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Report to the Secretary of Transportation

January 1997

AIR TRAFFIC CONTROL

Improved Cost Information Needed to Make Billion Dollar Modernization Investment Decisions

GAO/AIMD-97-20

GAO

United States
General Accounting Office
Washington, D.C. 20548

Accounting and Information
Management Division

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January 22, 1997

The Honorable Federico Peña
Secretary of Transportation

Dear Mr. Secretary:

This report addresses the reliability of the cost information critical to capital investment decision-making on air traffic control projects. Specifically, we evaluated the Federal Aviation Administration's processes for estimating what projects will cost and the related accounting for actual project costs.

This report contains recommendations to you. The head of a federal agency is required by 31 U.S.C. 720 to submit a written statement on actions taken on these recommendations. You should send your statement to the Senate Committee on Governmental Affairs and the House Committee on Government Reform and Oversight within 60 days after the date of this report. You must also send the written statement to the House and Senate Committees on Appropriations with the agency's first request for appropriations made over 60 days after the date of this report.

We are providing copies of this report to the Subcommittees on Transportation of the House and Senate Committees on Appropriations, the House and Senate Committees on the Budget, the Director of the Office of Management and Budget, the Administrator of the Federal Aviation Administration, and other interested parties. Copies will also be made available to others upon request. Please call me at (202) 512-6412 if you have any questions concerning the report. Other contributors to this report are listed in appendix V.

Sincerely yours,

Dr. Rona B. Stillman
Chief Scientist for Computers
and Telecommunications

Executive Summary

Purpose

Wisely managing new investments in capital assets, whether commercial real estate, factory plant and equipment, or information technology, requires complete and reliable information about alternative investment options, such as what the investment is expected to cost and whether actual costs are in line with expectations. The Federal Aviation Administration (FAA) is in the midst of a multibillion dollar, mission-critical capital investment program aimed at modernizing its aging air traffic control (ATC) infrastructure. The vast majority of these ATC capital investment projects, both in terms of money and number, involve software-intensive information acquisition, processing, and display systems. Past GAO reports have noted that ATC modernization projects routinely cost considerably more than envisioned, in part because of poor cost estimates.

Because of the importance of complete and reliable estimated and actual cost information to ATC investment management decisions, GAO examined FAA's ATC project cost estimating and cost accounting practices. Our objectives were to determine whether (1) ATC project cost estimates are based on good estimating processes and (2) actual ATC project costs are being properly accumulated.

Background

Faced with growing air traffic volume and a deteriorating ATC infrastructure, in 1981 FAA began an ambitious ATC modernization program. This program, which includes investments in both new ATC facilities and related support as well as new and upgraded software-intensive computer systems, totals over 200 separate projects that FAA estimates will cost more than $34 billion between 1982 and 2003. Of this total, 169 projects, estimated by FAA to cost about $21 billion, are ATC information systems. In fact, FAA expects the cost to develop and deploy ATC information systems between now and the year 2003 will be $6.9 billion, or about one-third, of the information systems component of the modernization.

Over the past 15 years, FAA's ATC modernization projects have experienced substantial cost overruns, lengthy schedule delays, and significant performance shortfalls. To illustrate, the long-time centerpiece of this modernization program—the Advanced Automation System—was restructured in 1994 after estimated costs tripled from $2.5 billion to $7.6 billion and delays in putting significantly less-than-promised system capabilities into operation were expected to run 8 years or more. Because of the size, importance, complexity, and poor track record of the

modernization program, GAO designated it a high-risk information technology initiative in 1995.[1]

In 1994, GAO reported on how leading organizations improved mission performance through information technology. Among other matters, GAO reported that successful organizations manage information system projects as investments, continually assessing the quality of projects' estimated costs and carefully monitoring projects' actual costs against these estimates.[2] This "best practice" relative to cost estimates has since been embodied in the Clinger-Cohen Act of 1996, which requires the selection of information technology investments on the basis of competing projects' estimated costs, benefits, and risks. In addition, the Chief Financial Officers (CFO) Act of 1990 requires federal agencies to maintain integrated accounting and financial management systems that permit the development and reporting of cost information and the systematic measurement of performance.

According to Carnegie Mellon University's Software Engineering Institute (SEI), deriving credible estimates of software-based systems' costs is a function of how thorough and disciplined an organization's estimating processes are. Accordingly, SEI has published six institutional process requisites that organizations in the business of building or acquiring software-intensive systems must possess if they are to consistently produce reliable cost estimates.[3] These are

- a corporate memory, or historical database(s), for cataloging cost estimates, revisions, reasons for revisions, actuals, and other descriptive information, such as any constraints or trends that affect the project;
- structured processes for estimating software size and the amount and complexity of existing software that can be reused;
- cost models calibrated/tuned to reflect demonstrated accomplishments on similar past projects;
- audit trails that record and explain the values used as cