in the year 2005. The user benefits calculations are directly driven by air traffic growth projections for each year of the study. Annual traffic volume determines potential savings in aircraft operating time and the associated reduction in passenger travel delay.

NAS Capacity and Safety. Airport capacity is not assumed to be a limiting factor for air traffic growth in this study. The study assumed that airborne capacity growth will occur and that it will be accommodated by airports. The present level of operational safety will be maintained. Specific additional costs that might be required to support operational safety are not included. The assumption is that new equipment inherently supports safety.

Controller Staffing. Controller staffing costs were not addressed in the study. Only maintenance costs of installed equipment are considered in each alternative system. The rationale for this is that controller staffing levels are subject to future operational scenarios for which details are not available.

Impact of Other Modernization Projects

As part of the study, Congress requested consideration of the impacts of other modernization projects implemented or begun since AAS was initiated. The FAA has many new technology programs proceeding at different paces[13,14]. Some of these systems have affected airspace management. Some have also provided benefits to users and thereby diluted some benefits previously attributed uniquely to the AAS. Among the technology impacts considered were the following programs:

- Enhanced Traffic Management System (ETMS)
- Interim Support Program (ISP)
- Voice Switching and Control System (VSCS)
- Display Channel Complex Replacement (DCCR)
- Mode-S/Data Link, GPS/GNSS, and ADS
- Terminal ATC Automation (TATCA)
- Advanced En Route ATC (AERA)

Consideration of these programs influenced the definition of the study alternatives and, to some extent, the overall approach. Each is briefly discussed below.

Enhanced Traffic Management System (ETMS). The ETMS has become the strategic management tool of the NAS for balancing airspace demand against available capacity primarily on the ground. The effect of this system is to reduce in-flight delays, with a resultant increase in ground delays. This represents a change from the operational environment of the previous decade. The system also supports some direct routing under a service known as the National Route Program. Both effects were factored into the analysis of user benefits. Because of this system, there is less overall in-air delay to mitigate and there are fewer user aircraft who will benefit from direct routes (because some are already receiving them).

Interim Support Program (ISP). The ISP supports terminal area ATC facilities. The program includes sustainment of old equipment as well as implementation of two additional ARTS-IIIE systems in MCFs. Because this is a near-term program, these systems are included in the baseline system. ARTS-IIIEs have some capabilities similar to those designed into the AAS TAAS segment. Some user benefits attributable to improvements in terminal area operations can be realized with either of these automation systems. Therefore, the capabilities of the ARTS-IIIE systems were factored into the analysis of benefits in terminal areas.

Voice Switching and Control System (VSCS). The VSCS is a necessary adjunct of AAS and is included in the alternatives. Within the study, VSCS equipment is assumed both for both the en route centers with ISSS, and the MCFs with TAAS. In this study the VSCS equipment size has been adjusted to the number of Common Console positions required in each facility. This number is based on air traffic growth projections.

Display Channel Complex Replacement (DCCR). The DCCR will provide a replacement for the aging Display Channel Complexes (DCCs) in eight en route centers. The current DCCs are regarded as insupportable both in logistics and maintenance staff. Since the DCC is critical en route automation equipment, the replacement is included as a part of the baseline system. The effect is greater capital cost, but reduced maintenance costs, in the affected en route centers[15].

Mode-Select (Mode-S)/Data Link, Global Positioning System/Global Navigation Satellite System (GPS/GNSS), and Automated Dependent Surveillance (ADS). Data link communications and satellite-based navigational aids -- the GPS and the international concept known as the GNSS -- will become an important part of instrument operations in the future. The combination of the two provides an ADS capability that will enable better ATC coverage over oceanic and remote areas in the future NAS. (These areas currently depend upon periodic position reports radioed by pilots.) The AAS will accommodate these technologies when they become available. However, additional interface hardware and software may be required. The impact of these technologies is global, but concerned with communication and surveillance, as opposed to ATC automation. The methods and approaches to implementation are currently a strong focus in FAA research, engineering and development. Although they will be part of the future NAS environment, the effect on ATC automation costs and benefits was viewed as indirect and subject to future operational scenarios.

Terminal ATC Automation (TATCA). The technology from this program supports user benefits in the terminal area. The CTAS developed under this program provides software and ATC display data that can help to reduce delay within congested terminal areas. The study assumed that this new technology could be successfully implemented with the ARTS-IIIE, TAAS, or the New TRACON automation system. The effects of this technology were considered under the analysis of user benefits. Development and implementation costs were estimated separately from TAAS costs.

Advanced En Route ATC (AERA). The AERA technology is concerned with advancing en route automation software to support greater flight route efficiency and choice for aircraft users. This technology has been customarily grouped with the AAS and embedded within the AAS ACCC segment. The present study assumes a more modular view that the ACCC is initially a replacement of the en route Host Computer System, with a re-engineering of current Host software function in the Ada computer language and the integration of basic communication functions. AERA is viewed as software that will be developed and then added to the new en route host platform as a major upgrade that will then enable substantial benefits. These include enhanced controller functions and support for direct fuel efficient routes for large numbers of aircraft. The modular view is supported by the fact that there is a current FAA initiative to explore early deployment of AERA functionality by means of an add-on (or outboard) processor to the current Host Computer System; that is, AERA functionality is not necessarily unique to the AAS ACCC segment. In the user benefits analysis, AERA is assumed to operate on the ACCC because it is the hardware/software platform designed to support this functionality. Early implementation of AERA services (assuming an outboard processor) was explored in the sensitivity analyses. Costs of AERA implementation were separated from ACCC program costs.

3 CURRENT SYSTEM OPERATIONS (BASELINE)

Baseline Concept

Basis for cost comparison. The Baseline represents the current system without substantial automation change. The current system costs are projected over the assessment period (1993 to 2020). A comparison of these costs with the costs of the various AAS segments forms the basis for determining FAA (provider) benefits. The cost of maintaining the current system is high and growing. Introducing segments of the AAS incurs capital expenditures but reduces maintenance costs. Any net cost reductions result in provider benefits.

Limitations. Although the Baseline is used as a reference for comparison, it is unreasonable to assume that maintaining the current automation system for the entire 28-year assessment period is a viable option. Much of the equipment under consideration is very old, some of it dating back more than twenty years. The issues of age, obsolescence, and availability of both parts and qualified maintenance personnel all suggest that near-term replacement of equipment will be necessary. Some critical near-term replacements are included in the definition of the Baseline.

Description

Current facilities and equipment. Baseline equipment and facilities reflect the current fielded NAS air traffic control system architecture. The Baseline is architecturally and functionally the system in place today. Current equipment is maintained without replacement over the study period. The facilities include en route centers, terminal facilities hereafter called TRACONs, planned and existing consolidated terminal facilities (hereafter called MCFs), and air traffic control towers. Similar non-operational equipment contained within both the FAA Technical Center, and the FAA Academy training facility at Oklahoma City, OK was also costed.

List of equipment types. The following list shows the equipment considered in the baseline system. Each entry is a system of components that provides one or several high level functions.

EN ROUTE CENTERS	
Computers	-Host, Host Software, EARTS
Display Channels	-CDC, DCC, DCCR
Backup Radar Channel	-DARC, EDARC
Flight Data Input/Output	-FDIOC
Peripheral Adapters	-PAM, PAMRI
Communications Switch	-WECO

TRACONS	
Computers and Traffic Display	-ARTS-IIA, -IIIA, -IIIE, ARTS Software
Associated Equipment	-ARTS-IIIA PAM, ARTSA
Flight Data Input/Output	-FDIOR
Communications Switch	-ICSS
Radar Adaptor	-SRAP

TOWERS	
Traffic Display	-BRITE/D-BRITE
Flight Data Input/Output	-FDIOR
Communications Switch	-ICSS
Television Microwave Link	-TML
Tower Data Display System	-TDDS

Limited improvements allowed. Capital investments are not usually allowed within the baseline case of a benefit/cost study. The only exceptions in this study are selected programs already committed and required to maintain near-term operations (the DCCR in eight en route centers, two planned ARTS-IIIE computers, and the Integrated Communications Switching System (ICSS-B) phase of the Terminal Voice Switch Replacement in TRACONs).

MCF assumptions. The existence of five MCFs equipped with various ARTS computer equipment is also assumed. This is consistent with approved plans at the time the study was conducted. Some additional costs are required to complete these five MCFs. Only the three MCFs with ARTS-IIIE computer systems are assumed to be operational during this scenario (after the ARTS-IIIE systems are complete), although five physical facilities are ready for use. The TRACONs associated with the two "unfinished" MCFs remain in operation as unconsolidated facilities. The ARTS-IIIE systems present in the Baseline are assumed to be capable of supporting some advanced technology, such as the CTAS program, which will provide benefits to users. The impact of this technology is addressed in the benefits analysis.

Costs

Current cost basis. This assessment considers investment categories of development, capital, transition, and facility costs. Maintenance is the principal driver of Baseline costs and includes:

-Labor	Labor costs consider the annual labor years required by the FAA to maintain particular systems. The estimates are based upon the FAA staffing standards and are adjusted for overall differences between the staffing standards and actual expenditures.
-Parts	Parts costs consider annual parts replacement by the FAA. Parts costs do not include inventory of spares.

-Contracts This category comprises both parts and labor for those systems for which the FAA contracts its maintenance rather than perform it in-house.

Cost growth basis. The cost growth models described in Section 2 are applied to the current year maintenance costs to project maintenance costs into future years. Considering that most ATC equipment is extremely old, this cost growth is the strongest and is the most significant cost driver in the Baseline.

Cost profile. Figure 4 summarizes the significant maintenance costs that are projected for the baseline system. All costs are expressed as present value 1992 dollars, discounted at 4.5%. The total cost for continued operation of the baseline automation system through the year 2020 is projected to approach $9 billion.

	Capital Investment	Hardware Maintenance			Software Maintenance	Total
		En Route	Terminal	Tower		
Baseline	$0.13	$2.67	$3.94	$1.63	$0.47	$8.84

(Billions of 1992 Dollars)

Figure 4 - Summary of Total Baseline Costs

Figure 5 shows the growth of Baseline maintenance costs by facility type over the study period.

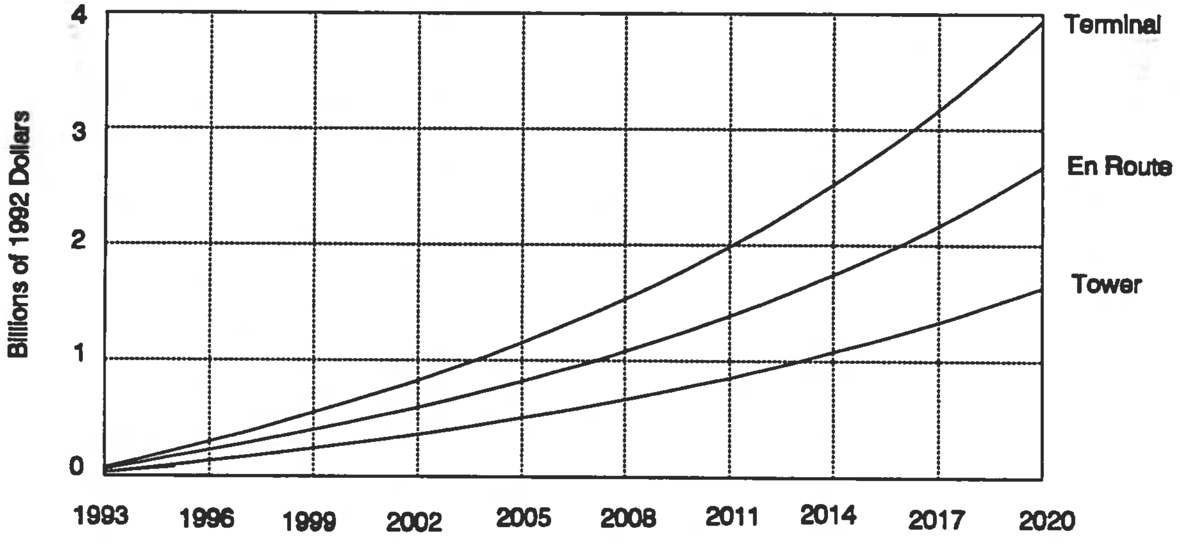

Figure 5 - Cumulative Projection of Baseline System Costs by Facility Type

4 INITIAL SECTOR SUITE SYSTEM (ISSS)

ISSS Implementation

Study Alternative 1 introduces the ISSS into the en route centers. This is the second stage of modernization of the aging .en route center automation equipment. Initially, the Peripheral Adapter Module (PAM), which provides an interface to aircraft surveillance sensors, is replaced by the PAM Replacement Item (PAMRI). This task has been accomplished, and for the purposes of this study, capital costs are considered sunk.

The ISSS consists of an array of intelligent workstations known as Common Consoles, which include in their design a powerful processor, a high resolution color display, and a Local Communication Network (LCN) which enables the Common Consoles to communicate with the central processing facility (Host Computer System), and each other. The ISSS Common Consoles replace the present controller displays (PVDs), and the host interface (CDC or DCC). The VSCS will be installed and integrated with the Common Consoles to replace the current Western Electric Company (WECO) voice communication equipment. The VSCS is generally included as part of this segment. ISSS equipment will also be installed at the FAA Technical Center and the FAA Academy for evaluation and training.

The last stage in en route modernization replaces the Host Computer System with a distributed architecture computer system and modernized software. This is discussed and analyzed in Alternative 3.

The deployment schedule for the ISSS and VSCS is shown in Figure 6. Deployment of the VSCS as stand-alone communication switches has started. The first fully integrated ISSS is scheduled to be operational in the Seattle en route center in October 1996 and the final ISSS installation scheduled for completion by July 1998. The AAS schedule is based on the information derived from current FAA plans as provided by FAA program managers, and contract support personnel.

ISSS and Current NAS Architecture

The original AAS program plan involved the full consolidation of all TRACON functions into the en route centers to create ACFs. This approach was recently abandoned for operational considerations, and replaced with the MCF concept that involves limited consolidation of several TRACONs in large metropolitan areas. The en route centers retain their present configuration. This results in a considerable reduction from the planned number of Common Consoles required in the centers. For the purposes of this study, the ISSS in the centers was resized to accommodate the expected en route traffic in the year 2005. The number of Common Consoles in the centers remains fixed at this level in the remaining study alternatives.

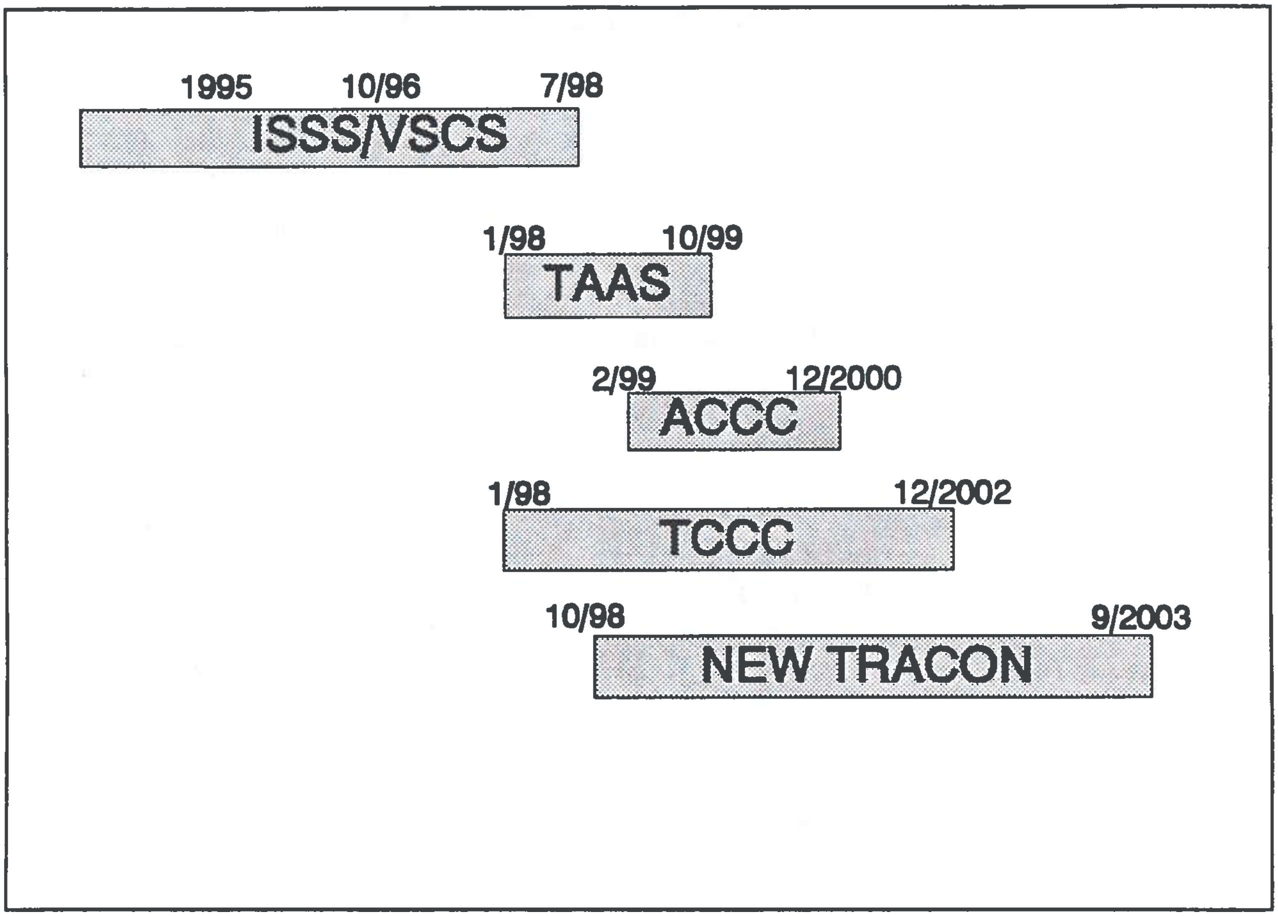

Figure 6 - AAS Implementation Schedule

ISSS Features

Enhanced Reliability and Availability. Maintenance of the present en route automation system is labor intensive. The ISSS/VSCS is designed to provide a tenfold increase in display/communication systems reliability and a corresponding reduction in en route center maintenance costs for the provider.

Programmable High Resolution Color Displays. Replacement of the monochrome PVDs with high resolution color displays will provide state-of-the-art display technology at the controller workstations. Combined with the Common Console processing capabilities, this has the potential to greatly enhance the controller work environment.

Electronic Display of Flight Data. The ISSS design includes the display of flight data electronically on Common Console screens. Electronic display is intended to replace the current paper strips used to transmit flight plan information and record controller actions.

Future ATC Enhancements. The ISSS places powerful workstations at each controller position. Combined with the color displays, this may provide some of the necessary ingredients for future enhanced air traffic control functions and operations. However, integration of future functionality depends strongly on the central processing capability. In this alternative, the existing Host Computer System remains in service; future limitations on its capabilities remain an issue, but were not evaluated.

Assessment of ISSS Benefits to the Provider

Quantitative Estimates of Maintenance Cost Savings. Capital investment costs required to develop and deploy the ISSS are shown in Figure 7. Compared to the Baseline maintenance costs, implementation of the ISSS results in a hardware maintenance cost reduction from $2.67 billion to $1.17 billion. Since the ISSS is a software-intensive system, implementation increases software maintenance costs from $0.47 billion to $1.07 billion. ISSS software maintenance costs include the costs of centralized support at the FAA Technical Center. Overall, ISSS implementation reduces total maintenance costs from $8.71 billion to $7.81 billion, a saving of $0.9 billion to the service provider over the study period.

	Capital Investment	Hardware Maintenance			Software Maintenance	Total
		En Route	Terminal	Tower		
Baseline	$0.13	$2.67	$3.94	$1.63	$0.47	$8.84
Alterative 1	$1.99	$1.17	$3.94	$1.63	$1.07	$9.80

(Billions of 1992 Dollars)

Figure 7 - Baseline and ISSS Capital and Maintenance Costs

The capital investment and maintenance costs for both the Baseline and the ISSS are shown graphically in Figure 8. The figure illustrates the maintenance cost distribution among the FAA facilities. Figure 8 also shows the large reduction in en route center hardware maintenance costs which takes place after ISSS deployment occurs.

Also, Figure 8 shows the required ISSS capital investment cost. The capital investment cost for ISSS is $1.99 billion compared to $0.13 billion for the baseline system. The capital cost includes the ISSS and VSCS development costs, equipment acquisition costs, the costs of modifying the center facilities to accommodate the ISSS installations, and the costs of transition from the present system to the ISSS.

The high ISSS capital costs should be viewed in the context of the full AAS modernization. Since the ISSS is the major element of the AAS program, it must absorb the cost of developing the Common Consoles, LCN, VSCS and the associated software development. The subsequent

ACCC and TAAS implementation phases are the beneficiaries of this large ISSS development effort and would not be feasible without it.

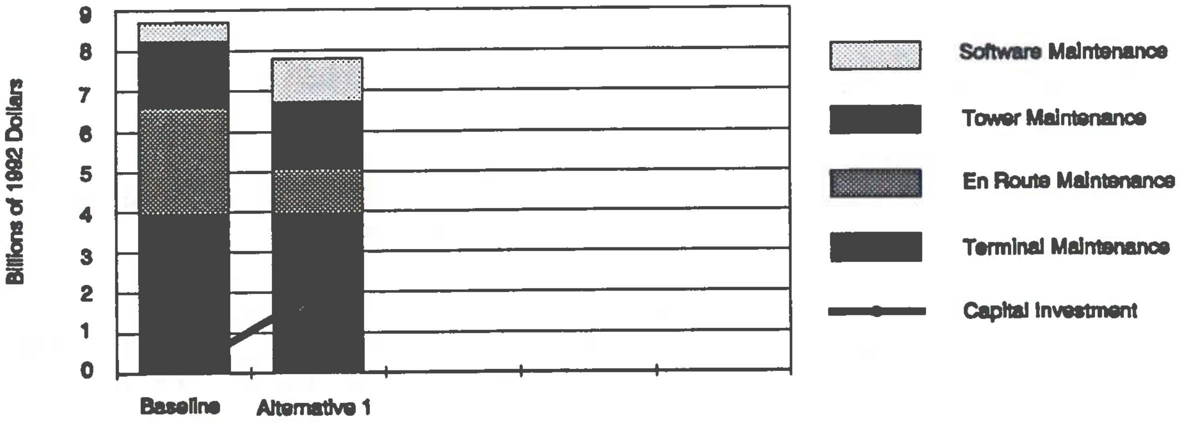

Figure 8 - Cost Comparison of Baseline and ISSS Alternatives

Qualitative Assessments

The ISSS provides a potentially improved work environment for ATC controllers. Several ISSS features promise to yield other significant provider benefits.

Programmable High Resolution Color Displays. Improved displays with customizable profiles have the potential to reduce controller stress and increase controller capability to handle more traffic by presenting aircraft tracks, weather, and other parameters. The enhanced display format can also improve controller situational awareness and make identification of required actions easier. Increased system reliability will also serve to improve controller confidence in the system.

Electronic Display of Flight Data. Past studies have shown that substantial benefits are achievable through the introduction of electronic display of flight data to eliminate the handling of printed paper strips. This has implications for controller staffing and workloads.

Future ATC Enhancements. A problem that occurs at centers is a temporary overload in one center, caused by traffic being rerouted around weather in an adjacent center. This situation leads to an unequal distribution of workload among controllers. A way of alleviating this situation is to dynamically resector across center boundaries to provide for a better traffic load distribution. The ISSS capability for this remains constrained by the limitations of the Host Computer System. The VSCS equipment is also under manual control. Truly dynamic reconfiguration capability requires implementation of the ACCC. But, the ISSS is a critical building block toward the achievement of this capability.

While it seems reasonable that the ISSS features discussed may yield substantial benefits in the form of improved controller productivity, discussions with various FAA organizations failed to yield any operational data or information that could be used to quantify these benefits. The consensus is that results must wait for the actual deployment of the ISSS to provide the human factors measurements necessary to quantify these benefits. This will begin with the deployment of the first ISSS at the Seattle en route center. During the transition period the present system and the ISSS will be operated in parallel, providing the ideal environment to perform the necessary measurements.

ISSS and User Benefits. While the ISSS is a critical AAS segment, it does not appear to provide any user benefits by itself. This is because achieving user benefits associated with reconfiguration (dynamic resectorization or increasing the number of sectors) is practical only after the Host Computer System is replaced with the ACCC. The ISSS alone provides only the display capability for improved user services.

5 TERMINAL ADVANCED AUTOMATION SYSTEM (TAAS)

TAAS Under Limited Consolidation

Alternative 2 introduces the TAAS equipment in a way that is consistent with the NAS architecture as of the time of the study. The limited consolidation approach assumed in the study consists of combining TRACONS that service large metropolitan airport areas into MCFs. Consolidation into MCFs promises to produce significant benefits in the form of reduced operating costs and more efficient management of terminal area flow. The study assumed an MCF configuration of five facilities serving New York, Chicago, Denver, Southern California, and Dallas-Fort Worth.

TAAS Adapted to MCF Configuration. The original TAAS concept facilitated full consolidation of the en route centers and TRACONs. Essentially, TAAS added central processing and software to the ISSS architecture in the ACFs to perform the necessary terminal area control functions. An additional TAAS configuration designated ACF Type B (ACF-B) was also defined to accommodate DoD facilities that perform only TRACON-related functions. (The DoD depends upon FAA facilities for en route services.) DoD had made the decision to modernize their ATC facilities by purchasing AAS equipment. This will achieve commonality of ATC equipment throughout the government. This study sized the ACF-B TAAS for use in each specific MCF. This included an adjustment of the number of Common Consoles, scaling of the VSCS, and similar considerations resulting in different terminal area facility costs from those planned in the current AAS contract.

Some MCFs Initially Equipped with the ARTS-IIIE. The first MCF was created in New York and was originally called the New York Common IFR (Instrument Flight Rules) Room. Since it consolidated existing TRACONS that were equipped with ARTS-IIA and ARTS-IIIA equipment, the new facility needed upgraded equipment to accommodate the larger volume of traffic under control of a single equipment facility and that could handle the larger number of sensors (radars). The ARTS-IIIE was developed to meet these requirements. Since the TAAS will not become available in time to accommodate the commissioning of two near-term MCFs in Dallas/Fort-Worth and Chicago, ARTS-IIIEs will be installed. The Denver and Northern California MCFs will be completed later, and will receive TAAS equipment. Eventually all MCFs are assumed to be upgraded to the TAAS equipment.

Alternative 2 Includes Both ISSS and TAAS. The costs and benefits of implementing ISSS in the Centers were assessed in Alternative 1. In Alternative 2, ISSS implementation is retained in the centers and TAAS is implemented in the MCFs. This is a natural sequence. Without first completing the technology development for Common Consoles, and software in the ISSS segment, the TAAS segment cannot be deployed in any facility. The TAAS design is dependent on the Common Console, LCN, VSCS, and associated software development efforts. The schedule for TAAS implementation is shown in Figure 6.

TAAS Features

Enhanced Reliability and Availability. The TAAS is replacing ARTS equipment that is approaching the end of its design life. The TAAS ACF-B configuration defined in this alternative includes the VSCS. This is a modern system replacing old ATC display technology and communication equipment.

Modernized Platform. The TAAS is a modernized platform that can benefit the provider in various ways by replacing the aging ARTS equipment.

Future ATC Enhancements. Several planned ATC system enhancements require additional processing capability and digital, preferably color, displays. The TAAS provides an integrated modern platform meeting these requirements.

Assessment of TAAS Benefits to the Provider

Quantitative Estimates of Maintenance Cost Savings. The costs of maintaining the MCFs equipped with ARTS under the baseline system were compared to TAAS maintenance costs. The results in Figure 9 show a hardware maintenance savings of $1.95 billion over the Baseline. Compared to Alternative 1, the hardware maintenance costs for TAAS in five MCFs decrease by $450 million. Since the system is more software-intensive, software maintenance costs grow to $1.33 billion, an increase of $260 million above Alternative 1. Overall, the implementation of ISSS and TAAS results in a maintenance cost reduction of $1.09 billion, compared to the Baseline.

	Capital Investment	Hardware Maintenance			Software Maintenance	Total
		En Route	Terminal	Tower		
Baseline	$0.13	$2.67	$3.94	$1.63	$0.47	$8.84
Alterative 1	$1.99	$1.17	$3.94	$1.63	$1.07	$9.80
Alterative 2	$2.41	$1.17	$3.49	$1.63	$1.33	$10.03

(Billions of 1992 Dollars)

Figure 9 - Baseline, ISSS, and TAAS Capital and Maintenance Costs

The capital investment for completing implementation of TAAS is approximately $420 million. Most of this cost is for the development of the TAAS software, which includes all functions now performed in the ARTS-IIIA equipment. The capital investment and maintenance costs for the Baseline, ISSS (Alternative 1) and ISSS and TAAS (Alternative 2) are shown in Figure 10. The figure graphically represents the hardware maintenance cost reduction achievable through the implementation of ISSS in en route centers and TAAS in MCFs.

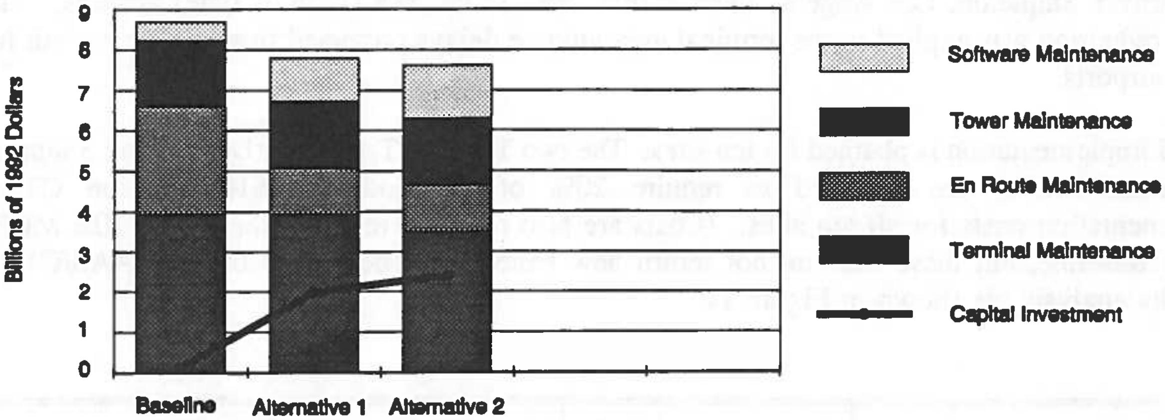

Figure 10 - Cost Comparison of Baseline, ISSS, and TAAS Alternatives

Assessment of TAAS Benefits to Users

__CTAS Is a Major New Program to Improve Terminal Operations.__ CTAS is an FAA program designed to improve traffic flow in terminal airspace. CTAS meters traffic to ensure maximum flow to the arrival runway. An important CTAS feature is the generation of advisories to controllers, informing them of speed and descent commands to issue to arriving aircraft. CTAS implementation requires digital displays and additional processing capability.

__CTAS Can Be Implemented on the TAAS Platform.__ The TAAS with its distributed computer architecture and Common Console workstations is a modern platform that enables implementation of CTAS in the MCFs.

__CTAS Will Be Implemented at Three MCFs Equipped With ARTS-IIIE.__ The ARTS-IIIE design uses monochrome Full Digital ARTS Displays (FDADs) in its design. CTAS can be implemented at these sites using separate stand-alone CTAS processors, a special ARTS interface, and the FDADs. For this study, the assumption was made that CTAS will be operational at the three ARTS-IIIE sites in the Baseline. CTAS benefits at the two remaining MCF sites are considered to have been enabled by TAAS.

__CTAS Costs and Benefits.__ The portion of total annual delays that are projected to occur within the terminal airspace was estimated at 27%, based on an analysis of FAA Air Traffic Operations Management System (ATOMS) data for 1989-1992. The study assumed that CTAS will reduce delay in terminal airspace on average by 10.12% (from analyses conducted by Lincoln Labs for the CTAS program[16]). In this study the savings attributed to CTAS are treated as an overall benefit to terminal airspace users. The study did not attempt to separate the impact of various portions of the CTAS technology, some of which actually reside in en route centers.

TAAS/CTAS benefits are assumed for the Denver and Southern California MCFs, which include the Denver Stapleton, Los Angeles International, and Santa Ana (John Wayne) airports. The delay reduction was applied to the terminal area volume delays projected from traffic growth for these airports.

CTAS implementation is planned for ten sites. The two TAAS/CTAS sites (Denver and Southern California MCFs) are assumed to require 20% of the budgeted $160 million CTAS implementation costs for all ten sites. (Costs are also required to equip the ARTS-IIIE MCFs in the Baseline, but these sites do not return new benefits.) The results of the TAAS/CTAS benefits analysis are shown in Figure 11.

Scenario	Implementation Cost	Air Carrier Benefits	Passenger Benefits
CTAS/TAAS	$32	$85	$208

(Millions of 1992 Dollars Discounted at 7%)

Figure 11 - Initial Implementation Costs and User Benefits for CTAS

In this result, an investment of $32 million will yield $85 million in benefits to air carriers and $208 million in passenger benefits. The estimate excludes the CTAS benefits attributable to the three ARTS-IIIE MCF sites under the Baseline. In fact, these sites would be equipped with CTAS when upgraded to TAAS and continue to produce user delay reductions. But, neither the implementation costs nor the benefits are counted because they are not unique to the TAAS upgrade. Benefits for the five remaining CTAS sites are addressed in Alternative 4, where the benefit potential of the New TRACON automation system is assessed.

Qualitative Assessments

Modernized Platform. The TAAS design represents a modern platform that will accommodate a variety of new terminal ATC functions now being developed. The presence of TAAS will support the implementation of these new subsystems without the need for expensive stand-alone systems for each new function. Replacement of various ARTS equipments establishes commonality across the MCFs and between the en route centers and MCFs. This can reduce the FAA-related requirements in such areas as training and spares.

Programmable High Resolution Color Displays. High resolution color displays may serve to increase controller situational awareness and reduce stress in MCFs, just as the ISSS does in the en route centers. Potentially, this may provide increased controller productivity.

Future ATC Enhancements. Several planned ATC system enhancements require additional processing capability and digital, preferably color, displays. The TAAS provides an integrated modern platform meeting these requirements. The TAAS equipped MCFs will also have the capacity to accommodate any expected future growth in terminal area traffic volume. This will remove any ATC system equipment impediments that could result in traffic delays.

TAAS and User Benefits. The TAAS design provides a new terminal airspace system whose ability to handle 16 radar inputs and large computing power that will readily accommodate increased terminal traffic volume. This enhanced capability, combined with the improved work environment for the controller, are expected to support controller productivity gains. The efficient management of large volumes of consolidated terminal airspace using the TAAS can yield additional benefits to users as reduced delays and fewer diversions to alternate airports.

Another TAAS feature likely to yield additional user benefits is its availability as a modern platform for new applications. An example of this potential benefit is the use of the TAAS processors and Common Consoles to display weather information superimposed on the improved depiction of air traffic. Expected benefits include enhanced safety and more efficient routing around areas impacted by adverse weather conditions in congested terminal airspace.

6 AREA CONTROL COMPUTER COMPLEX (ACCC)

Full En Route Center Automation

In this alternative, 22 centers provide only en route ATC services, and five MCFs provide consolidated terminal area services supported by the TAAS equipment (from Alternative 2). Towers and TRACONs continue as in the Baseline. In this scenario, the en route centers receive the committed improvements described in the Baseline and the ISSS as described in Alternative 1. The focus in this scenario is the addition of the ACCC into the 20 Continental U.S. (CONUS) en route centers. The centers at Honolulu, Hawaii and Anchorage, Alaska are also fully modernized to be equivalent to CONUS centers, replacing current En Route ARTS (EARTS) equipment. Figure 6 includes the schedule for the ACCC segment, implementation along with the other AAS segments, as provided by the Advanced Automation Program Office (AAPO).

ACCC Under Limited Consolidation

The definition of ACCC in this scenario differs from the current AAS contract. In this scenario, ACCC includes the full (and only) replacement of the en route Host Computer Systems with AAS Central Processors and additional necessary interface and gateway hardware. Under the contract this hardware, along with additional Common Consoles, comes from the TAAS segment. In this alternative, the costs of the Host replacement hardware are based on related contract costs from the AAS contract TAAS segment. The discussion of the ISSS explained how the Common Consoles were accounted for and costed. No new Common Consoles are added to the CONUS en route centers in this alternative; there are already enough to meet the projected demand for the year 2005. En route centers at Honolulu and Anchorage receive all necessary equipment to replace their current EARTS. This includes Common Consoles, networking, Central Processors, gateways and interfaces.

ACCC Features

The ACCC technology adds several features to the en route center environment that could potentially support benefits to providers and users.

Enhanced Maintainability. As defined in this scenario, the ACCC replaces the en route Host Computer Systems. Although the Hosts in service are significantly more reliable than their predecessors, the distributed processing environment of the ACCC will add a dimension of modularity that should simplify hardware maintenance significantly. Of even greater significance is the replacement of the aging Host software with modern Ada code under central maintenance at the FAA Technical Center. Although additional maintenance costs come with this software, it also represents the fundamental modernization of the en route centers. Maintenance improvements were assessed as recurring cost reductions to the provider.

Enabling Platform for Future ATC Functionality. The ACCC Host replacement is the platform for AERA services. These are the primary source of future user benefits as controllers can support user preferred routes. The ACCC should also support routing preferences tailored to criteria other than efficiency, such as routes to avoid severe weather conditions or to increase passenger comfort. The ability of AERA to provide improvements in route efficiency was assessed quantitatively for benefits to air carriers and their passengers.

Other Impacts. The full ACCC in en route centers overcomes Host limitations and fully integrates the VSCS. This level of automation addresses several areas with strong potential for future benefit, but which could only be addressed qualitatively within this study:

- En Route Operational Enhancements
- Capacity Enhancements
- Controller Productivity

Assessment of ACCC Benefits to the Provider

Quantitative Estimates of Maintenance Cost Savings. Figure 12 illustrates the benefits to the FAA under Alternative 3. Hardware maintenance costs are further reduced by this replacement. The costs of maintaining the Host software at the FAA Technical Center are eliminated, but this cost saving is offset by the additional costs to maintain the ACCC software. When compared with the baseline system, this scenario reduces total maintenance costs (including software maintenance) by $1.2 billion, or approximately 14%. Under this scenario (which includes five TAAS MCFs) hardware maintenance costs are reduced by $2.2 billion -- $1.7 billion in the en route facilities and $0.5 billion in the terminal facilities. Software maintenance costs are increased by $1.0 billion from the Baseline. Implementation of ACCC accounts for about $60 million of the total savings, when Alternative 3 is compared to the results from the Alternative 2.

	Capital Investment	Hardware Maintenance			Software Maintenance	Total
		En Route	Terminal	Tower		
Baseline	$0.13	$2.67	$3.94	$1.63	$0.47	$8.84
Alterative 1	$1.99	$1.17	$3.94	$1.63	$1.07	$9.80
Alterative 2	$2.41	$1.17	$3.49	$1.63	$1.33	$10.03
Alterative 3	$2.70	$0.97	$3.49	$1.63	$1.47	$10.26

(Billions of 1992 Dollars)

Figure 12 - Baseline, ISSS, TAAS, and ACCC Capital and Maintenance Costs

Figure 13 summarizes the capital investment and maintenance costs for Alternative 3 and the preceding alternatives. It shows increasing capital investment and software maintenance costs with each successive alternative along with the decreasing hardware maintenance costs.

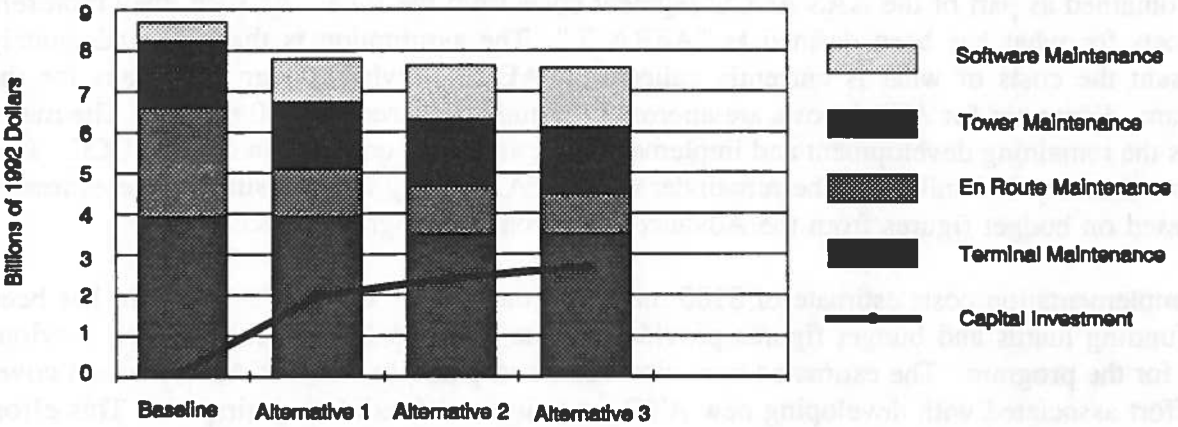

Figure 13 - Cost Comparison of Baseline, ISSS, TAAS, and ACCC Alternatives

Assessment of ACCC Benefits to Users

Benefits to Users Arise from AERA Services. The ACCC is intended as the platform that will support AERA services. This is the fundamental source of user benefits generally attributed to the AAS. As described in Section 2, the benefits of AERA were analyzed quantitatively, factoring the impact of the ETMS into the baseline level of benefits. Consequently, a significant share of the user benefits from direct fuel efficient routes are not uniquely attributed to the AERA services hosted on the ACCC.

AERA Implementation Schedule. The distributed central processors and re-engineered Host software included in the ACCC were assumed as a necessary prerequisite for AERA implementation. The implementation schedule model for AERA was assumed to follow the implementation of ACCC. Phase-in of AERA begins in 1999 and is complete by 2001. Although the basic assumption is that AERA services will phase in with the AAS ACCC segment by 2001, full transition to AERA services will also require substantial changes in the management of en route airspace. Thus, full effectiveness might be delayed until later than 2001. Schedule delays in this category are dependent upon the future operation of the ATC system.

Early Implementation. An earlier deployment schedule for AERA might also be considered, based on current investigations at the FAA. A new concept study is in progress at the FAA to determine the feasibility of deploying AERA with the current Host using an outboard processor. Both the costs and schedule for deploying AERA in this manner are highly uncertain. Initially these uncertainties in deployment did not appear strong enough to warrant additional analysis. However, interest in the impact of earlier AERA deployment was expressed following the initial briefing of the study results. An earlier implementation schedule beginning in 1996 was examined as part of the sensitivity analysis (see Section 8).

AERA Investment Costs. The additional investment cost for implementing AERA is based on the remaining costs in the program for development, testing, and transition. Cost data were obtained as part of the AAS ACCC segment costs from the FAA. As such, they represent the costs for what has been defined as "AERA 2." The assumption is that these adequately represent the costs of what is currently called Full AERA Services under new plans for the program. Estimates for AERA costs are approximate and are placed at $100 million. The major cost is the remaining development and implementation, assuming completion of the ACCC. This is approximately $65 million. The remainder covers FAA testing and transition. The estimates are based on budget figures from the Advanced Automation Program Office.

The implementation costs estimate of $100 million is uncertain. The AERA program has been in a funding hiatus and budget figures provided by the Program Office are based on previous plans for the program. The estimated transition costs and phase-in time for AERA do not cover the effort associated with developing new ATC procedures and redefining airspace. This effort may be substantial, taking place slowly over the course of regular operations. Controller training and acceptance periods may also be longer than anticipated. The effect of all these factors has the potential to increase AERA implementation costs, but this analysis was not within study scope.

Major Air Carriers. As described in Section 2, the 9,770 major air carrier flights in the ETMS flight data sample were scaled to the annual national figure of 6,203,950 major air carrier departures for the base year. Flights of less than 500 nautical miles were eliminated based on terminal area operational constraints. In addition, 1000 flights per day were attributed to expanded operation of the National Route Program, which currently grants direct routes. This left 2,361,565 flights for the base year that is about 38% of all flights in the major air carrier category. The average difference between optimal time over standard routes and direct routes was 3.64 minutes per flight in the sample. The total potential for savings in air carrier operating hours and passenger hours translates into dollars for the base year based on savings in aircraft direct operating costs. Passenger time savings were computed based on average seating and average load factor. The calculation is scaled by the assumed AERA effectiveness and the assumed traffic growth rate. Then the annual benefits stream is discounted to a present value. Results are shown in Figure 14.

Non-Major Air Carriers[17]. Benefits to non-major air carriers were calculated in a fashion similar to the major carriers. It was assumed that direct routes associated with the NRP apply only to major air carriers because they fly many more scheduled long routes, so there is no adjustment of this part of the sample. An estimated 1,386,000 flights over 500 nautical miles in length were calculated for the base year. The average time savings is 3.88 minutes per flight for flights over 500 nautical miles in length. User benefits results for this category are also shown in Figure 14.

Category	Implementation Cost	Traffic Growth	Air Carriers	Passengers
Major Carriers	$100	2.0%/year	$1,379	$3,352
Non-Major Carriers		1.9%/year	$110	$136

(Millions of 1992 Dollars Discounted at 7%)

Figure 14 - AERA User Benefits

The AERA concepts and procedures have the potential to provide benefits that are substantially larger than the additional investment (in addition to the ISSS and ACCC automation modernization) required to enable them. Although there is potential for this technology, it is currently an R,E&D activity and subject to uncertainties of timing, acceptance, and effectiveness. This places some uncertainty on the time frame for return to users of AERA benefits.

Passenger Time Savings Generally Short. Passenger time savings benefits were estimated quantitatively based on average seating, load factor, and the value of passenger time. While this yields substantial monetary benefits, the actual time saving per flight was established according to size. For the sample of major air carrier flights over 500 nautical miles in length (reduced by the share attributable to the NRP), this analysis demonstrated that over 99% of flights offer time savings that never exceed 15 minutes. Savings of even a few minutes per flight can be measured as cumulative reductions in aircraft direct operating cost expenditures. For passengers, such savings may not appear significant. The airline traveller is faced with a variety of delays including boarding, gate holds, and taxi. The airborne savings estimated for AERA will speed the traveller's trip, but are only one facet of the overall delay problem. The travelling public is apt to be more concerned with the dependability of published airline schedule information.

Qualitative Assessments

The en route software assumed under Alternative 3 is the initial build for the ACCC. This provides a functional equivalent of the current Host software, and also includes enhanced surveillance, tracking, conflict and weather functions. Integration of the VSCS control functions is also included so that reconfiguration of sectors becomes fully automated. With this improvement, the display and communications for sector splitting or combining can be accomplished dynamically in software. The initial build of the new software does not include AERA functionality, although it is engineered to be ready to upgrade to the AERA functionality. It is also ready to support direct communication and integration with other systems, notably the ETMS. These various improvements should have a positive impact on en route operations, future NAS capacity, and controller productivity.

En Route Operational Enhancements. The ISSS adds basic display capacity for the creation of additional en route sectors, but center dynamic reconfiguration remains constrained by the capacity limitations of the Host Computer System. Additional NAS modification software must be added to the Host as part of the ISSS. With this addition, the Host system may reach capacity limits. The full ACCC in en route centers overcomes Host limitations and fully integrates the VSCS to support efficient dynamic reconfiguration, including resectorization across center boundaries. This should mitigate delays associated with temporary overloads in a center caused by traffic being rerouted around weather in an adjacent center. Automated reconfiguration also addresses unbalanced workloads and communication bottlenecks.

Capacity Enhancements. The ACCC Host replacement represents the processing capability for future growth in overall capacity. The ISSS and associated gateways increase radar sensor handling capability but the Host limits the number of aircraft radar tracks until it is replaced. With ACCC, capacity can increase from the current 940 tracks per en route center up to 6000. The ATC system will have increased capability to process flight plans -- up to 7000 versus the current limit of 2500. Future NAS capacity depends upon many factors including airport runways, terminal area flow management, and the capacity of en route control facilities. The ACCC will remove current limitations in en route capacity.

Controller Productivity. The ACCC environment with full AERA services is intended to support the transition of en route controllers to a new role as *air traffic managers*. Many tasks now performed by controllers can be offloaded to the automation system. These changes are expected to permit higher workloads with safety that exceeds current operational standards. This may allow optimization of future staffing levels within en route centers, but the quantitative impacts are dependent upon future operational scenarios. Major procedural changes in conjunction with training, transition, and acceptance by controllers are also required.

7 TOWER CONTROL COMPUTER COMPLEX (TCCC)

Final Segment of AAS implementation

Alternative 4 includes all of the modernization in the baseline system and prior alternatives. TCCC equipment is also now installed in 152 towers. A "New TRACON" automation system is installed in the 183 unconsolidated Terminal Radar Approach Control (TRACON) facilities. The New TRACON system is not part of the AAS, but was assumed as necessary in this scenario to support the TCCC facilities. Under the original AAS contract scenario, there was no need for a new terminal area system because all TRACONs were to be consolidated into ACFs (equipped with TAAS). The TCCC can communicate with the TAAS-equipped MCFs, under the limited consolidation approach. However, the current ARTS equipment cannot communicate and integrate functions with the planned TCCC in the remaining stand-alone TRACONs. The New TRACON system also addresses the need to relieve the considerable maintenance burden of the current ARTS equipment. The overall scenario includes the 20 en route centers in the Continental U.S., plus the centers in Honolulu and Anchorage, all operating with ACCC, as defined in Alternative 3. Five MCFs operate with the TAAS capability as defined in Alternative 2. There are also 283 smaller towers that continue to operate without the TCCC modernization. No other modernization, such as the Tower Interim Display System (TIDS), is assumed for these 283 other towers.

Figure 6 includes the schedule for the TCCC (along with the other AAS segments) provided by the Advanced Automation Program Office. Implementation of the New TRACON system is assumed to coincide with the implementation of the TCCC.

TCCC Integrates Tower Functions. The TCCC replaces equipment in current towers with equipment that integrates data and displays from multiple airport information and support systems such as the Pre-Departure Clearance (PDC) system and the Automated Terminal Information System (ATIS). TCCC displays will also provide surveillance data formerly from the D-BRITE facility, flight plan data formerly from the Flight Data Input/Output (FDIO) service, and airport environmental data. TCCC provides interface capabilities with the terminal automation control functions of TAAS and the New TRACON automation system. TCCC also automates control of several manually controlled tower subsystems (airport lighting, environmental monitors, and maintenance systems), provides advanced displays, and incorporates interfaces for automated controller/pilot voice and data communications.

Alternative 4 Models TCCC As Defined in the AAS Program. The TCCC assumed within this alternative is consistent with the planned implementation at the time of the study. Current plans within the TCCC segment involve a phased implementation, with initial automation of non-critical airport data and systems. This will be followed by replacement of the surveillance, flight plan, and voice communications equipment. The final modernization will reflect the relative level of operations at particular airports. Although the study does not make a distinction among relative levels of TCCC equipment implementation in the tower facilities, the final counts of particular TCCC equipment and components are equivalent. Costs were developed using Program Office data, and may not agree with current contract TCCC assumptions.

New TRACON Automation System. The New TRACON automation system assumed for terminal area modernization in this study is based on concepts currently under development within the FAA. Although not firmly specified in terms of procurement requirements, the system's functional role in the ATC system is well defined. The general system design is a derivative of ongoing R,E&D prototype demonstrations and concept studies. The system design will meet the requirements for all unconsolidated TRACONs. It is modular and scaleable to meet TRACON operational loads from level one to level five. It is based on standard open system data communications and operating systems technology. Thus, it will provide a common supportable hardware and software replacement for the wide mix of ARTS-IIA and ARTS-IIIA systems currently in service. Furthermore, the design is assumed to support interfaces to the AAS (en route centers and TCCC-equipped towers). It can also host future ATC functional enhancements, such as the CTAS and integrated weather displays.

TCCC and New TRACON System Features

The technology introduced into TRACONs and associated towers in this alternative can enhance ATC maintenance and operations in various ways to support benefits to providers and users.

Enhanced Maintainability. Both towers and TRACONs suffer from a diversity of equipment types. The TCCC and the New TRACON system both establish commonality of equipment within their respective facility types. This has direct potential for maintenance benefit to the provider.

Enabling Platform for Future ATC Functionality. The TCCC is a general purpose control and display system intended to integrate many tower functions. It will form a suitable platform for various future airfield systems. The New TRACON system will have processing characteristics and display features similar to the TAAS. Thus, it should have similar flexibility for future expansion.

Capacity Enhancements. The New TRACON automation system will have modular scaleable architecture, alleviating capacity limitations currently attributed to ARTS equipment.

Assessment of Benefits to the Provider

Quantitative Estimates of Maintenance Cost Savings. Together, TCCC and the New TRACON system replace aging equipment in 152 towers and 183 TRACONs. Since the replaced equipment in these facilities accounts for nearly two-thirds of the total hardware maintenance costs in the baseline system, Alternative 4 shows a substantial reduction in system maintenance costs. In fact, the combined effect of TCCC and the New TRACON system, added to that of TAAS in the MCFs, dramatically reduces the hardware maintenance costs in the terminal and tower facilities from $5.6 billion to $1.7 billion. Figure 15 illustrates the cost reduction benefit to the FAA of implementing Alternative 4, saving $4.4 billion in total hardware and software maintenance costs when compared with the Baseline.

	Capital Investment	Hardware Maintenance			Software Maintenance	Total
		En Route	Terminal	Tower		
Baseline	$0.13	$2.67	$3.94	$1.63	$0.47	$8.84
Alterative 1	$1.99	$1.17	$3.94	$1.63	$1.07	$9.80
Alterative 2	$2.41	$1.17	$3.49	$1.63	$1.33	$10.03
Alterative 3	$2.70	$0.97	$3.49	$1.63	$1.47	$10.26
Alterative 4	$3.81	$0.97	$1.05	$0.72	$1.57	$8.12

(Billions of 1992 Dollars)

Figure 15 - Summary of All Alternative Costs

Figure 16 summarizes the capital investment and maintenance costs for Alternative 4 and the preceding alternatives. When compared with the Baseline, Alternative 4 modernization reduces total maintenance costs (including software maintenance) by approximately 50%. Hardware maintenance costs are reduced by $5.5 billion -- $1.7 billion in the en route facilities, and $3.8 billion in the terminal and tower facilities. Software maintenance costs increase by $1.1 billion.

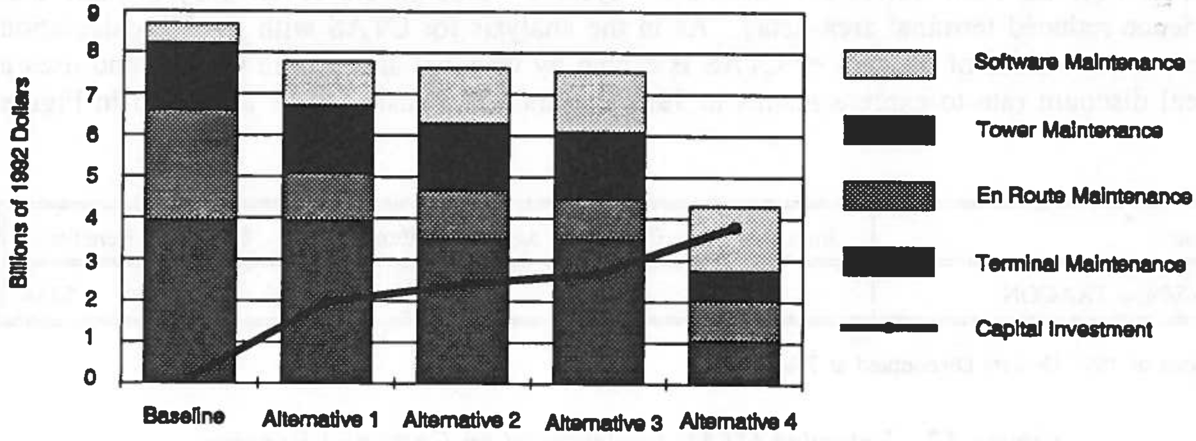

Figure 16 - Comparison of Costs Among All Alternatives

Assessment of Benefits to Users

__CTAS and the New TRACON System.__ This alternative introduces TCCC modernization into the busiest towers in the air traffic control system, and upgrades support from the associated terminal area facilities with the New TRACON automation system. The TCCC modernization offers the potential for user benefits related to enhanced airport operations. Combined with the New TRACON automation system, there should be enhancements to capacity within terminal airspace. These issues were assessed qualitatively. The New TRACON automation system is assumed to be similar in capability (although not in scale) to the TAAS; that is, it is assumed to be capable of receiving the CTAS enhancements for improving terminal operations and flow. This was assessed quantitatively, according to the plans for the CTAS program. ACCC automation is also present in this alternative, but the focus here is the new benefits enabled by the TCCC segment of AAS and the New TRACON automation system.

Details of the terminal area delay reduction benefits of the CTAS technology have been discussed in Section 2. In this alternative, all unconsolidated TRACONs are candidates for the CTAS technology. The CTAS program includes plans for five additional sites. These represent five TRACON facilities that collectively service nine relatively busy airports.

__CTAS Implementation Schedule and Cost.__ The implementation of CTAS in five additional facilities is assumed to follow the implementation of the New TRACON automation system. The new sites phase in CTAS according to the assumed schedule for implementation of the New TRACON system from 1998 to 2002. Each of these sites receives an additional one-tenth or 10% of the budgeted costs. The additional cost for this implementation phase is approximately $80 million.

__Analysis.__ In this scenario, additional CTAS installations are done in TRACONs equipped with the New TRACON automation system. This covers seven busy airports that experience reduced terminal area delay. As in the analysis for CTAS with TAAS, calculation of the present values of benefits of CTAS is driven by terminal area traffic volume and uses a 7% real discount rate to express results in 1992 dollars. The basic results are given in Figure 17.

Scenario	Implementation Cost	Air Carrier Benefits	Passenger Benefits
CTAS/New TRACON	$80	$178	$434

(Millions of 1992 Dollars Discounted at 7%)

Figure 17 - Extended CTAS Implementation Costs and Benefits

The results for this scenario are better than for the initial TAAS implementation because more airports with higher traffic volume are involved and no benefits are eroded by assumed previous implementation (ARTS-IIIE systems). With additional New TRACON sites, implementation costs should decrease with economies of scale and user benefits would be much higher.

Qualitative Assessments

Various benefits may come with the TCCC and the associated New TRACON automation system technology, particularly since they will be designed to work well together in managing terminal airspace and airport operations.

Enabling Platform for Future ATC Functionality. After implementation, the TCCC will provide a potential display and control automation platform for other systems under development, such as the Airport Surface Traffic Automation (ASTA) and airport portions of the Terminal ATC Automation (TATCA) program. The general capabilities of the TCCC have the potential to improve controller management of airport activities, aid in the efficient use of terminal airspace, and maintain safety as air traffic grows.

Capacity Enhancements. The modernized TRACON systems will accommodate future growth in terminal airspace capacity. This automation system is expected to support expansion in a manner similar to AAS modernization by virtue of modular scaleable architecture. The system could generally handle more terminal area radar sensor inputs and will have increased capability to process flight plans and aircraft radar tracks. The system should also be able to support future ATC enhancements including overlays of weather information.

8 SENSITIVITY ANALYSIS

This section summarizes the quantitative analyses from all of the study alternatives followed by a discussion of sensitivity analyses performed against the assumptions.

Comparison of the AAS Modernization Alternatives

Maintenance Savings. Results from each of the AAS alternatives show significant potential benefits to the FAA from modernizing the ATC system. This is primarily from reduced hardware maintenance costs compared to the baseline system. Obtaining maintenance benefits and the opportunities conferred by modernization also requires implementation costs. Figure 18 shows the total discounted cost of implementing and maintaining the ATC automation system over the study period for the baseline system and each AAS alternative. To be cost effective, an alternative should show similar or reduced cumulative costs compared to the Baseline. Alternative 4 is clearly the most cost effective, intersecting the Baseline. The first three AAS alternatives appear very similar, especially when considered in light of the confidence bands discussed later in this section. Their long-term trend from also indicates cost-effectiveness.

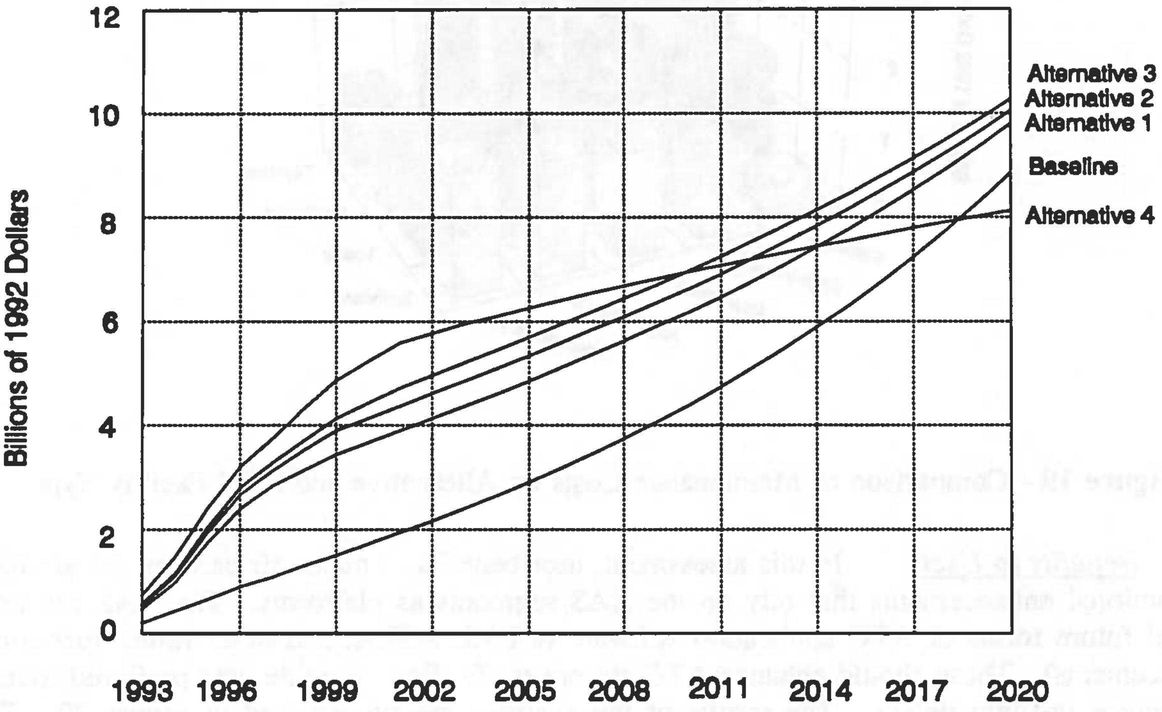

Figure 18 - Comparison of Cumulative Costs Over Time

The differences in the alternatives result primarily from the impact of modernization on maintenance costs. Figure 19 shows, for each alternative, the composition of the total maintenance costs by facility type (1992 dollars discounted at 4.5%). The chart confirms that the most significant reduction in hardware maintenance costs is in terminal area facilities in Alternative 4. This alternative includes full AAS modernization (as defined in the study) and a New TRACON automation system that replaces the large number (183) of obsolete ARTS-IIA and ARTS-IIIA terminal automation that systems. Maintenance cost reductions in the en route centers from the upgrade to the ISSS in Alternative 1 are next in significance. Tower maintenance costs are also reduced in Alternative 4 with the TCCC equipment standardization. TAAS also provides a maintenance savings in Alternative 2. Although hardware maintenance costs consistently decrease with modernization, software maintenance costs grow at each stage. The new systems are software-intensive, but associated software maintenance growth levels out as the AAS segments are added.

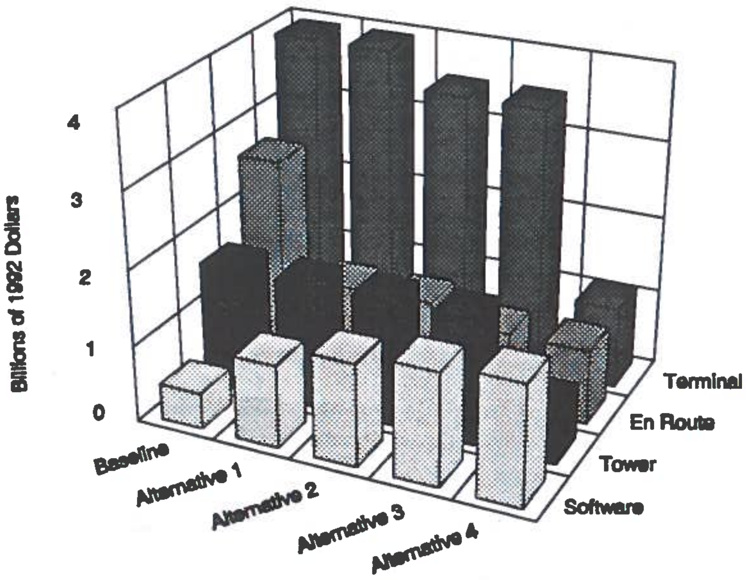

Figure 19 - Comparison of Maintenance Costs by Alternative and ATC Facility Type

Benefits to Users. In this assessment, user benefits to major air carriers are ascribed to functional enhancements that rely on the AAS segments as platforms. The AAS can host several future forms of ATC application software (CTAS, AERA, and other future functional enhancements). These should enhance ATC system traffic flow, provide user preferred routes, and reduce in-flight delays. The results of the analyses are summarized in Figure 20. The additional costs for implementation are compared to the value of benefits to air carriers and passengers for functional enhancements in the automation scenarios in Alternatives 2, 3, and 4. The Alternative 1 scenario does not appear because user savings associated with ISSS en route modernization were not quantified. However, ISSS offsets disbenefits that continue as long as the current en route system remains in service.

Assessment Alternative	Functional Enhancement	Implementation Cost	Major Air Carrier Benefits	Passenger Benefits
2	CTAS/TAAS	$32	$85	$208
3	AERA/ACCC	$100	$1,379	$3,352
4	CTAS/New TRACON	$80	$178	$434

(Millions of 1992 Dollars Discounted at 7%)

Figure 20 - ATC Functional Enhancement Costs and Major Air Carrier Benefits

The costs listed are the incremental costs for the implementation of CTAS and AERA in the AAS platforms already installed. The costs of this benefits-enabling technology are small compared to the benefits realized. As noted earlier, R,E&D activity needs to be followed by successful implementation before the functional enhancements are considered risk free.

The results for the second CTAS scenario are more impressive because more airports with higher traffic volume are involved. The TAAS scenario does not count benefits for the three MCFs that started with ARTS-IIIE equipment. The overall benefits of the CTAS technology appear to address terminal area delay. Even at the limited scale of implementation considered in the CTAS budget, substantial benefits accrue.

The estimated monetary savings to passengers are substantial, but generally represent only a few minutes per flight. This is a small improvement in flight time, and is likely to be insignificant to most passengers when compared to their total trip time. The major benefit for the airline passenger is expected to be improved adherence to flight arrival schedules due to the introduction of better methods and tools to respond to weather and other special circumstances.

Sensitivity Analyses

A limited number of sensitivity analyses were performed on study results. Sensitivities of provider and user benefits were examined. Variations selected for examination in the provider-side cost analysis were based on the likelihood of producing significant changes. The areas selected were:

- Cost growth assumptions (particularly maintenance)
- Schedule slip (AAS implementation schedules)
- Terminal area consolidation (number of MCFs implemented)

The estimation of user benefits is also subject to assumptions. While 7% is the assumed discount rate, benefits estimation procedures[18] require calculation at additional real discount rates of 4% and 10%. These were applied to the calculation of benefits associated with CTAS and AERA. Since CTAS benefits are strongly driven by air traffic growth, an assumption of no growth was also considered.

The largest source of user benefits comes from AERA services. The effectiveness of AERA services in granting user preferred trajectories is a major determinant of these benefits. Values of 40% and 80% were used for comparison to the assumed value of 60%. Other assumptions in the estimate of AERA benefits were also considered, including early implementation employing an outboard processor connected to the Host. Air traffic growth was also considered.

__Cost Growth Assumptions.__ The major assumptions driving cost growth in this assessment are the rates used to escalate maintenance and parts costs. The basic analysis assumed a maintenance growth model with relatively high growth rates for maintenance parts and labor after a system reaches 15 and 25 years of service. Many current ATC systems in service fall into these age categories. This accounts for the large expenses estimated for maintaining the baseline system. To test the sensitivity of the analysis to primary maintenance growth rate parameters, the analysis was repeated using rates that were varied slightly around the assumed values (Figure 21).

Equipment Category	Assumed Growth		Variation	
	15-25 years	Over 25 years	15-25 years	Over 25 years
Electro-Mechanical	6%	11%	4% and 7%	10% and 12%
Electronic	4%	9%	2% and 5%	8% and 10%

Figure 21 - Variation in Maintenance Growth Rates

Results of this variation in growth rates, shown in Figure 22, indicate a confidence band of 10% around the maintenance cost results. Within the limits of this confidence band the maintenance costs for Alternatives 1, 2, and 3 do not appear significantly different from the baseline system. In effect, these modernization alternatives should be equivalent to the Baseline (and each other) in cost effectiveness. The costs of modernization are offset by reductions in hardware maintenance at each stage. Alternative 4 continues to demonstrate a significantly lower system maintenance cost, indicating the significance of maintenance costs in the terminal area facilities.

Maintenance Growth	Baseline	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Higher Rates	10.4	11.0	11.1	11.3	8.2
Assumed Rates	8.8	9.8	10.0	10.3	8.1
Lower Rates	7.9	9.2	9.5	9.7	8.1

(Billions of 1992 Dollars Discounted at 4.5%)

Figure 22 - Impact of Changes in Maintenance Growth Rates

AAS Schedule Slip. Schedules assumed for the AAS implementation in this assessment are based on best estimates provided by the Advanced Automation Program Office. To test schedule sensitivity, slips of one and two years were applied to all segments of the AAS. The impact of these slips includes additional development costs (equal to the amount of the prior year) for each year of slip. Since the phasing out of current equipment is also delayed with schedule slips, associated maintenance cost savings are delayed. A one-year slip produced very little change. The results for the longer two-year slip are compared to those assuming the schedule in Figure 23. Even for the longer slip, the impact is small (on this scale) compared to total system costs.

	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Assumed Schedule	9.8	10.0	10.3	8.1
Two Year Slip	10.0	10.1	10.4	8.2

(Billions of 1992 Dollars Discounted at 4.5%)

Figure 23 - Impact of AAS Schedule Slip

Terminal Area Consolidation. This study initially assumed that five MCFs would be implemented, relocating the functions of 19 TRACONs to consolidated facilities in Chicago, New York, Denver, Dallas/Fort-Worth, and Southern California. After the initial assessment under this effort, four additional MCFs have been identified by the FAA. These new MCFs would consolidate 23 additional TRACONs into facilities in Central Florida, the Potomac region, Northern Georgia, and Northern California. Consolidation of four additional MCFs involves facility establishment and personnel relocation costs. There is an accompanying shift of equipment costs from 23 New TRACON automation systems in Alternative 4 to four TAAS equipment suites in Alternative 2. The results are presented in Figure 24.

	Baseline	Alternative 1	Alternative 2	Alternative 3	Alternative 4
5 MCFs	$8.8	$9.8	$10.0	$10.3	$8.1
9 MCFs	$8.8	$9.8	$10.1	$10.4	$8.2

(Billions of 1992 Dollars Discounted at 4.5%)

Figure 24 - Comparison of Five Versus Nine MCFs

Despite the shift in costs, the results indicate that a nine MCF consolidation is similar in cost to five MCFs at the scale of total ATC automation system expenditures.

Sensitivity of AERA Benefits. Sensitivity of the AERA benefits to major air carriers was examined by varying the following assumptions:

- Real discount rate
- Effectiveness of AERA in enabling user benefits
- Hourly direct operating costs
- Minimum flight length for AERA series
- Annual rate of air traffic growth
- AERA implementation schedule

The effects of real discount rate and AERA effectiveness are both compared in Figure 25. Annual traffic growth is 2% per year.

Real Discount Rate	Air Carriers			Passengers		
	AERA Effectiveness			AERA Effectiveness		
	40%	60%	80%	40%	60%	80%
4%	$1,439	$2,158	$2,878	$3,498	$5,247	$6,996
7%	$919	$1,379	$1,838	$2,235	$3,352	$4,469
10%	$611	$917	$1,222	$1,436	$2,228	$2,971

(Millions of 1992 Dollars)

Figure 25 - Discount Rates and AERA Effectiveness Versus User Benefits for Major Carriers

Strong dependence on the real discount rate is clear. The present value of future benefits erodes strongly at the higher discount rate of 10%. The lower 4% discount rate produces an even larger swing in the positive direction.

The effectiveness of AERA services in producing user benefits was set at 40% and 80% to compare with the assumed value of 60%. The lower effectiveness of 40% still predicts substantial benefit to users from AERA implementation. The variation of user benefits with the effectiveness of AERA is a simple linear dependence.

The assumed AERA effectiveness of 60% may be conservative, particularly when considered against other conservative assumptions used in the calculation. Flights less than 500 nautical miles in length were excluded based on operational restrictions in terminal areas. The future system may eventually integrate CTAS and AERA functionality to support many direct flights with rapid ascent and descent profiles within terminal areas. One thousand flights per day were attributed to an expanded National Route Program (NRP). The expectation is that the NRP will be integrated with AERA, both services functioning as one. The higher effectiveness of 80% is considered a reasonable attainment for the ATC system, once AERA has been operational for a few years. Potential for even higher effectiveness exists over the long term.

The assumed value of air traffic growth applied to the AERA analyses is 2%. Initial briefings of the study results brought some inquiries on the dependence on traffic growth, including the impact of no growth in air traffic. Sensitivity to this assumption is more subtle and is a non-linear dependence. An assumption of no air traffic growth reduces the estimated value of air carrier benefits from $1,379 million to $1,026 million.

During initial study results briefings, interest was also expressed in earlier implementation of AERA services. Achieving early AERA functions by means of an outboard processor connected to the en route Host Computer System is currently under consideration by the FAA. While this is not yet an option with demonstrated technical feasibility, early implementation beginning in 1996 and completing in 1998 was used for comparison. Results are compared in Figure 26.

AERA Deployment	Air Carriers	Passengers
1999 - 2001	$1,379	$3,352
1996 - 1998	$1,714	$4,168

(Millions of 1992 Dollars Discounted at 7%)

Figure 26 - Impact of Early AERA Implementation (60% AERA Effectiveness)

Under the early implementation scenario, benefits begin to arrive three years earlier. This increases the present value of benefits in any AERA scenario to which it is applied by approximately 24%. The likelihood of a successful early implementation is not known. The costs of early implementation were not estimated in this study.

Following initial briefings of the study results, discussion indicated interest in the minimum flight length (below 500 miles) at which AERA services are applicable. There is decreasing agreement among experts as the minimum is reduced below 500 nautical miles. A minimum of 200 nautical miles does not appear technically feasible because of inherent constraints on the structure of terminal area airspace. However, reducing the minimum flight length applicable to (or eligible for) AERA services increases the benefits population. In addition, direct operating costs could be as high as $1800 per hour depending on the future aircraft fleet mix. This operating cost is consistent with the basic constraints applied to obtain the $1652 per hour figure. Three additional AERA benefits scenarios were analyzed at the higher $1800 per hour cost for minimum "AERA-applicable" flight lengths of 500, 400, and 300 nautical miles. These results are shown in Figure 27. The assumed AERA effectiveness of 60% and the higher value of 80% were used for these scenarios.

Minimum Flight Length 500 Nautical Miles

Real Discount Rate	AERA Effectiveness			
	Air Carriers		Passengers	
	60%	80%	60%	80%
4%	$2,351	$3,135	$5,247	$6,996
7%	$1,502	$2,003	$3,352	$4,469
10%	$999	$1,332	$2,228	$2,971

Minimum Flight Length 400 Nautical Miles

Real Discount Rate	AERA Effectiveness			
	Air Carriers		Passengers	
	60%	80%	60%	80%
4%	$2,699	$3,598	$6,022	$8,029
7%	$1,724	$2,299	$3,847	$5,129
10%	$1,146	$1,528	$2,557	$3,410

Minimum Flight Length 300 Nautical Miles

Real Discount Rate	AERA Effectiveness			
	Air Carriers		Passengers	
	60%	80%	60%	80%
4%	$3,364	$4,486	$7,506	$10,008
7%	$2,149	$2,866	$4,796	$6,394
10%	$1,429	$1,905	$3,188	$4,251

(Millions of 1992 Dollars)

Figure 27 - AERA User Benefits vs. Minimum Flight Length (Major Carriers at $1800/Hour)

***Sensitivity of CTAS Benefits*.** CTAS benefits were split in this study between TAAS under Alternative 2 and the New TRACON automation system under Alternative 4. Sensitivity was examined around the basic assumptions in real discount rate and air traffic growth. Calculation of the additional cost streams uses standard discounting such that the results are expressed as total present values in the same base year dollars. Results for the various discount rates are given in Figure 28.

Discount Rate	Air Carriers		Passengers	
	TAAS	New TRACON	TAAS	New TRACON
4%	$133	$283	$323	$687
7%	$85	$178	$208	$434
10%	$57	$117	$139	$285

(Millions of 1992 Dollars)

Figure 28 - Effect of Discount Rate on CTAS Benefits to Users

The assumed rate of air traffic growth in the CTAS analyses is 2%. Following initial briefing of results, the dependence of the results on traffic growth was examined. In particular, the impact of no growth in air traffic was studied. An assumption of no air traffic growth reduces the combined value of air carrier benefits in both scenarios from $263 million to $134 million. Total passenger benefits decrease from $642 million to $327 million.

9 FINDINGS AND CONCLUSIONS

Findings

The Volpe Center study examined the maintenance costs of the present automation system in detail. The study considered the cost of implementing each segment of the AAS and the resultant effects on system capabilities, maintenance, and operational use. This detailed examination of the present system and its modernization led the analysis team to the following findings and conclusions:

The current ATC system requires upgrade. The current ATC automation system continues in service beyond its design lifetime and is maintenance intensive. The costs of maintaining terminal area and tower facilities are the largest because of the large number of facilities as compared to the en route centers. This system is not likely to be supportable or to accommodate future traffic growth.

The AAS segments each reduce recurring maintenance costs. Within the uncertainties calculated (via study sensitivity analyses) for growth in maintenance costs of current automation system elements, implementation of each successive AAS segment was found to justify its capital investment through the reduction of maintenance costs.

The AAS can be viewed as a set of modernized ATC system platforms. The ATC system will undergo significant changes in the next decade. The air traffic control algorithms used in the past will be replaced by new control procedures that provide greater cockpit autonomy and improved operational efficiency for air carriers. The modern platforms provided by the AAS will potentially allow effective use of automated tools and information technology to support re-engineering the entire ATC process.

Additional investment can produce greater benefits. Once platform modernization is achieved, enhanced ATC concepts and procedures have the potential to provide benefits that are substantially larger than the additional investment required to produce them. Technologies, such as CTAS and AERA, appear promising. They are currently the subjects of ongoing research and development activity and are subject to uncertainties of timing, acceptance, and effectiveness.

AAS enables significant savings for air carriers. The largest portion of user benefits accrues from implementing services to support direct, fuel-efficient routes. Air carriers are expected to benefit significantly in terms of fuel savings and reduced crew time. However, the expected saving of a few minutes per flight is likely to be insignificant to most passengers when compared to their total trip time.

Conclusions

The Volpe Center study of the benefits and costs of the AAS approached the analysis by segments rather than the system as a whole. The study concentrated on the automation aspects of the ATC system and applied conservative assumptions to the estimation of benefits to users. Some uncertainties exist in the results. Within the limits of study sensitivity confidence bands, the results suggest that the total of scenario capital and maintenance costs are comparable whether the FAA only pursues modernization of the en route centers with ISSS, or if it continues into other phases of the system. The results indicate substantial additional maintenance savings when a New TRACON automation system is installed and associated towers are modernized. The user benefits that accrue from additional modernization further differentiate the alternatives.

A larger view of these results includes the understanding that each of the system alternatives requires substantial additional expenditures to achieve the next level of modernization. With each investment in modernized equipment comes corresponding savings in hardware maintenance, and increases in software maintenance. The shift to a software-based system is a necessary part of modernization. The source of improved system capacity and flight route efficiency is the modernized software and the advanced operational ATC procedures that it enables.

ENDNOTES

1. Reference: *Benefit/Cost Study for the Advanced Automated Air Traffic Control System*, Report DOT/FAA/AP-84-32, The MITRE Corporation, April 1985.

2. Reference: *The Advanced Automation System: A Benefit/Cost Study and Risk Analysis*, Report MTR-87W235, The MITRE Corporation, December 1987.

3. Source: *FAA Aviation Forecasts*, Report FAA-APO-93-1, FAA Office of Policy and Plans, February 1993.

4. Reference: *Office of Management and Budget Circular No. A-94*, Revised, Attachment to Transmittal Memorandum No. 64, OMB, October 29, 1993.

5. Source: "Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs", Report FAA-APO-89-10, FAA Office of Aviation Policy and Plans, October 1989.

6. Source: "Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs", op. cit.

7. Source: *FAA Aviation Forecasts*, op. cit.

8. Source: "Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs", op. cit.

9. Source: "Economic Values for Evaluation of Federal Aviation Administration Investment and Regulatory Programs", op. cit.

10. Reference: *Evaluation of the Capacity and Delay Benefits of Terminal Air Traffic Control Automation*, Report DOT/FAA/RD-92/28, Steven B. Boswell, Lincoln Laboratory, 23 December 1992.

11. Quarterly revenue schedules submitted by airlines to RSPA for use in establishing airline size classification based on yearly business volume.

12. Reference: *FAA Aviation Forecasts*, op. cit.

13. Reference: *Aviation System Capital Investment Plan*, U.S. DOT/FAA, December 1991.

14. Reference: *The 1991 Federal Aviation Administration Plan for Research, Engineering and Development*, U.S. DOT/FAA, August 1992.

15. Since this study, the DCCR program has been cancelled. Study results were not reformulated to reflect this change.

16. Reference: *Evaluation of the Capacity and Delay Benefits of Terminal Air Traffic Control Automation*, op. cit.

17. Results developed after the initial study briefings were completed.

18. Reference: *OMB Circular No. A-94*, op. cit.

APPENDIX A

Advanced Automation System (AAS) Overview

A.1 Introduction

The AAS will provide a new automation system that includes improved controller workstations, computer software, and processors. The AAS will provide: the capacity to handle the projected traffic load and the capability to perform the new functions to be introduced into ATC into the twenty-first century; increased productivity through introduction of new sector suites; a high degree of reliability and availability; and the capability for enhancement to perform other functions subsequently introduced into the system.

A.2 AAS Implementation

The AAS top-level design was accomplished through a top down system approach that paralleled the Host Computer System (HCS) development and deployment. Controller sector suites consist of Common Consoles (CC) used for en route and terminal functions. They incorporate an improved computer human interface that includes the use of color displays and electronic presentation of flight data to enhance controller productivity. To achieve a fully capable system, the FAA's development contract calls for implementing AAS in segments to provide smaller, more manageable steps. The segments are:

- Peripheral Adapter Module Replacement Item (PAMRI)
- Initial Sector Suite System (ISSS)
- Terminal Advanced Automation System (TAAS)
- Tower Control Computer Complex (TCCC)
- Area Control Computer Complex (ACCC)

The PAMRI will replace the input/output capabilities of the existing Peripheral Adapter Module (PAM) interface hardware for the HCS, Data Receiver Group (DRG), and Radar Multiplexor (RMUX) equipment. It will provide increased interface capabilities with external facilities/radars, provide higher data transmission rates for radar site interface, and replace aging equipment. The PAMRI will be delivered to 20 Continental United States (CONUS) ARTCCs, and the FAA Academy. PAMRI will provide sufficient redundancy to support ISSS transition and simultaneously support full ATC operations.

The ISSS, which constitutes the largest portion of the AAS program, interfaces with the current HCS and replaces mechanical flight strip printers, en route displays, and associated display processing systems with state-of-the-art color display work stations, new fault tolerant software, and modern, distributed computer communication networks. The relationship of ISSS to the overall ATC environment and other AAS segments is shown in Figure A-1. The ISSS will also provide improved display of weather and traffic, flexibility in control sector staffing and configuration, and an improved computer human interface. ISSS provides a controller with early operational use of the AAS configuration. The ISSS will be operational in 20 CONUS ARTCCs. Units will also be delivered to the FAAAC and to the FAATC.

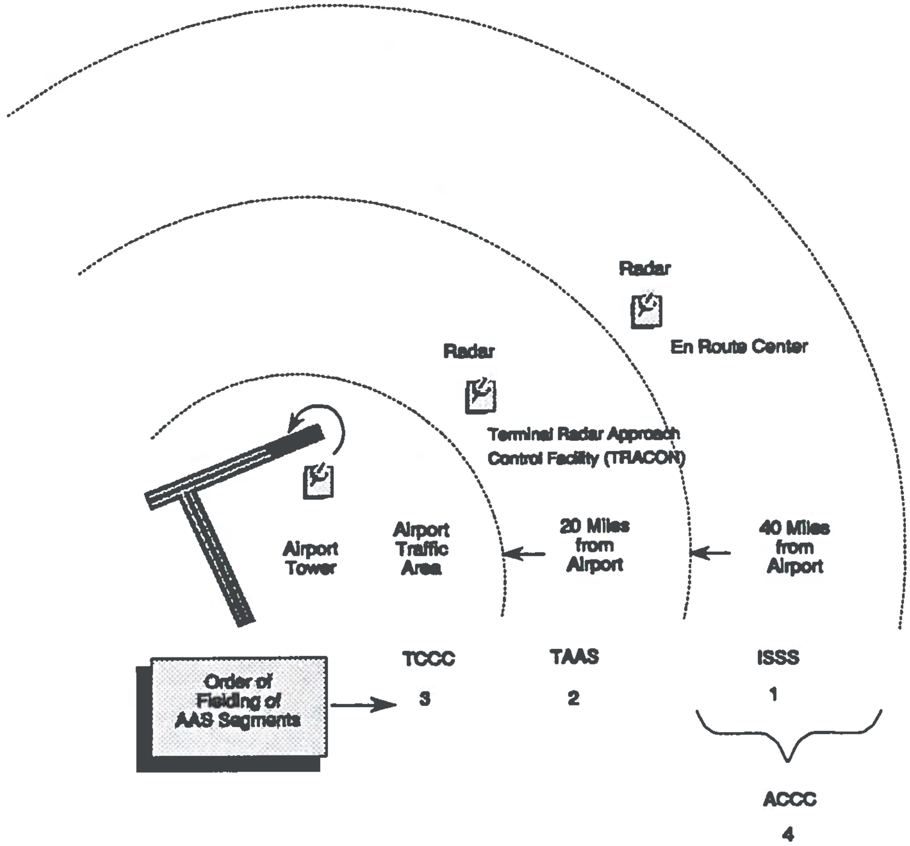

Figure A-1 ATC System and AAS Segment Coverage

The TAAS will replace the approach/departure control functionality of the existing Automated Radar Terminal Systems (ARTS IIA & IIIA) in Metroplex Control Facilities (MCFs). The TAAS will incorporate hardware elements including consoles, networks, and software already developed for ISSS. The TAAS also provides the opportunity for implementation of new approach/departure control functionality, such as the Center-TRACON Automation System (CTAS) in MCFs. Under the current limited consolidation plans, the TAAS will be installed in 9 MCFs. Units will also be delivered to the FAAAC and FAATC for training and logistics support.

The TCCC will replace the Digital Bright Radar Indicator-Tower Equipment (D-BRITE) displays and today's paper flight strip processing capabilities with new tower controller work stations called the TCCC position consoles (TPC) designed specifically for the tower cab environment. Common AAS hardware, software, and networks will provide dedicated processing capability at each tower, along with new hardware to handle communications and airport equipment interfaces. The TCCCs will be deployed over an extended period since it requires the presence of the TAAS in the MCFs and the arrival of New Tracon equipment replacements for the ARTS in the TRACONs. TCCC equipment will also be installed at the FAATC and the FAAAC.

The ACCC will replace the HCS and will integrate all en route functionality into a common hardware, network, and software configuration. The installation of the ACCC segment is the conclusion of the ACCC upgrade activity. The ACCC will be implemented at 20 ARTCCs in the CONUS as well as in the Alaska and Hawaii Centers. Units will also be provided to the FAA Academy for training, and the FAATC for field support.

ISSS establishes the common hardware suite for AAS. Basic ISSS system components include:

- Local Communications Network (LCN)
- Common Console (CC)
- Central Processor (CP)/Backup Central Processor
- Backup Communications Network (BCN)
- Monitor & Control (M&C) Console

The LCN is the communication backbone infrastructure for meeting key AAS requirements associated with capacity, response time, reliability, and availability. The LCN is an International Standards Organization (ISO) 802.5 (16 MBPS) token-ring network that employs a multi-ring architecture with redundant bridges, gateways, and network managers to provide a high level of fault tolerance/availability and increased workload capacity. The LCN serves as the "highway" for moving data in support of ISSS surveillance, message, and recording functions.

The Common Console is based on a commercial computer running a version of the UNIX operating system that, with the Main Display Controller (MDC) and a large color monitor, provide for processing and display of ATC surveillance data. Within ISSS, the CCs perform limited processing of the surveillance data forwarded from the HCS or the Enhanced Direct Access Radar Channel (EDARC).

The CP and its backup CP are IBM 9000 series processors (or a later generation of computer). The ISSS CP will perform system analysis recording and playback (SAR).

The BCN is an ISO 802.3 (10 MBPS) Ethernet network that serves as the backup to the LCN and the primary communication path for EDARC data.

The M&C terminal is a CC with software designed for the Airways Facilities (AF) System Engineer (SE) for surveillance, message, and recording functions to manage and maintain AAS components within the ISSS.

A.3 Program Status

FAA is now in the fifth year of its contract with the International Business Machine Corporation (IBM) to design and produce the AAS. The PAMRI deployment was completed. The development of the ISSS experienced serious problems that are being resolved. Several key recovery milestones have been successfully passed. The first ISSS will be installed in the Seattle ARTCC in late 1996. The other segments are in replanning.

APPENDIX B

Derivation of Provider Benefits

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B.1 INTRODUCTION

As described in the main body of this report, the AAS Benefit/Cost study partitions the analysis of benefits into two distinct parts, analyzing benefits to the provider (FAA) separately from benefits to the users (airlines, passengers). This appendix describes the approach used in the analysis of provider benefits.

The study analyzed the ATC automation upgrade provided by AAS as a series of alternatives based on the AAS segments. The main body of this report contains a complete description of these alternatives. Provider benefits accrue based on the cost effectiveness of each alternative. To assess cost effectiveness, total costs for the baseline system and each alternative over the study timeframe (1993-2020) were developed and compared. Since the total costs associated with a given alternative depend on the equipment items, and how many of each item exist in that alternative year by year, our approach focused on facility definition, facility refurbishment cost, and all other equipment costs. The process included the following steps:

- Identify and classify the NAS facilities that contain automation equipment.
- Select the equipment items for which costs should be developed.
- Specify the equipment implemented for each alternative in the NAS facility category.
- Determine the cost categories for data collection.
- Develop costs for each equipment item by cost category.
- Analyze the data using the cost model.
- Summarize the results.

Cost analysis is performed using a spreadsheet; this appendix describes the spreadsheet's input data. The spreadsheet itself is described in Appendix D. Section B.2 discusses the classification of NAS facilities, the criteria for selecting the equipment items to be costed, and the definition of the alternatives in terms of the equipment they contain. Section B.3 defines the cost categories, provides cost data for individual equipment items, and identifies data sources.

B.2 FACILITY DESCRIPTION

B.2.1 Classification of NAS Facilities

The study assumes a NAS configuration consisting of 22 ARTCCs, 5 MCFs, 183 TRACONs and 435 ATCTs. For the purposes of cost analysis, these facilities are grouped into 19 facility categories. The use of facility categories simplifies the modeling and the costing activity while still providing representative results.

For ARTCCs, TRACONs and ATCTs, the approach entails categorizing facilities by size as indicated by instrument operations, radar positions or sectors, and AAS processor size. This results in the definition of 12 generic facility categories: Four for ARTCCs, five for TRACONs and three for ATCTs. The remaining seven facility categories correspond to actual existing facilities: the FAATC, the FAAAC and the five MCFs. A variety of sources were used in the determination of the facility categories, including Operational Planning Management Team (OPMT) analyses, the MITRE 1987 study, and the ACF cost effectiveness study by Booz, Allen, and Hamilton, Inc. Specifically:

- ARTCC categorizations are based on an analysis of VSCS size categories, radar positions or sectors, AAS processor size categories, and natural grouping of instrument flight operations or annual aircraft handled data, based on the FAA traffic forecast of instrument operations[1] in 2005.
- TRACON size categories correspond to those used by MITRE[2] and subsequently by Booz, Allen, and Hamilton, Inc[3].
- ATCT categories are extracted from the OPMT Issues Working Group analysis of FAA Order 7031.2C[4].

Figures B-1 through B-3 describe the ARTCC, TRACON and ATCT facility categories, and specify the number of actual facilities in each category. Representative facilities in each category are also identified.

B.2.2 Equipment Selection

The focus of the study is ATC automation equipment and software. Accordingly, an ATC equipment list was developed as the framework for the analysis. This list identifies both hardware and software items and forms the basis for defining alternatives and developing their costs. The equipment list identifies current automation equipment that will be replaced by AAS, AAS equipment differentiated by AAS segment, and non-AAS equipment that is required for AAS to work properly. Common support equipment, such as surveillance, navaids and communications, is excluded from the analysis. Since these equipment items are common to all alternatives, their inclusion would have no impact on study results.

ARTCC Category	Instrument Operations (in Millions)	Radar Positions	Number of Facilities	Representative Facilities
"ctr.1"	1 - 2	43	5	ZSE ZAB ZDV
"ctr.2"	2 - 3	51	13	ZID ZJX ZTL
"ctr.3"	> 4	57	2	ZMA ZAU
"ctr.4"	< 1	18	2	ZAN ZHN

Figure B-1 ARTCC Category Facility Definition

TRACON Category	Instrument Operations (in Millions)	Radar Positions	Number of Facilities	Representative Facilities
"trm.1"	< .085	2	31	GAL CPR PUB
"trm.2"	.085 - .25	3	82	ALO COF CAE
"trm.3"	.25 - .47	6	37	ROC SDF CLE
"trm.4"	.47 - 1	9	30	AUS PIT I90
"trm.5"	> 1	16	3	MIA ATL

Figure B-2 TRACON Category Facility Definition

ATCT Category	Type	Number of Facilities	Representative Facilities
"twr.1"	Stage 1	80	YNG
"twr.2"	Stage 2	72	HRL
"twr.3"	Stage 3	283	YNG

Figure B-3 ATCT Category Facility Definition

The equipment list contains 36 hardware items and 13 software items. Figure B-4 shows the equipment suite of the baseline system and alternatives for each facility type (ARTCC, MCF/TRACON, ATCT). A description of these equipment items is provided in the Airways Facilities Sector Level Staffing Standard System[5].

ALTERNATIVE	EQUIPMENT TYPE	ARTCC	MCF/TRACON	ATCT
Baseline	Hardware	CDC/DCC/PVD	ARTS IIA	BRITE/DBRITE
		DCCR	ARTS IIIA	FDIOR
		EARTS	ARTS IIIA PAM	ICSS
		EDARC/DARC	ARTS IIE	Leased
		FDIOC	ARTSA	TDDS
		PAM	FDIOR	TVSR
		PAMRI	ICSS	TML
		WECO	Leased Voice System	
			SRAP	
	Software	Host Software	ARTS software	
Alternative 1 - 4	Hardware	ESARTS	ESARTS	ESARTS/STS
		ISSS	TAAS	TCCC
		ISSS COMMON CONSOLES	TAAS COMMON CONSOLES	
		VSCS	VSCS	
		ACCC	New TRACON A	
		ACCC COMMON CONSOLES	New TRACON B	
			New TRACON COMMON CONSOLES	
	Software	ISSS Software(1)	TAAS Software(1)	TCCC Software(1)
		ISSS Software(2)	TAAS Software(2)	TCCC Software(2)
		ACCC Software(1)	New TRACON Software(1)	
		ACCC Software(2)		
		VSCS Software(1)		
		SPS En route		

(1) Centrally maintained (at FAATC)
(2) Locally maintained (at sites)

Figure B-4 Equipment Suite Definition

The following criteria were used to develop the equipment list:

Equipment in the Baseline

- The equipment item is currently in place (e.g., ARTS IIA) or is nearing implementation completion (e.g., two additional ARTS IIIEs).

AND

- The equipment item will be replaced by AAS equipment (e.g., CDC/PVDs) or by AAS-related equipment (e.g., WECO switch).

Equipment in the Alternatives

- The equipment is part of an AAS segment (e.g., ISSS common consoles)

OR

- The equipment is AAS-related, that is, it is required for an AAS segment to work (e.g., VSCS and New TRACON automation system).

B.2.3 Equipment Specification for Baseline and Alternatives

The cost model calculates equipment counts and costs by year for each alternative and uses these values to determine the total cost for the alternative. This section describes the input data that forms the definition of an alternative.

Facility Counts specify the number of actual facilities in each of the facility categories. Since these counts do not change from one alternative to another, the same facility count data are used in the definition of every alternative. The facility count data were by-products of defining the categories. Since actual facility data were used to determine the categories, the number of actual facilities in each category was easily determined. Facility counts used in the study are shown in Figures B-1 through B-3.

Base Year Equipment is a list that specifies the count for equipment items that exist in a typical facility of each category in 1993, the first year of the study. Since all alternatives have the same starting point, the same base year equipment data are used for every alternative.

The approach taken to specify the study's base year equipment was to select representative facilities for each facility category and, based on the equipment in those facilities, to develop an initial equipment list for that category. These initial lists were further refined by generating total equipment counts over all facilities, and comparing those total counts to the totals in the Facility Schedule Inventory File (FSIF) maintained by the Volpe Center, and adjusting the equipment lists accordingly. This process was repeated until the base year definition approximated the existing ATC system.

The representative facilities selected for each category, and the resultant equipment lists, are shown in Figures B-1 through B-3.

Facility Definition is a list that specifies the count[6] of equipment items that exist in a typical facility of each category. A separate facility definition is specified for each alternative including the Baseline. These definitions were defined incrementally, since the alternatives themselves are incremental, each replacing equipment in the previous alternative.

Identification of the equipment for each alternative was derived from a variety of sources. The FSIF was the primary source of the Baseline equipment counts. Additional information to define the baseline system was obtained from the Capital Investment Plan (CIP), the FAATC, and the Systems Engineering and Integration Contractor (SEIC). For Alternatives 1 through 4, the data sources include FAA program offices, the FAATC, and the AAS and VSCS development contracts.

The equipment size and/or quantity estimates for VSCS and the AAS segments were derived from the development contracts in consultation with the AAS program office and the SEIC. Information regarding the New TRACON system, ESARTS and ESARTS/STS was provided by the SEIC. TVSR data were provided by the FAA.

Transition Schedule is a list that specifies, for each equipment item, the start date and duration of its transition into or out of facilities. A separate transition definition is used for each alternative. The number of equipment items which transition is the difference between the base year count and the facility definition count. Transition periods are defined as the time between the first and last installation (or decommissioning)[7].

FAA Program offices provided information regarding deployment schedules for AAS, VSCS and TVSR. For ESARTS, TVSR and the New TRACON system, this information was obtained from the SEIC.

B.3 COST DESCRIPTION

The cost data for this study were divided into five separate categories: Development, Capital, Transition, Facilities, and Maintenance. A variety of sources were used to identify the costs associated with each of these categories for the equipment items in the study alternatives. The following paragraphs define each category and identify the sources of the cost data for each.

B.3.1 Sunk Costs

All cost data are referenced to 1 January 1993. Costs before this date are considered sunk costs and thus not part of future expenditures. The focus of this study is the remaining development and implementation costs for each alternative as well as the costs of maintaining the equipment and systems comprising each alternative. The sunk costs for the AAS segments were obtained from the AAP office based on the IBM contract expenditures through 1 January 1993.

B.3.2 Development Costs

Development Costs are the non-recurring costs associated with hardware and software development including program management, program engineering, and a collection of other costs. As defined and used here, the development cost category collects and contains all the non-recurring cost not captured in the capital, transition, maintenance or facility categories.

The development costs are derived using data from several sources. For non-AAS equipment items such as the New TRACON automation system, data were provided by the FAATC and the SEIC. VSCS development costs were derived through analysis of the VSCS contract.

LIST OF ILLUSTRATIONS FOR APPENDIX C

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ENDNOTES FOR APPENDIX B

1. Reference: *Terminal Area Forecast, Fiscal Years 1990 - 2005*, FAA Aviation Forecast Branch, APO-110, July 1990.

2. Reference: *Advanced Automation System: A Benefit/Cost and Risk Analysis*, Report MTR-87W235, The MITRE Corporation, December 1987.

3. Reference: *Area Control Facility (ACF) Cost Effectiveness Study*, Final Report, Booz, Allen, and Hamilton, Inc, prepared for FAA, 15 February 1991.

4. Reference: *FAA Order 7031.2C: Airways Planning Standard Number 1, Terminal Air Navigation Facilities and Air Traffic Control Services.*

5. Reference: *Airways Facilities Sector Level Staffing Standard System*, DOT FAA, ASM-260, 1380.40C, Draft copy, 12 November 1992.

6. Since the count of equipment may change over the study time frame, it is necessary to provide the "post-transition" count in the facility definition specification for an alternative. The timing of the changes in equipment count is determined from the transition schedule data for that alternative.

7. To account for situations where equipment is both deployed and phased out during the study timeframe, two transitions may be specified for each equipment item. The first transition corresponds to the change from the base year count to the facility definition count. The second transition is from the facility definition count to zero.

8. Since the study, the DCCR program has been cancelled. Study results were not reformulated to reflect this change.

9. Staffing Standard items entitled "sps en route" and "sps arts" relate, at least in part, to site-specific software maintenance and adaptation activities. For this reason, the maintenance labor associated with these items is allocated to software.

10. Reference: *Maintenance Cost Growth Factor Estimates for Aging Air Traffic Control Equipment*, TIM No. 6966-1-1, The Analytic Sciences Corporation, 30 March 1993.

- For new equipment, the birth year is aligned with the first scheduled Operational Readiness Demonstration (ORD).

B.4 COST ANALYSIS

As previously noted, cost analysis is performed by a spreadsheet model whose input data consist of the facility definitions and cost data described in this Appendix. Based on these inputs, the spreadsheet calculates equipment counts and costs by year for each alternative. The annual costs for each alternative are used to determine a total discounted cost. A detailed description of the cost analysis spreadsheet is provided in Appendix D.

maintenance costs in the first five years as infant mortality items are eliminated, maintenance personnel gain experience, and troubleshooting and overhaul procedures are being developed. This is followed by a constant maintenance rate for the next 10 years when personnel training is complete, equipment designs are fully refined, and test equipment and procedures are operational. After 15 years, the equipment enters a stage where supply problems arise and components begin to wear out. Electro-mechanical equipments, such as keyboards, have a 6% annual maintenance costs increase, while electronic equipment exhibits only a 4% annual cost increase. After 25 years, there are severe problems because of major parts wearing out, experienced maintenance personnel retiring, and unavailability of parts as a result of technological obsolescence. The growth ranges are subject to some uncertainty that was factored into the sensitivity analyses.

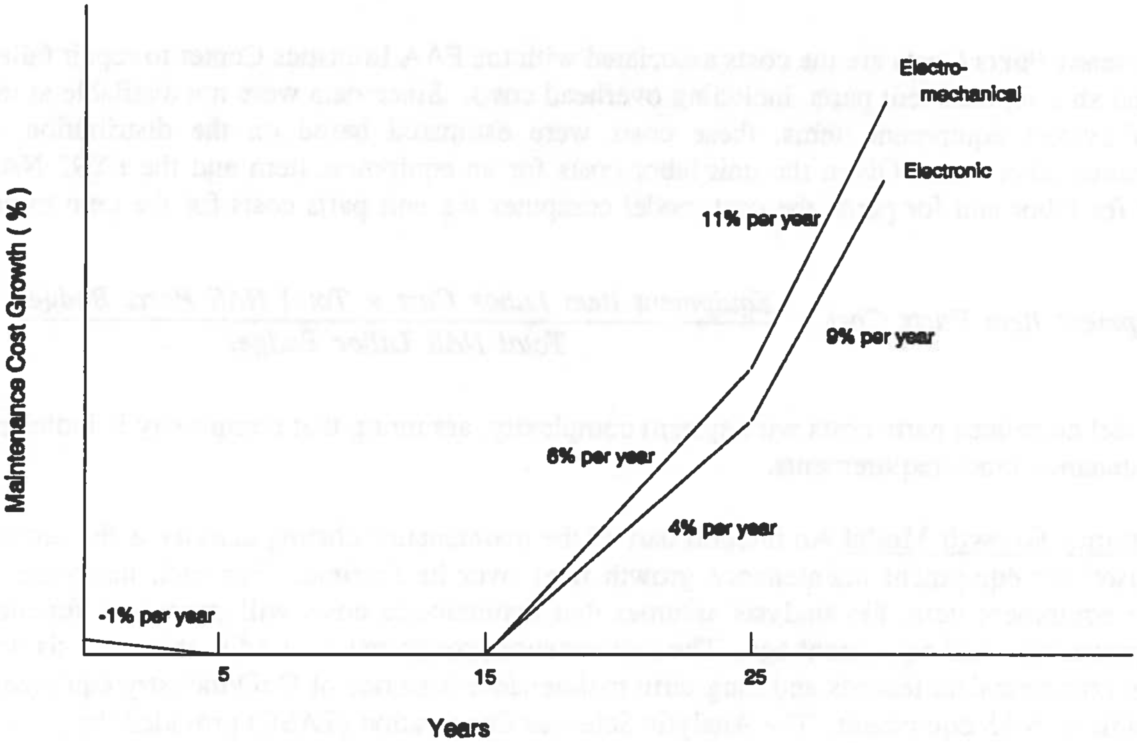

Figure B-11 Maintenance Growth Model

Equipment Age: For each system/equipment item, a 'birth year' is assigned to denote the beginning of the normal life cycle. Birth dates were determined as follows:

- For equipment that is currently fielded, birth years were determined from the FAA FSIF database. The earliest active date for each of the equipment items was chosen as the birth year.

Software Item	Annual Maintenance Cost
ARTS Software	4060.0
HOST Software	14766.0
ISSS Software	25939.2
TAAS Software	17601.6
New TRACON Software	4060.0
TCCC Software	1852.8
ACCC Software	14359.2
VSCS Software	3575.0

Figure B-10 Software Maintenance Costs at the FAATC - Total Annual Costs ($K)

Replacement Parts Costs are the costs associated with the FAA Logistics Center to repair failed items and ship replacement parts, including overhead costs. Since data were not available at the level of system equipment items, these costs were estimated based on the distribution of maintenance labor costs. Given the unit labor costs for an equipment item and the FY92 NAS budgets for labor and for parts, the cost model computes the unit parts costs for the item to be:

$$\textit{Equipment Item Parts Cost} = \frac{\textit{Equipment Item Labor Cost} \times \textit{Total NAS Parts Budget}}{\textit{Total NAS Labor Budget}}$$

This model correlates parts costs with system complexity, assuming that complexity is indicated by maintenance labor requirements.

Maintenance Growth Model An integral part of the maintenance costing activity is the growth model used for equipment maintenance growth rates over its lifetime. For each hardware or software equipment item, the analysis assumes that maintenance costs will grow as a function of equipment type and equipment age. The maintenance growth model used in this analysis was based on complete data records and long-term maintenance histories of DoD/industry equipment comparable to AAS equipment. The Analytic Sciences Corporation (TASC) provided the growth curves[10] used in this study. Several growth curves are defined corresponding to different types of equipment (electronic, electro-mechanical, or software) and different types of maintenance costs (labor, contract, parts). Each growth curve specifies the percentage increase (or decrease) in maintenance costs based on equipment age. An annual percentage increase or decrease is estimated for four age ranges: early life (0-5 years), mid-life (5-15 years), late life (16-25 years), and post design life (25+ years). Further, since ATC equipment can be grouped by technology type - electronic or electro-mechanical - two sets of estimated growth factors were developed, corresponding to these two types of equipment.

Figure B-11 illustrates the maintenance growth data for both electronic and electro-mechanical equipment. Both equipment types exhibit the same initial characteristics; i.e., a 1% decline in

Equipment	Contract Maintenance	Maintenance Labor	Replacement Parts
ARTS IIA		72.3	57.5
ARTS IIIA		243.8	193.9
ARTS IIIE		1048.0	833.3
ARTSA		29.6	23.5
ESARTS	3.3	10.9	
FDIOR		9.9	7.9
ICSS	38.3	25.3	
Leased Voice System	51.4		
SRAP		47.0	37.4
TVSR	25.0		
TAAS	352.4	346.6	
TAAS Software (site)	1302.3		
VSCS	154.4	64.7	
New TRACON		145.4	115.6
SPS ARTS		49.3	

Figure B-8 Maintenance Costs for Terminal Area Equipment - Annual Unit Cost ($K)

Equipment	Contract Maintenance	Maintenance Labor	Replacement Parts
BRITE/DBRITE		4.7	3.8
ESARTS/STS	3.3	13.8	
FDIOR		9.9	7.9
ICSS	38.3	25.3	
Leased Voice System	51.4		
TDDS		6.6	5.2
TVSR	25.0		
TML		10.2	8.1
TCCC	15.3	44.2	
TCCC Software (site)	48.6		

Figure B-9 Maintenance Costs for Tower Equipment - Annual Unit Costs ($K)

For non-AAS equipment included in the alternatives, such as the New TRACON systems, ESARTS, and TVSR, capital cost data were obtained from the SEIC.

The capital data are summarized in Figure B-5.

B.3.4 Transition Costs

Transition costs are the one-time costs associated with training personnel in the operation and usage of newly installed system(s) and associated equipment. Basic transition costs include the costs of AF and AT personnel working overtime to learn the new systems through shadow (parallel) system operations and the costs associated with developing, presenting and attending special courses.

Transition cost data were obtained from several different sources:

- For AT transition costs, the overtime required for AT personnel to learn the new systems through shadow operations was derived from information provided by FAA (ATZ). Dual operations were costed at 20% overtime at 1.5 times salary for two months for ISSS; five months for TAAS; one month for the New TRACON system; and one month for ACCC. TCCC has no planned shadow operations.

- For AF transition costs, the number of AF personnel was derived from "scaled" staffing standard values provided by the SEIC. The scaled values reflect the difference between the budgeted and actual size of the work force and account for overhead costs. An average annual salary of $55,157 to be used with the scaled staffing standard values was provided by the SEIC.

- For Training costs, AAP provided information for the AAS segments. In addition, TCCC course training data were derived from information provided by AAS Implementation Branch Training.

The transition data are summarized in Figure B-5.

B.3.5 Facility Costs

Facility costs are the costs associated with the required changes to the ATC facilities to accommodate new systems. These costs cover new building construction, expansion, or refurbishment for site adaptations and personnel relocation (called permanent change of station or PCS). These costs were provided by the SEIC and include contract support and systems engineering. The data are summarized in Figure B-6.

Equipment	Development Costs (total remaining)	Capital Cost (unit cost)	Transition Costs (total remaining)
ARTS IIIA PAM Upgrade	3900.0		
ARTS IIIE		22000.0	
DCCR	41900.0		
ESARTS	12746.9	489.0	
ESARTS/STS	13970.0	16.1	
ICSS		370.0	
TVSR		300.0	
ISSS	808271.8	3868.6	25202.9
ISSS Common Consoles		63.1	
VSCS (main procurement)	323834.0	27311.6	3806.0
TAAS	257000.0	3950.9	27535.0
TAAS Common Consoles		65.2	
VSCS Category 2		8325.6	
VSCS Category 3		10575.6	
New TRACON A	40140.0	848.4	986.0
New TRACON B		1628.4	
New TRACON Common Consoles		100.0	
TCCC	435425.0	1465.3	8180.0
ACCC	156581.0	5050.8	6599.7
ACCC Common Consoles		65.2	

Figure B-5 Non-Recurring Costs ($K)

For TAAS, the limited consolidation plan of five MCFs is assumed for this study (reflecting the current approved field configuration). Since AAS contract data are not consistent with this plan, a different approach was employed. Determining the AAS equipment to be specified for the MCFs involved several steps. Using the 1993 air traffic projections to the year 2005, the required number of instrument operations and number of radar positions were determined. From the data, the number of Common Consoles was determined. The costs of the Common Consoles with auxiliary displays were based on the segment buy under ACCC/TAAS ($65.2K per unit). In terms of other TAAS equipment requirements, the MCFs are considered a close match to the ACF-B configuration, intended for military operations, with the primary item being the central processor. The TAAS equipment costs are, therefore, based on ACF-B costs. The costs are increased by a percentage to account for the fact that this will be a smaller buy than originally planned in the IBM contract; the volume being lower, the cost would likely be higher.

Currently, TCCC segment designs include several equipment items that were not included in the IBM AAS contract at the time of this study. An estimate of these additional TCCC capital cost items was obtained from the SEIC.

For the AAS segments, the approach was to start with the total contract value for each segment, subtract sunk costs, add a portion of the contract cost that are not segment-specific (such as program management and engineering), add cost for schedule slips, and remove non-development costs. The FAA AAP Office projection of IBM contract expenditures by segment, which excluded sunk costs, was the starting point. To this was added an allocation of the non-segmented program costs, based on the relative percentage of the contract hardware cost for each segment. Adjustments were then made to factor in the anticipated program schedule slips, to allocate non-segmented costs, and to remove costs for equipment procurement and maintenance. These adjustments were based on analysis of the AAS development contract and on data provided by the AAP. The items removed were the sunk cost to 1 January 1993, the first year contract maintenance items, and remaining capital costs minus their sunk portion. In particular, for each segment:

Baseline Development Costs are minimal since most systems in the Baseline are already installed and operational. The baseline system incurs development costs, however, for the DCCRs[8] and ARTS-IIIEs. Development costs were obtained from the CIP Program 52-21 for the ARTS and from FAA ARD-100 for the DCCR.

ISSS Development Costs were determined by adjusting the IBM Contract cost for several factors. AAP projected an ISSS schedule slip of 12 months and suggested that its cost impact could be determined by averaging the expenditures for the last three years resulting in a $134,700K cost increment. AAP estimated that 30% of the ISSS capital costs were sunk.

TAAS Development Costs were determined by adjusting the IBM Contract cost for a 5-7 month slip projected by AAP. AAP suggested a $15,000K cost increment due to this schedule slip.

TCCC Development Costs were determined by adjusting the IBM Contract cost for the number of TCCC towers. AAP advised that the number of towers would be 152.

ACCC Development Costs were determined by adjusting the IBM Contract cost to remove AAP's allocation for AERA 2 costs.

These development cost data are summarized in Figure B-5.

B.3.3 Capital Costs

Capital costs are the non-recurring costs of procuring the sub-systems and equipment, such as ISSS common consoles, VSCS or ESARTS.

For the Baseline, the Capital costs were obtained from the CIP Programs and FAA personnel.

For the AAS alternatives, the Capital Costs for AAS equipment were obtained from the IBM contract CLIN items for the respective AAS segments. Since the IBM contract assumed full consolidation of terminal facilities into en route centers, revised contract values are used for the limited consolidation plan. Contract target rather than ceiling costs are used. These items are reported as capital cost per equipment unit. A discussion of issues unique to individual AAS segments is provided in the following paragraphs.

C.1 INTRODUCTION

Users of the ATC service include air carriers and their passengers. Under the basic assumptions of this study, user benefits are attributed to advanced software technology hosted on new automation platforms. The automation platforms provided by the AAS and related modernization are the enabling technology for software tools and information technology to support new ATC concepts and procedures which can impact the entire ATC process. These new concepts and procedures have the potential to provide benefits which are substantially larger than the additional investment (over and above equipment modernization) required to enable them. The study treated the additional costs and benefits of these programs separately from ATC platform modernization.

Although there is tremendous potential for advanced ATC technologies, they are currently research and development activities and are thus subject to uncertainties of timing, acceptance, and effectiveness. This places corresponding uncertainty on the beneficial return to users. This drove some of the assessment in a qualitative direction and motivated sensitivity analysis on the quantitative estimates.

C.2 SOURCES OF USER BENEFITS

To establish the current view of technology and user benefits, the Volpe Center team first reviewed previous published work by MITRE[1,2] and others currently concerned with ATC system benefits[3,4]. The MITRE study approach was to treat the AAS and its applications as one program. The quoted AAS benefits include both provider and user benefits. In 1991 the Martin Marietta Corporation, the FAA System Engineering and Integration Contractor (SEIC), performed an "economic update" of the MITRE study which refreshed the numerical assumptions used to derive the benefits, such as the value of passenger time, the relative effects of en route delay reduction, and average aircraft direct operating costs. Expenditures up to this point were considered sunk. This update did not fundamentally alter the basic assumptions of sources of benefits.

The team interviewed members of the FAA and their contractors directly involved with the AAS, AERA, and other ATC modernization programs. Members of the study team visited the AAS Development Demonstration Facility, the AERA Protolab, and the I-Lab at FAA Headquarters. An expert panel of experienced AT personnel was convened by the team for intensive discussion of the benefits of the various portions of AAS hardware and software technology and other ATC modernization. A modified form of the Delphi method was applied to gather opinions and achieve consensus[5]. The view which generally emerged was that hardware modernization alone did not firmly establish a basis for estimating user benefits quantitatively. In particular, arguments for the effects of sector-splitting capabilities of the AAS in reducing en route delay could not be firmly established. On the other hand, the benefits of the AERA technology continue to be well-accepted. Areas which showed strong evidence of future benefit and for which data were available were analyzed quantitatively. Lack of data and evidence guided some of the analysis toward qualitative assessment. The basic areas considered were as follows:

- The impact of automation technology on en route flow and direct routing -- this area has customarily been identified as the largest source of potential user benefits. The AERA technology is designed to provide controllers with software and displays to calculate and grant direct fuel efficient routes and/or user preferred trajectories (UPTs). The Enhanced Traffic Management System (ETMS) also supports services which include en route flow management and direct routing. The benefits of AERA were analyzed quantitatively with the impact of the ETMS as a baseline level.

- The impact of automation technology on congestion in terminal areas -- traffic growth will continue to cause increasing delays in terminal area airspace. The Center-TRACON Automation System (CTAS) technology developed under the TATCA program provides software and display aids to better manage approach and departure streams. The benefits of CTAS technology operating in terminal area facilities were assessed quantitatively.

- The ability of the modernized system to accommodate future growth in overall capacity -- the AAS program is generally associated with meeting future airspace demand. In-air capacity of the NAS is only part of the overall picture. The AAS addresses in-air capacity, but the issues are complex and subject to many future scenarios. This area was treated qualitatively.

- The ability of the AAS to overcome limitations in en route operations -- sector-splitting limits have been previously identified as a significant source of en route delay. Changes in the management of airspace, primarily due to flow control using the ETMS, have shifted delays from the en route segment to terminal areas and the ground. Sector-splitting capabilities will have some effect, but are subject to future operational scenarios. This area was treated qualitatively.

- The general impact of ATC improvements -- infrastructure modernization is a basic influence on the general efficiency of the national transportation system. The AAS program also embodies new technology which may have beneficial application elsewhere. These impacts were considered qualitatively.

C.3 QUANTITATIVE ANALYSIS OF USER BENEFITS

As discussed, quantitative user benefits are attributed to software which can be implemented on modernized ATC platforms. Each of the study alternatives was reviewed for the level of automation which it could support. ISSS is considered a prerequisite for the en route portion of the CTAS technology, but does not enable CTAS by itself. ISSS is also a precursor of the ACCC in en route centers, but again does not support AERA by itself. Thus, the scenario of Alternative 1 which includes the ISSS implementation is not part of the quantitative analysis, except insofar as the ISSS supports benefits under the other alternatives. Alternatives 2 and 4 introduce automation which can support the terminal area portions of the CTAS technology. These alternatives form the backdrop for the analysis of quantitative benefits in the terminal area. The AERA analysis was performed assuming the ACCC automation scenario of Alternative 3. The costs of implementing the benefit enabling technology are treated separately from the equipment costs calculated in the analysis of provider benefits.

The general approach to user benefits calculation is that functional software enhancements have positive impacts in the form of reduced airborne delays and the capability for controllers to grant direct routes to reduce flight time. These, in turn, provide savings in fuel and other direct costs for air carriers and reduced travel times for airline passengers. Air carriers benefit based upon savings in fuel, crew time, and maintenance. Passengers also benefit, based on the hourly value for their time saved. However, a savings of only a few minutes per flight is likely to seem relatively insignificant to most passengers when compared to their total trip time and other delays encountered. Benefits based on the value of passenger time are customarily performed in the analysis of transportation systems. They have been included to support comparison with other studies.

A number of assumptions apply to the quantitative estimation of both provider and user benefits. These include the study time period, the projected growth in air traffic, and required discount rates to be applied. The direct operating costs of air carriers are also a fundamental scaling parameter in benefits calculations. The value of time is used to express passenger benefits.

Study Time Frame

The time frame for user benefits analysis is the same as that applied for provider benefits analysis and covers 1993 - 2020. Similarly, the base year is 1993. All costs associated with technology which enables benefits prior to 1993 are assumed to be sunk.

Air Traffic Growth

Benefits to users are calculated as value streams over the study years. In any given year the number of users (aircraft and passengers) is proportional to the total aircraft traffic. Total traffic generally increases from year to year. Annual air traffic growth was assumed at 2%, as in the analysis of provider benefits, based on discussion with the FAA.

A value of 1.9% was applied to the category of non-major air carriers over the period from 1993 to 2004, as addressed in the FAA Office of Aviation Policy and Plans (APO) traffic projections[6]. Beyond 2004 this category was assumed to show constant yearly growth at the same rate of 1.9%.

Discount Rates

Procedures and guidelines for the determination of benefits were based on OMB guidelines[7] and FAA system evaluation guidance[8]. The real discount rate applied to user benefits value streams is 7%. Real discount rates of 4% and 10% are also required as sensitivities.

Air Carrier Direct Operating Costs

The estimate of average aircraft hourly operating costs was derived directly from sample flight data. Data from 11,420 actual flights in the NAS was obtained, as explained below, from the Enhanced Traffic Management System. The data were segregated by major air carriers and non-major air carriers as per RSPA classification for the most recently reported quarter of Form 41. A "major air carrier" is defined as one who achieves more than $1 billion in annual revenues. Major carriers constituted 9,770 of the flights or about 85% of the sample. The remainder of the sample includes a mix of commuter and air taxi carriers, business jet aircraft, and other piston engine general aviation users. This was grouped under the aggregate category of non-major aircraft carriers.

All flights were analyzed for total aircraft types and airborne hours of utilization. For each aircraft type the hourly costs of fuel (based on consumption at cruising altitude), crew, and maintenance were used to form a properly weighted average for the fleet mix in the sample data. Crew and maintenance were inflated from 1987 data using standard FAA adjustment methodology[9]. The analysis estimated an average hourly operating cost of $1652 (in 1992 dollars) for major air carriers. It was recognized as reasonable based on the assumptions and is close to values used by the FAA in other current analyses, such as the Aviation System Capacity Plan[10].

Discussions with the Air Transport Association (ATA) indicated that the value used for aircraft operating costs is lower than values used in their analyses. Direct operating costs are subject to some variation depending upon the actual costs of particular air carriers[11]. For example, wide-body jets typically experience costs between $3000 and $4000 per hour. Air carriers also allocate costs for insurance, taxes, depreciation, and leases as hourly direct costs. This makes the composition of their numbers inherently larger. A value of $1800 was examined within the sensitivity analyses.

Non major air carrier operating costs are considerably lower at an $171.50 per hour for the fleet average. This includes fuel, crew, and maintenance costs and is based on 1987 data for 121 general aviation aircraft types, weighted by airborne hours. The data are from FAA, Economic Values for Evaluation of FAA Investment and Regulatory Programs. The 1987 figures were inflated to 1992 dollars using standard FAA adjustment methodology.

Passenger Load and Value of Passenger of Time

Savings of even a few minutes per flight can be beneficial to airlines because the associated cost savings are cumulative. Time savings to passengers is of less tangible value, particularly if the savings are only a few minutes per flight. Passenger benefits are included in the analyses because they are a customary measure of benefits for transportation programs.

The study also calculated passenger benefits for all flights. This is based on the value of passenger time and the average number of passengers per flight. The value of passenger time is set at $42 per hour, based on FAA guidance and practice. This value is used in current FAA studies to facilitate comparisons between studies and programs. The study assumed an average value of 153 seats per major air carrier aircraft. The average passenger load factor in this category is 62.5%. This makes the average passenger load approximately 95.6 per plane. These values are based on the forecast for FY 1993 from the FAA Aviation Forecasts[12].

For the non-major air carrier category, the value of passenger time is based on averages for business trips on commuter and air taxi carriers, business jet aircraft, and other piston engine general aviation aircraft weighted by the number of trips on each type. The aggregate 1992 value of $82.60 per hour is derived from 1987 data[13]. The figures were inflated to the base year with standard FAA adjustment methodology. The average number of seats per aircraft in this category was 4.97 in 1987 and the load factor was 51.55%. The average passenger load is then approximately 2.56 per plane.

C.3.1 AERA and User Preferred Trajectories

C.3.1.1 Data Sources

The AERA Program is developing advanced software intended for the AAS ACCC automation environment in en route centers[14]. This software will provide controllers with the information and displays necessary to manage airspace more flexibly so that more direct flight routes can be granted. In addition, user preferences for special routes which maximize comfort or speed based on winds and weather will be accommodated. The general category of such routes is often referred to as "user preferred trajectories" or UPTs. For the purposes of analysis, UPTs were assumed to be the most direct possible routes; that is, they were modeled as great circle routes. On average, great circle routes will tend to maximize fuel savings. While greater savings may be possible for specific flights based on altitude, winds, and direction of travel, the great circle assumption enabled a timely analysis of the problem. The benefit provided by AERA is the ability to grant direct routes in place of the standard routes. It was, therefore, necessary to obtain a good sample of standard route information.

Flight Route Data

Initially the study reviewed flight sample data from previous studies. However, the presence of the ETMS at the Volpe Center provided a unique opportunity to sample actual current flights over a period of three days to support this study. The ETMS receives flight plan and surveillance data for every aircraft in the NAS. In preparing to collect data, 35 airports were selected. Largely these consist of the airports with the most operations. However, a few of the top 35 airports showed strong involvement with only one or two other airports in the list. These were dropped in favor of the next busiest airports that had more involvement. This was determined by examining an origin-destination matrix created form the flights contained in the June 1990 file of the DOT Airline Service Quality Performance System.

Data for all flights between the selected city pairs was collected for the study by members of the ETMS support staff over a period of three days (February 7, 8, and 9 of 1993). The data provided a sample of 11,420 flights from which to analyze overall traffic and identify Continental United States (CONUS) airports with high activity. The sample covers a Sunday, Monday and Tuesday during fair weather over most of the CONUS during a fairly average Winter travel period. Some seasonal bias is likely. This includes reduced North-South travel routes and a lower overall level of traffic. Despite these shortcomings, the sample is substantially larger than that used in previous studies. All of the flights departed and arrived in domestic airspace only. The sample extracted from the ETMS included the following data items for each flight:

- Flight Identification -- The flight plan number as registered and handled in the NAS. The data enables distinguishing commercial airline and air transport flights from general aviation users.
- Departure Airport -- Originating point for the flight. The data are used to determine the level of activity for particular airports.
- Arrival Airport -- Destination point for the flight. The data are also used to determine the level of activity for particular airports.
- Aircraft Type and Class -- The data help to characterize the user population in terms of speed, fuel usage, operating costs, and passenger load.
- Total Traffic Management (TTM) -- The ETMS uses this term for the predicted time over all segments of the standard flight plan route computed from the optimal speed of the craft taking into account winds aloft information (available to the ETMS). This is essentially an optimal flight time for the standard route. Note that this is not the same as that published in airline schedules, which allow for some airborne and ground delay.
- Free Flow Time -- The predicted time for the aircraft if it could travel a great circle route from the origin to the destination. The same speed and winds aloft information as used for the TTM is used by the ETMS to form this calculation.
- Actual Time -- The reported time for the aircraft to travel the actual route from the origin to the destination. It is essentially a "wheels up" to "wheels down" time as reported by the pilot. These data provide a measure of the distribution around the TTM data. They were also used to calculate total airborne hours which was used to weight fleet equipment types by airborne hour utilization. This is part of the operating cost calculations.

The data extraction process was also used to perform some of the basic analysis. The fundamental calculation is the difference between the standard route and the free flow times. This difference is a prediction of the improvement which direct routing could provide. The standard route rather than the actual time is used as the basis of improvement in order to assess potential benefits against the current system in optimal operation. Again, the assumption is that the great circle is a reasonable measure of that improvement. For some flights the difference was negative. These data suggest the fact that winds can make standard routes faster than great circle routes. These differences were set to zero on the assumption that a flight trajectory less optimal than the standard route would not be preferred by users. The difference was also expressed as a percentage of the standard route time to help characterize the relative improvement available as a benefit.

AERA Effectiveness and Minimum Flight Length

An exhaustive analysis of AERA effectiveness was not within the scope of the present study. The study assumed an effectiveness of 60% for the AERA services in granting efficient routes. This is the same value assumed in previous AAS benefit/cost analysis[15]. Presumably, controllers would attempt to reduce all eligible routes by as much as possible.

After presentation of the study results and discussions, the 60% assumption appeared conservative. This was particularly true in the light of the exclusion of UPTs which could be supported by the ETMS. Some proponents of AERA claim 100% effectiveness as a realistic goal. The AERA technology will likely not be capable of granting the most efficient routes to all users of the ATC system all of the time. It is also likely that some users will prefer routes which are optimized for other factors such as passenger comfort or maximum speed. The 60% assumption was adopted essentially for the purposes of comparative analysis. A sensitivity range of plus or minus 20% was also assumed; that is, effectiveness limits of 80% and 40% are used for comparison. The 80% value is viewed as an attainable goal after AERA services have been operational for a number of years. The impact of effectiveness on benefits is discussed in the sensitivity analyses.

In this analysis it was assumed that flights of less than 500 nautical miles could not be improved by the application of AERA services. Discussions with FAA Air Traffic personnel indicated that it is not clear how user preferred trajectories could be granted within terminal airspace. This region typically extends up to 200 miles around airports. For origin-destination (OD) airport pairs closer than 500 miles it appeared unlikely that any benefits could be achieved using the AERA technology because very little en route airspace would be transited. Flight paths are restricted within terminal airspace because of constraints in defined approach and departure routes, noise control, security and so on.

After discussion of the study results, the 500 nautical mile exclusion appeared conservative, though still reasonable. Permitting shorter minimum flights to be supported by AERA services increases the effective user population. Exclusion minimums of 400 and 300 nautical miles were used for comparison in the sensitivity analyses.

AERA Implementation Schedule and Cost

The ACCC en route host replacement hardware and software will be designed to support the new AERA software. In the basic scenario, the full benefits associated with AERA are realized after all en route centers are upgraded to ACCC and the AERA functionality is installed. To model this the implementation schedule for AERA was assumed to follow that of the ACCC as in study Alternative 4. Phase-in of AERA begins in 1999 and is complete by 2001. The re-engineered host software included in the ACCC was assumed as a necessary and sufficient prerequisite to AERA implementation.

Although the basic assumption is that AERA services will phase in with the AAS ACCC segment by 2001, full transition to AERA services will also require substantial changes in the management of en route airspace. Thus, full effectiveness might be delayed until later than 2001. Although there is a potential for long-term schedule delay, it depends upon the future administration of the ATC system. This was not examined in the study.

An earlier deployment schedule for AERA might also be considered, based on current investigations at the FAA. A concept study will determine the feasibility of deploying AERA with the current Host Computer System and an outboard processor. This program is only in the beginning stages and results are not currently available. Both the costs and schedule for deploying AERA in this manner are uncertain. Initially these uncertainties in deployment did not appear strong enough to warrant additional analysis. Tying AERA to ACCC remains the reasonable underlying assumption for the study. However, interest in the impact of earlier AERA deployment was expressed by the ATA and others following briefing of the study results. An earlier deployment phase-in period of 1996-1998 was used to examine the impact on user benefits. The impact of early AERA deployment on implementation costs was not considered.

The additional investment cost for AERA is based on estimates of remaining development costs, testing, and transition. Cost data were obtained as part of the AAS ACCC segment costs from the FAA. As such, they represent the costs for what has been defined as "AERA 2". The assumption is that this adequately represents the costs of what is currently referred to as Full AERA Services (FAS) under new plans for the program. The estimates for AERA costs could only be approximated, and are placed at $100 million. The major cost is the remaining development and implementation, assuming completion of the ACCC. This is approximately $65 million. The remainder covers FAA testing and transition.

Any current estimate of AERA costs is subject to uncertainty. The AERA program has been in a funding hiatus and budget figures provided by the AAS Program Office are based on previous plans for the program. The AERA program budget will be revised with renewed activity under newer plans. The estimated transition costs and phase-in time for AERA do not cover the effort associated with developing new ATC procedures and redefining airspace. This effort may be substantial, although it will take place slowly over the course of regular operations. Controller training and acceptance time periods may also be longer than anticipated. In addition, the widespread application of AERA may depend to some extent on improvement of navigation and collision warning and avoidance systems within participating aircraft. This dependence is implicit in the sense that reduced separation standards may be required in order to assign large numbers of aircraft to direct routes in high volume airspace. The in-aircraft systems enable safe reduction of separation standards. All of these factors have the potential to increase AERA implementation costs and lengthen the implementation schedule, but an analysis was not within the scope of the study.

C.3.1.2 Analysis of AERA Benefits

The ETMS sample data were analyzed for the benefits to "major" and "non-major" air carriers. Major air carriers are defined per Research and Special Programs Administration (RSPA) classification as having more than one billion dollars in annual revenue for the most recently reported quarter of Form 41 data. The majority of flights represent major carriers. The non-major air carrier category represents the remainder of the sample. Non-major carriers include commuter and air taxi operators, business aircraft, and other light aircraft IFR flights.

Major Air Carriers

The first step in analysis was to annualize the data sample. The 9,770 major air carrier flights were used to scale the annual national figure of 6.2 million major air carrier departures recorded in FY 1992 (FAA Aviation Forecasts FY 1993 - 2004). The sample data were divided by categories of flight distance, referred to as stage lengths, in bins of 500 nautical miles up to 1500 nautical miles. This is shown in Figure C-1.

Stage Length (Nautical Miles)	Sample Departures (Major Air Carriers)	% of Total
Below 500	5,476	56.05
500 - 1000	3,585	36.69
1001 - 1500	591	6.05
Over 1500	118	1.21
Totals	9,770	100.00
Over 500	**4,294**	**43.95**

Figure C-1 Sample Major Carrier Departures by Stage Length

The bins in the sample were then fractionally scaled to the total for 1992. This predicts annual traffic by stage length in the same distribution as the three-day ETMS sample (Figure C-2).

Stage Length (Nautical Miles)	Sample Departures (Major Air Carriers)	Annual Departures (Major Air Carriers)
Below 500	5,476	3,477,260
500 - 1000	3,585	2,276,475
1001 - 1500	591	375,285
Over 1500	118	74,930
Totals	9,770	6,203,950
Over 500	**4,294**	**2,726,690**

Figure C-2 Annual (Base Year) Major Carrier Departures by Stage Length

Assuming that flights of less than 500 nautical miles could not be improved suggests that approximately 44% of annual major air carrier flights could potentially benefit from direct routes.

Central Flow Control currently provides a service known as the National Route Program (NRP). The NRP currently grants between 100 and 200 direct flights each day. These are long routes over 1500 nautical miles and above Flight Level 390 (barometrically indicated altitude of 39,000 feet). Discussions with Central Flow Control and other experienced AT personnel indicate that the NRP should be expandable. The NRP could be adjusted to cover more flight levels and trips as short as 750 miles in length. Based on discussions with experts, the study team estimated that under these conditions the NRP might accommodate as many as 1000 flights per day. Under this assumption, this level of UPTs could be realized under the Baseline. So as not to attribute this level of benefit uniquely to the AERA services, the annualized distribution of 2,726,690 major air carrier flights over 500 miles stage length was reduced by 365,000 flights per year to 2,361,565. The reduction is applied to the largest stage length bins first. The results of the adjustment are shown in Figure C-3. This further reduces the user population eligible for AERA benefits to approximately 38% of the total annual major air carrier flights.

Stage Length (Nautical Miles)	Sample Departures (Major Air Carriers)	Annual Departures (Major Air Carriers)
Below 500	5,476	3,477,260
500 - 1000	3,585	2,276,475
1001 - 1500	134	85,090
Over 1500	0	0
Totals	9,195	5,838,825
Over 500	**3,719**	**2,361,565**

Figure C-3 Annual (Base Year) Major Carrier Departures by Stage Length Adjusted for NRP

The difference between optimal time over the standard route and time over free flow (great circle) direct route is the available savings for each particular flight. The average difference for flights within particular ranges of stage length is a convenient way to express the benefits represented in the sample. This analysis appears in the right hand columns of Figure C-4.

Stage Length (Nautical Miles)	Sample Departures (Major Air Carriers)	Average Savings (Minutes)
Below 500	5,476	2.87
500 - 1000	3,585	3.66
1001 - 1500	134	3.19
Over 1500	0	0.00
Total	9,195	▨
Over 500	**3,719**	**3.64**

Figure C-4 Major Carrier Potential Average Time Savings Per Flight by Stage Length

Each of the averages within the stage length bins is only a few minutes. This is intuitively reasonable; that is the current ATC system is relatively efficient for this category of air carriers. Standard major air carrier routes tend to be fairly straight on average, although there is some room for improvement. Also, the differences are between modeled optimum performance of the current system and the shortest possible routes modeled by great circles. These differences do not contain any of the typical delays that result from diversions or slowing because of weather or congested en route sectors. This analysis does not consider these effects.

The impact of the NRP is that it diverts most of the potential benefits associated with long flights. It is important to recognize that future plans are to essentially integrate the operations of AERA and the ETMS under an integrated en route automation system. The benefits of each will ultimately be inseparable. The point of the analysis here is that some benefits could be achieved for the longest routes with the ETMS even if the ACCC and AERA technology were not developed.

To estimate the potential savings for the base year, the annualized total number of departures by stage length is multiplied by the average number of minutes of time saving available and expressed in hours. Passenger time is computed on the basis of average seating (153 per aircraft) and average load factor (62.5% occupancy). This is shown in Figure C-5.

Stage Length (Nautical Miles)	Annual Departures (Adjusted for NRP)	Average Savings (minutes)	Potential Annual Air Carrier Savings (Hours)	Potential Annual Passenger Savings (Hours)
Below 500	3,477,260	2.87	166,455	15,917,228
500 - 1000	2,276,475	3.66	138,843	13,276,838
1001 - 1500	85,090	3.19	4530	433,149
Over 1500	0	0.00	0	0
Totals	5,838,825		309,827	29,627,215
Over 500	**2,361,565**	**3.64**	**143,372**	**13,709,987**

Figure C-5 Major Air Carrier Potential Annual Savings

The total potential for savings in air carrier operating hours and passenger hours translate into dollars for the base year assuming $1652 per hour for aircraft operating costs and $42 per hour for the value of passenger time, respectively. The AERA services will achieve some portion of the full potential savings benefits for air carriers and passengers.

Results and Sensitivity

Benefits begin to accrue in 1999 as AERA is phased in, with full benefits phased in after 2001. Calculation of the present values of benefits of AERA assumed a real 7% discount rate to express results in 1992 dollars. The various assumptions applied to estimate the benefits of AERA are subject some uncertainty. Sensitivity analysis was applied around the results for comparisons. Sensitivity was examined by varying the assumptions in the following areas:

- Real discount rate
- Effectiveness of AERA in enabling user benefits
- Hourly direct operating costs for major carriers
- Minimum flight length for AERA services
- AERA implementation schedule
- Air traffic growth

Real Discount Rate

OMB guidance[16] requires additional calculation of benefits at real discount rates of 4% and 10%. These alternate discount rates provide high and low comparisons. The effect of discount rate was examined in combination with sensitivity to AERA effectiveness discussed below.

AERA Effectiveness

Figure C-6 summarizes the results for user benefits of AERA at different effectiveness levels. Annual aircraft traffic growth rate is 2%.

Real Discount Rate	Air Carriers			Passengers		
	AERA Effectiveness			AERA Effectiveness		
	40%	60%	80%	40%	60%	80%
4%	$1,439	$2,158	$2,878	$3,498	$5,247	$6,996
7%	$919	$1,379	$1,838	$2,235	$3,352	$4,469
10%	$611	$917	$1,222	$1,486	$2,228	$2,971

(Millions of 1992 Dollars)

Figure C-6 AERA User Benefits for Major Carriers At 2% Annual Traffic Growth

At the real discount rate of 7%, the 1992 constant dollar estimates of the present value of AERA benefits are $1,379 million for the air carriers and $3,352 million for passengers. The effectiveness of AERA services in producing user benefits was varied from 40% to 80% around the assumed value of 60%. The lower effectiveness of 40% still predicts substantial benefit to users from AERA implementation. The dependence on the effectiveness of AERA is a simple linear relationship; that is, as AERA effectiveness is increased, benefits increase proportionately. Dependence on the real discount rate is also shown. The basic relationship shown in the results is a fairly strong inverse dependence.

Minimum Flight Length and Direct Operating Cost

Discussion of the study results indicated strong interest in the minimum flight length which AERA services will be able to support. There is decreasing agreement among experts as the minimum is reduced below 500 nautical miles. A minimum of 200 nautical miles does not appear technically feasible because of inherent constraints on the structure of terminal area airspace. Reducing the minimum flight length supported by AERA services increases the population eligible for benefits. In addition, the direct operating cost could be as high as

$1800/hour depending on the future aircraft fleet mix. This operating cost is consistent with the basic constraints applied to obtain the $1652/hour figure. Three additional AERA benefits scenarios were analyzed at the higher $1800/hour cost for minimum flight lengths of 500, 400, and 300 nautical miles. These are shown in Figure C-7. The assumed AERA effectiveness value of 60% and the higher value of 80% are also compared in these scenarios.

Minimum Flight Length 500 Nautical Miles

Real Discount Rate	AERA Effectiveness			
	Air Carriers		Passengers	
	60%	80%	60%	80%
4%	$2,351	$3,135	$5,247	$6,996
7%	$1,502	$2,003	$3,352	$4,469
10%	$999	$1,332	$2,228	$2,971

Minimum Flight Length 400 Nautical Miles

Real Discount Rate	AERA Effectiveness			
	Air Carriers		Passengers	
	60%	80%	60%	80%
4%	$2,699	$3,598	$6,022	$8,029
7%	$1,724	$2,299	$3,847	$5,129
10%	$1,146	$1,528	$2,557	$3,410

Minimum Flight Length 300 Nautical Miles

Real Discount Rate	AERA Effectiveness			
	Air Carriers		Passengers	
	60%	80%	60%	80%
4%	$3,364	$4,486	$7,506	$10,008
7%	$2,149	$2,866	$4,796	$6,394
10%	$1,429	$1,905	$3,188	$4,251

(Millions of 1992 Dollars)

Figure C-7 AERA Benefits vs. Minimum Flight Length (Major Carriers at $1800/Hour)

AERA Implementation Schedule

Some early recipients of study results also expressed interest in the possibility of earlier implementation of AERA services. While this is not yet an option with demonstrated technical feasibility, an assumption of deployment in 1996 - 1998 was used for comparison. This is shown in Figure C-8. The 60% effectiveness was applied to this calculation.

Air Carriers		Passengers	
AERA Deployment Period		AERA Deployment Period	
1999-2001	1996-1998	1999-2001	1996-1998
$1,379	$1,714	$3,352	$4,168

(Millions of 1992 Dollars at 7% Discount Rate)

Figure C-8 Sensitivity of Major Carrier AERA Benefits to Implementation Schedule

Under the early deployment scenario benefits arrive three years earlier and accrue for three years longer. This increases the net present value of benefits in any AERA scenario by approximately 24%. However, such an actual deployment scenario is still under evaluation and the outcome cannot be predicted.

Air Traffic Growth

The value of air traffic growth applied to the AERA analyses is 2% for major air carriers. Briefings of the study results brought some inquiries on the dependence on traffic growth, specifically the impact of no growth in air traffic. Sensitivity to this assumption is more subtle and is a non-linear dependence. The annual traffic volume is a basic determinant of the benefits in any given year. The value of 2% was considered reasonable and consistent with FAA forecasts. However, a specific inquiry was directed at an assumption of *no air traffic growth* over the study period. Such an assumption reduces the estimated value of air carrier benefits from $1,379 million to $1,026 million.

Passenger Time Savings

As discussed, passenger time savings benefits were estimated quantitatively based on average seating, average load factor, and an assumed value of $42.00 per hour. This yields substantial monetary benefits. However, the actual time saving represented by these benefits is generally small compared to overall flight times. This was established by reconsidering the ETMS data sample from the point of view of potential time savings instead of flight stage length. That is, the time savings were scaled by the AERA effectiveness of 60% and binned according to length of time. This analysis was applied to the sample of major air carrier flights over 500 miles in length and reduced by the 1000 flights per day share attributable to the NRP. This is shown in Figure C-9.

This analysis demonstrates that over 99% of AERA benefits to passengers are for savings of less than 15 minutes per flight. These savings are cumulative and measurable to air carriers as reductions in direct operating cost expenditures. However, for passengers, such savings may not

Time Savings (Minutes Per Flight)	% of Total	Cumulative %
0 - 4	67.57	67.57
5 - 9	25.30	92.87
10 - 14	6.08	98.95
15 - 19	0.81	99.76
20 - 24	0.19	99.95
25 - 29	0.03	99.97
Over 30	0.03	100.00

Figure C-9 Time Savings for Major Air Carriers in Flight Data Sample

appear that significant relative to overall flight time. The real issue for the travelling public is the dependability of published schedule information. The airline traveller is faced with a variety of ground delays including boarding, gate holds, and on the taxiway. Airborne savings provided by AERA will speed the traveller's trip but are only one facet of the overall delay problem.

Non-Major Air Carriers

Analysis of UPT benefits to non-major air carrier was conducted in a similar fashion to the major carriers. The three-day ETMS sample showed 1650 flights in this category. As in the analysis of the major air carrier data, the sample was divided by categories of flight distance (stage lengths) in bins of 500 nautical miles up to 1500 nautical miles. This is shown in Figure C-10.

Stage Length (Nautical Miles)	Sample Departures (Non-Major Air Carriers)	% of Total
Below 500	1,551	94.00
500 - 1000	73	4.42
1001 - 1500	23	1.39
Over 1500	3	0.18
Totals	1650	100.00
Over 500	**99**	**6.00**

Figure C-10 Sample Non-Major Carrier Departures by Stage Length

The annual departure total is 23,100,000 combined commuter, air taxi, and other general aviation (FAA Aviation Forecasts FY 1993 - 2004). This figure is much higher than the annual total for major air carriers (6,203,690) and reflects the much large fraction of aircraft in this category which operate primarily on short trips in terminal airspace. The sample data show this trend.

The distribution of flights by stage length was annualized by fractional scaling against the base year total as shown in Figure C-11.

Stage Length (Nautical Miles)	Sample Departures	Annual Departures
Below 500	1,551	21,714,000
500 - 1000	73	1,022,000
1001 - 1500	23	322,000
Over 1500	3	42,000
Totals	1650	23,100,000
Over 500	**99**	**1,386,000**

Figure C-11 Annual (Base Year) Non-Major Carrier Departures by Stage Length

There is no adjustment of this part of the sample for participation in the National Route Program. The available NRP routes will be completely consumed by major air carriers. This sample set of non-major air carrier flights was also analyzed for potential time savings. Average savings by stage length are listed in Figure C-12.

Stage Length (Nautical Miles)	Sample Departures (Non-Major Air Carriers)	Average Savings Per Flight (Minutes)
Below 500	1551	
500 - 1000	73	4.62
1001 - 1500	23	1.74
Over 1500	3	2.33
Total	1650	
Over 500	**99**	**3.88**

Figure C-12 Non-Major Carrier Average Potential Time Savings Per Flight by Stage Length

The average potential time savings by stage length translate to total annual carrier operating and passenger time savings. The passenger time savings is computed from the average number of seats per aircraft (4.97) and the average load factor (51.55%). This is shown in Figure C-13.

The full potential for air carrier and passenger time savings translate into dollars for the base year using $171.50 per hour for aircraft operating costs and $86.20 per hour for the value of passenger time, respectively, from the FAA's economic values. These are applied against values for all flights in this category over 500 nautical miles.

Stage Length (Nautical Miles)	Annual Departures (Adjusted for NRP)	Average Savings Per Flight (Minutes)	Aircraft Savings (Hours)	Passenger Savings (Hours)
Below 500	21,714,000			
500 - 1000	1,022,000	4.62	78,694	20,617
1001 - 1500	322,000	1.74	9,338	23,924
Over 1500	42,000	2.33	1,631	4,179
Total	23,100,000			
Over 500	**1,386,000**	**3.88**	**89,633**	**229,720**

Figure C-13 Non-Major Carrier Potential Annual Savings

The forward extrapolation of potential dollar savings is based on the value of 1.9% for non-major air carriers over the period from 1993 to 2004. This value is from the FAA Aviation Forecasts FY 1993-2004. Beyond 2004 constant yearly growth the same as 2004 is assumed. Benefits begin to arrive in 1999 as AERA is phased in, with full benefits accumulating after 2001. AERA effectiveness is also assumed to be 60% for flights in this category.

Results and Sensitivity

Figure C-14 summarizes the results for non-major air carriers at traffic growth of 1.9% assuming AERA deployment in the 1999-2001 period.

Real Discount Rate	Air Carriers			Passengers		
	AERA Effectiveness			AERA Effectiveness		
	40%	60%	80%	40%	60%	80%
4%	$92.0	$137.9	$183.9	$113.5	$170.2	$227.0
7%	$58.8	$88.2	$117.6	$72.6	$108.9	$145.1
10%	$39.1	$58.7	$78.3	$48.3	$72.4	$96.6

(Millions of 1992 Dollars)

Figure C-14 AERA User Benefits for Non-Major Carriers

Figure C-15 compares results for non-major air carriers of AERA deployments in the 1996-1998 and 1999-2001 periods. The assumed effectiveness of 60% is applied to this calculation.

Air Carriers		Passengers	
AERA Deployment Period		AERA Deployment Period	
1991-2001	1996-1998	1991-2001	1996-1998
$88.2	$109.9	$108.9	$135.6

(Millions of 1992 Dollars)

Figure C-15 Sensitivity of Non-Major Carrier AERA Benefits to Implementation Schedule

C.3.2 CTAS and Terminal Area Delay

C.3.2.1 General

The CTAS technology attacks the problem of delay from congestion in terminal area airspace. The principal product of this program is the Final Approach Spacing Tool (FAST) which assists terminal area controllers in achieving and maintaining optimum spacing during approach. Supporting software is also provided in the adjacent en route centers. This includes the Traffic Management Advisor (TMA) and the Descent Advisor (DA). These tools smooth the transition between the en route center and the terminal area.

CTAS benefits depend upon alleviating delay within terminal airspace. Delay depends in turn upon the amount air traffic growth. The benefits calculations are driven by current air traffic growth projections over the entire study period. The analysis of CTAS benefits depends upon the effect of air traffic growth on terminal area congestion -- increased traffic without increase in ground or airspace capacity causes growth in delay.

Planned ATC modernization includes AAS technology and also covers other initiatives, particularly in terminal area facilities. The terminal area portions of CTAS technology can be hosted on TAAS or the "New TRACON" automation system. CTAS can also be hosted on ARTS-IIIE systems, as installed in the New York TRACON, and planned for Chicago and Dallas/Fort Worth. Thus, CTAS benefits for these sites could be realized under the Baseline scenario. The effect of this is to erode some of the benefit attributable to TAAS with CTAS.

Analysis was performed assuming the automation scenarios of both Alternative 2 and 4. CTAS plans cover initial implementation at five sites, followed by later implementation at five additional sites. The five initial sites are assumed to be MCFs under Alternative 2. Only the two MCF terminal areas not previously serviced by ARTS-IIIEs receive new benefits from CTAS; that is, Denver and Southern California MCFs. These cover airports in Denver, CO and Los Angeles and Santa Ana, CA. Under the Alternative 4 scenario, five additional sites are considered assuming that CTAS is hosted on the New TRACON system. These cover five TRACON facilities that collectively service seven airports assumed to receive CTAS.

The CTAS program provides automation tools for optimizing approach streams in terminal areas. The primary tools are those which operate in equipped terminal area facilities. The automation aids also include tools for en route center controllers to manage the handoff to the terminal area. These tools are implemented in the en route centers. The role of the en route centers in the CTAS implementation is essentially ignored in this analysis. Implementation costs are apportioned based only on the number of terminal area facilities equipped. The analysis assumes that the benefits apply only to the terminal airspace in which CTAS services are employed. User benefits of CTAS depend upon the effects of the technology on terminal area traffic flow[17].

C.3.2.2 CTAS Implementation Schedule and Cost

The CTAS technology has been demonstrated and is considered to be available for implementation in the near-term. Five sites are initially planned within the CTAS budget, to be followed by five additional sites later. The system is currently designed to operate on outboard processors at the en route centers and at TRACONs or MCFs. The near-term implementation of the CTAS is assumed to be possible on the three MCFs with ARTS-IIIE systems in the Baseline scenario. The costs of this implementation are not considered here because the benefits associated with these terminal areas are also not considered.

The implementation of the CTAS in the remaining two MCFs is tied to the TAAS schedule assumed for study Alternative 2. The phase-in schedule is for two years beginning in 1998. Costs for this implementation are apportioned from the budget for the program. A total of ten sites are budgeted. The two TAAS (Denver and Southern California MCFs) are assumed to require 2/10 or 20% of the budgeted $160 million implementation cost for the ten sites. The cost for this implementation phase is approximately $32 million.

The implementation of CTAS in five additional facilities is assumed to follow the implementation of the New TRACON system under Alternative 4. These sites phase-in according to the assumed schedule for implementation of the New TRACON system from 1998 to 2002. Each of these sites receives an additional 1/10 or 10% of the budgeted costs. The additional cost for this implementation phase is approximately $80 million.

C.3.2.3 Analysis

Analysis of the benefits of CTAS depends upon the effectiveness of that technology in reducing delay in congested terminal areas. Delay of flights arriving at a particular airport is caused by many factors, such as available runway capacity, number of defined instrument approaches, and terminal area congestion; that is, the amount of traffic in the terminal area airspace around the airport. Of greatest interest in the analysis of CTAS benefits is the effect of air traffic growth on terminal area congestion. Increased traffic in the local terminal area without increase in ground and airspace capacity causes growth in delay at a particular airport.

Prediction of Airport Delay

This analysis relied on an established method for predicting delay at airports as a function of growth in traffic. The method uses weighted regression equations based on observations to predict delay as function of traffic for specific airports. It was originally developed by Safeer and Geisinger at the FAA/APO[18,19]. It depends upon data reported under the FAA Standardized Delay Reporting System (SDRS) which covers 1976-1986 and the DOT Airline Service Quality Performance (ASQP) System which covers delays since 1987. The method has been used elsewhere such as in the annually updated FAA Aviation System Capacity Plan[20].

The FAA/APO delay forecasting equations relate airport traffic volume of operations (current or projected) to the airport capacity to service that volume. Operations are the total number of arrivals and departures at each airport. Airport capacity is usually defined in terms of Annual Service Volume, a composite measure of the ability to service traffic. The equations are fitted to available historical data for each airport and used to project average delay to future years. The results depend upon the predicted traffic growth scenario. As discussed in the analysis of AERA benefits, the basic annual growth rate for air traffic was assumed at 2% for all air carriers. No distinction is made in this analysis between major and non-major air carriers.

Forecast delays for the airports in each of the scenarios were computed using the FAA/APO equations for all ten airports in the analysis. In the Alternative 2 TAAS scenario, all five MCFs would likely receive the CTAS technology, but this analysis only counts those which do not have previous ARTS-IIIE systems replaced by TAAS. Three airports are involved as listed in Figure C-16. Base year (1993) and end year (2020) delay projections are listed.

MCF	Airport(s) Covered	Code	Base Year Delay (Thousands of Hours)	End Year Delay (Thousands of Hours)
Denver	Denver	DEN	45	162
Southern California	Los Angeles	LAX	75	166
	Santa Ana	SNA	10	36
Totals			130	363

Figure C-16 Airports Covered by CTAS Hosted on TAAS in MCFs (Alternative 2 Scenario)

In the second scenario, seven additional airports are covered by CTAS implemented in terminal area facilities equipped with the New TRACON automation system, listed in Figure C-17.

TRACON	Airport(s) Covered	Code	Base Year Delay Thousands of Hours	End Year Delay Thousands of Hours
Atlanta	Atlanta	ATL	97	224
Detroit	Detroit	DTW	35	80
Miami	Miami	MIA	41	140
San Francisco Bay	Oakland	OAK	8	30
	San Francisco	SFW	56	276
	San Jose	SJC	10	36
Jacksonville	Jacksonville	JAX	3	7
Totals			130	363

Figure C-17 Additional Airports Covered by CTAS Hosted on the New TRACON Automation System (Alternative 4 Scenario)

Extrapolation to Terminal Area Delay

The forecast delays for the subject airports cover all sources of delay. The main sources of delay at airports, in decreasing order of importance, include[21]:

- Weather
- Terminal Volume
- Center Volume
- Closed Runways/Taxiways
- NAS Equipment Interruptions and Other Causes

The percentages for these sources vary, although weather is always the greatest cause, responsible for more than 53% of total delay in recent years. The relative share attributed to congestion in the terminal area airspace -- terminal volume -- is the largest source of delay after weather, and has grown in recent years. The portion attributable to en route center volume is small but highly variable. It has decreased to as little as 2% in recent years. Closed runways and taxiways account for 3% to 6%, and failures of NAS equipment and other causes make up the remainder. For the purposes of this analysis, terminal volume is the most important cause because it can potentially be reduced using the CTAS technology. An estimated average over recent years for terminal volume is 27% of the total delay. For the average delay experienced at a particular airport, 27% of that delay is airborne within the terminal area airspace.

The effectiveness of CTAS in reducing airborne delay is assumed at the level estimated in studies under the TATCA program. The effectiveness of CTAS has been estimated at 10.12%; that is, the terminal area portion of airborne delay in a CTAS-equipped terminal area would be reduced by 10.12%. Since an average 27% of forecast delay is assumed to be airborne with the terminal area airspace, then the effect of CTAS will be to reduce the total delay at an airport by 2.73%. The results of the analysis for both implementation scenarios are discussed below.

Results and Sensitivity

Calculation of the present values of benefits of CTAS assumed a real 7% discount rate to express results in 1992 dollars. As in all user benefits analyses, OMB A-94 requires sensitivity analysis at discount rates of 4% and 10%. Calculation of benefit streams uses standard discounting such that the results are expressed as total present values in base year dollars. The basic results for the various discount rates are given in Figure C-18.

Real Discount Rate	Air Carriers		Passengers	
	TAAS	New TRACON	TAAS	New TRACON
4%	$133	$283	$323	$687
7%	$85	$178	$208	$434
10%	$57	$117	$139	$285

(Millions of 1992 Dollars)

Figure C-18 CTAS User Benefits for All Carriers At 2% Annual Traffic Growth

The results for the New TRACON automation system scenario are more impressive because more airports with higher traffic volume are involved. Also the TAAS scenario does not count benefits for the three MCFs which started with ARTS-IIIE equipment. In fact, these MCFs would continue to generate benefits with TAAS installed; they are not counted in the analysis because the benefits are not *uniquely* attributed to the TAAS technology. The overall benefits of the CTAS technology appear to address terminal area delay well. Even at the limited scale of implementation considered in the CTAS budget, substantial benefits accrue.

The assumed rate of air traffic growth in the CTAS analyses is 2%. Some inquiries were received as to the dependence of CTAS benefits on traffic growth following initial briefings of the study results. In particular the impact of no growth in air traffic was of interest. An assumption of no air traffic growth over the study period reduces the total estimated value of air carrier benefits in both scenarios from $263 million to $134 million. Total passenger benefits decrease from $642 million to $327 million.

C.3.3 Summary of Quantitative User Benefits

No quantitative benefits are ascribed to the AAS segments themselves. Rather, the AAS segments are expected to serve as platforms for several future forms of ATC application software (CTAS, AERA and other future functional enhancements) which will provide user benefits. These should enhance the ATC system ability to reduce in-flight delays and provide user preferred routes. The basic results of the benefits analyses are summarized in Figure C-19. The costs for implementation are compared to the value of benefits to air carriers and passengers for the automation scenarios in Alternatives 2, 3, and 4. As discussed, the Alternative 1 scenario does not appear because, although the ISSS modernizes the en route centers, it does not, of itself, generate quantifiable user savings. However, the ISSS is expected to offset major disbenefits which continue to accrue as long as the current en route system remains in service.

Scenario	Implementation Cost	Air Carrier Benefits	Passenger Benefits
CTAS/TAAS	$32	$85	$208
AERA/ACCC	$100	$1,379	$3,352
CTAS/New TRACON	$80	$178	$434

(Millions of 1992 Dollars, Discounted at 7%)

Figure C-19 Comparison of User Benefits and Implementation Costs

The overall results indicate that the costs of benefits-enabling application technology are small compared to the benefits which could be realized. As discussed, the costs listed are the incremental costs for the implementation of CTAS and AERA in the AAS platforms already installed. In summary, the quantitative results indicate the following:

- An investment of $32 million is required to implement CTAS in the two previously unequipped MCFs in the Alternative 2 (TAAS) scenario. This provides benefits to air carriers through reductions in delay over the study period estimated at $85 million. Benefits to passengers from reduced travel time are estimated at $208 million. Some benefits are diverted to ARTS-IIIE systems with CTAS under the baseline system.

- The investment cost for implementing full AERA services in 22 ACCC-equipped en route centers in the Alternative 3 system is estimated at $100 million. Benefits accrue to air carriers through the granting of user preferred routes. Assuming that AERA will realize a minimum of 60% of the available route improvement (compared to procedural routes), the present value of these benefits over the study period is estimated at $1.4 billion. Corresponding AERA benefits of reduced travel time to passengers are estimated at $3.4 billion. The benefit estimates for AERA are in addition to direct routing which could be provided under the National Route Program.

- Implementing CTAS in five additional terminal area facilities covering seven busy airports, under the scenario of Alternative 4 (hosted on the New TRACON automation system), requires $80 million. The additional benefit to air carriers and passengers is estimated at $178 million and $434 million, respectively. Benefits are greater than for CTAS in the TAAS-equipped MCFs because all sites are new; that is, no benefits are diverted to a previous ARTS-IIIE system.

Although substantial benefits are expected, there are also risks associated with new technology investment. RE&D activity needs to be followed by successful implementation before the CTAS and AERA initiatives are considered free of risk. In general, the air carrier benefits are of greater tangible value than time savings to passengers which are only a few minutes per flight. The major benefit of automation enhancements for the airline passenger is likely to be improved adherence to flight arrival schedules due to the introduction of better methods and tools to respond to weather and other special circumstances.

C.4 QUALITATIVE ASSESSMENTS

As discussed, the view which emerged in this study was that hardware modernization alone is not a basis for estimating user benefits quantitatively. The study does not dispute that there are various user benefits inherent within the AAS modernization. However, they could not be quantified with any certainty because of a lack of any operational data for the AAS platforms. Much of the data required for quantitative assessment can only be obtained with operational experience. Nevertheless, the beneficial impacts to users can be characterized qualitatively. Various capabilities and features of the modernized en route system are expected to translate into benefits for users in the future. The baseline system is also discussed briefly. The Volpe Center assessment of these areas is based on discussions with FAA and industry personnel and is believed to represent a consensus.

C.4.1 Baseline

The Baseline makes no provision to accommodate future air traffic growth. As a result, ATC processing capacity will very likely be unable to fully meet user demand and traffic delays (on the ground and in the air) will increase if current safety levels are to be maintained. The ATC environment under the current system is assumed to be characterized by additional flow restrictions and limitations due to crowding in key facilities and problems that may arise due to facility outages and maintenance issues. Continued operation under the Baseline system also raises the possibility of significant ATC service disruptions. Essentially the Baseline does not enable any benefits; in fact, there are likely to be substantial disbenefits to users. The Baseline is not viewed as an option that should be pursued for the NAS -- it is defined as the basis of comparison for the AAS alternatives in the study.

C.4.2 ISSS

Arguments for the effects of sector-splitting capabilities of the ISSS in reducing en route delay could not be firmly established. ISSS is a prerequisite for capabilities under the later TAAS and ACCC segments, but does not directly support the more substantial user benefits that might be realized under those segments. Lack of any operational data and definitive evidence guided analysis of the ISSS benefits toward qualitative assessment. The basic areas considered were the ability of the upgraded en route system to accommodate future growth in overall capacity and the ability of the ISSS to overcome limitations in the splitting of en route sectors.

En Route Operations Sector-splitting limits have been previously identified as a significant source of en route delay. However, changes in the management of airspace, primarily due to flow control using the ETMS, have shifted delays from the en route segment to terminal areas and the ground. This reduces the potential gain to be achieved by splitting en route sectors. The ISSS segment should improve sector-splitting capabilities by allowing easy reconfiguration of the operator display in the Common Console software. However, the reconfiguration is still constrained by the limitations of the en route Host Computer System. In addition, integration with the VSCS is only at the level of physical integration; that is, the VSCS must be manually operated from the keyboards and displays on the Common Console to achieve communications configurations which match changes in sectorization. Automatic reconfiguration of communications will be available when the VSCS is fully integrated in software during the ACCC segment.

Capacity The modernized en route system will accommodate future growth in overall capacity. The ISSS segment supports some expansion by virtue of modular scaleable architecture and display flexibility. It will handle more surveillance radar sensor inputs through the PAMRI. However, the capability to process flight plans and aircraft radar tracks is limited by the en route Host Computer System which remains in service under this segment. Although more operator positions can be accommodated under the ISSS, full en route capacity is achieved when digital radar gateways are added and the Host is replaced under the ACCC segment.

C.4.3 TAAS

The capability of the TAAS segment design is similar to the current ARTS-IIIA; that is, the management of terminal area airspace with TAAS is inherently no better than with the current ARTS-IIIA. This level of terminal area functionality does not confer any new benefits to the user community. The potential role of CTAS to enhance TAAS functionality has already been discussed. By itself, the TAAS technology may have some positive impacts on the capacity and efficient management of consolidated terminal area airspace covered by the MCFs.

Some improvement in the efficiency of airspace management will accrue simply by virtue of consolidated operations. That is, consolidated airspace management in MCFs should improve flow, *independent of the specific automation technology used.* The automation equipment must be appropriate for the management of consolidated operations; TAAS is intended for this role.

The beneficiaries of consolidated terminal airspace management are likely to be the non-major air carriers and general aviation operators. These users should experience fewer diversions.

Capacity The modernized consolidated terminal area facilities should accommodate future growth in traffic volume. The TAAS segment supports expansion in a manner similar to the en route modernization by virtue of modular scaleable architecture. This will handle more terminal area radar sensor inputs -- up to 16 radars versus 3 in current terminal area facilities. There will be increased capability to process flight plans and aircraft radar tracks. The general effect will be to remove limitations associated with current hardware and software.

Terminal Airspace Management The TAAS system will be integrated with VSCS and should possess similar reconfigurability to the AAS en route system. Terminal airspace is not managed in the same manner as en route airspace; that is, sector reconfiguration capabilities are not usually an issue within a single TRACON. However, the MCFs will consolidate terminal airspace over multiple terminal areas. The boundaries of airspace management responsibility are also expected to be greatly extended around MCFs compared to TRACONs. Airspace reconfiguration may well become an important part of efficient workload management at MCFs. Capabilities for reconfiguration should positively impact operations within MCF terminal area facilities equipped with TAAS.

C.4.4 ACCC

Under study Alternative 3, ACCC automation will replace the en route center Host Computer Systems and software. The software assumed for this alternative is only the initial build for the ACCC. This provides a functional equivalent of the current Host software. It also includes integration of the VSCS control functions so that reconfiguration of sectors becomes fully automated. The display and communications for sector splitting or combining can be accomplished dynamically in software. These various improvements should have a positive impact on future NAS capacity and other sources of en route delay, such as limitations in sector-splitting. Other benefit areas considered qualitatively include the ability of the modernized system to accommodate future growth in overall capacity and the ability of the ACCC to accommodate flexibility in operations.

Capacity The modernized system will accommodate future growth in overall capacity. The AAS segments, and particularly the ACCC, support expansion by virtue of modular scaleable architecture. The centers will be able to handle more sensor inputs -- up to 49 radars versus 15. They will have increased capability to process flight plans -- up to 7000 versus the current limit of 2500. The number of aircraft radar tracks increases from the current 940 per en route center up to 6000.

En Route Operations Sector splitting flexibility and higher capacity per sector should enable reduction of user delays associated with current center volume limitations. Sector-splitting limitations represent a source of en route delay, but one which could not be quantified within the study. The AAS enables the creation of additional en route sectors from the current limitation of 60 to between 90 and 155 sectors. The full ACCC in en route centers will support efficient dynamic resectorization across center boundaries. This is the result of the full integration of the VSCS software into the en route system; controller communications can be fully automated. This level of automation should mitigate en route delays associated with unbalanced workloads and communications bottlenecks. ACCC should also support routing preferences tailored to user criteria other than efficiency, such as routes to avoid severe weather conditions and increase passenger comfort.

C.4.5 TCCC and the New TRACON Automation System

Study Alternative 4 introduces TCCC modernization into the busiest towers in the ATC system, and upgrades support from the associated terminal area facilities with the New TRACON automation system. The TCCC modernization offers the potential for user benefits related to enhanced airport operations. Combined with the New TRACON system, there should be enhancements to capacity within terminal airspace.

Capacity Enhancements The modernized TRACON systems will accommodate future growth in terminal airspace capacity. This automation system is expected to support expansion in a manner similar to AAS modernization by virtue of modular scaleable architecture. The system will generally be able to handle more terminal area radar sensor inputs and will have increased capability to process flight plans and aircraft radar tracks.

After implementation, the TCCC will provide a display and control automation platform for other systems under development, such as the Airport Surface Traffic Automation (ASTA) and airport portions of the Terminal ATC Automation (TATCA) program. These programs are not costed under the alternative. (Only the terminal area portions of TATCA are considered.) The general capabilities of the TCCC have the potential to improve controller management of airport activities, aid in the efficient use of terminal airspace, and maintain safety as air traffic grows.

C.4.6 AAS and Technological Spinoffs

Analogous to the space program, the AAS is the proving ground for new information system technology which could potentially benefit society in various computer applications. The very high reliability and availability requirements of the en route portions of the AAS require implementation based on both hardware redundancy and software fault tolerance. As a system attempting to surpass the state-of-the-art, achieving what some authorities[22] designate as *ultra-availability*, the AAS software and hardware fault tolerance mechanisms are of great interest to the computer and information industries. The success of this technology will provide a model for other near real time information and display systems in the future.

C.4.7 AAS Modernization and the Nation

A fully modernized ATC system has the potential for benefitting the national interest and helping to achieve national goals. A common system shared by the FAA and the DoD can promote national budgetary cost savings and help to improve flexible and efficient use of all available airspace. When viewed in the context of logistical economics, a modernized ATC system can be directly linked to gains in national productivity[23]. Improved airline efficiency clearly fosters U.S. competitiveness in the world aviation market. Improvements in the air transportation infrastructure and in air operations are clearly necessary to the achievement of an integrated, seamless transportation service in the U.S.

ENDNOTES FOR APPENDIX C

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APPENDIX D

Cost Model Description

D.1 Overview

Figure D-1 shows the basic structure of the set of spreadsheets set up to perform the cost assessment. The cost model was implemented on a personal computer using Microsoft Excel for Windows Version 4.0 spreadsheet software. The underlying goal in its design was to separate the calculations from the data. To this end, a separate calculating engine was formed by collecting nine individual but related worksheets into a workbook. Excel's workbook concept allows for linking and simultaneous running of collections of worksheets. This workbook, shown on the left side of Figure D-1, contains all of the equations and definitions required to perform the analysis but contains no data. Rather, the workbook reads all required data from a separate worksheet. This data worksheet reads reference data about the assumed state of the system at start-up (1993). A separate data worksheet can then be assembled to represent any individual alternative or sensitivity to be studied. When the workbook completes calculation, the results are then copied back into a special portion of the input data worksheet to be saved. After several alternatives are run, the results can then be separately analyzed.

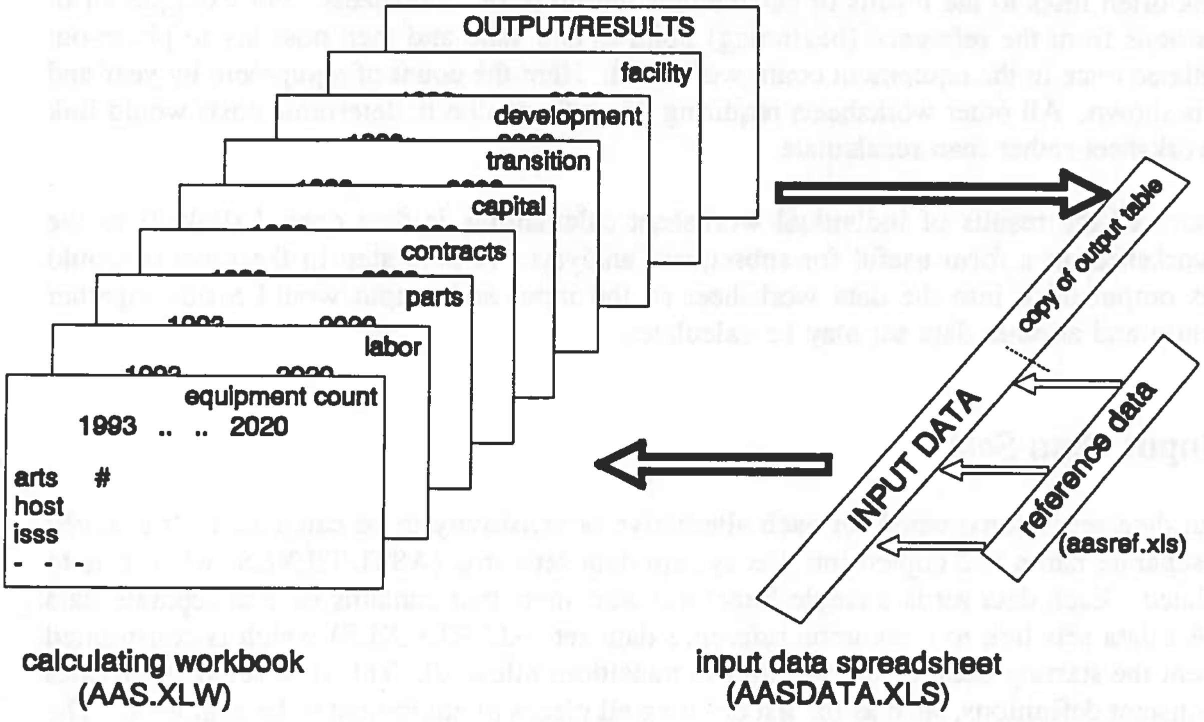

Figure D-1 - Cost Model Spreadsheet Structure

D.2 Calculating Workbook

The calculating workbook is comprised of a series of individual worksheets, most of which are responsible for calculating a single portion of the cost. The individual worksheets include:

- Equipment count
- Labor
- Parts
- Contracts
- Capital
- Transition
- Development
- Facility
- Output

The overall structure of each worksheet is the same. The final table produces the result, which is usually broken down by each year and for each major piece of equipment. Prior tables within any worksheet show necessary interim calculations for that sheet. A worksheet within the workbook often links to the results of calculations within prior worksheets. For example all of the transitions from the reference (beginning) point to end state and then possibly to phase-out are calculated once in the equipment count worksheet. Here the count of equipment by year and by type is shown. All other worksheets requiring this information to determine costs would link to this worksheet rather than recalculate.

A summary of the results of individual worksheet calculations is then copied (linked) to the output worksheet in a form useful for subsequent analysis. A later step in the process would copy this output back into the data worksheet so the input and output would reside together permanently and another data set may be calculated.

D.3 Input Data Sets

One input data set is constructed for each alternative or sensitivity to be calculated. It is saved under a separate name and copied into the system data set name (ASTUTE.XLS) when it is to be calculated. Each data set is a single Excel 4.0 worksheet that contains several separate data tables. All data sets link to a common reference data set (ALTREF.XLS) which is constrained to represent the starting point of the system (no transitions allowed). This data set also provides certain constant definitions, such as the list defining all pieces of equipment to be examined. The data for any given data set may be grouped and generally described as follows:

<u>System Definition</u> The data set describes a limited set of generic facilities. The system definition specifies the count of each type of generic facility that comprises the entire system to be studied. Any individual generic facility type is defined by specifying the numbers of the kinds of equipment it contains. The associated capital costs specifically address issues of the cost of transition.

Equipment Specific Data The master equipment list contains 65 entries. Each piece of equipment in the master equipment list is described by its:

- Total development cost
- Unit capital cost
- Year of birth (average across the system for existing equipment)
- Expected life in years
- Average number of expected maintenance labor years per unit
- Average expected parts cost (initial) per unit
- Average contracted maintenance cost
- Maintenance cost growth behavior category (eg. electronic, electro-mechanical, etc.)

Maintenance Growth Assumptions This is a quantifying of the maintenance cost growth model adapted for this analysis.

Equipment Transitions For each piece of equipment, this specifies the starting year and duration of transition from the beginning state to the (non-phased-out) end state. Additionally, the start and duration of any equipment phase-out are specified.

Other Data This category includes such constants as the base year of analysis, the end year, maintenance labor rates, and default equipment life.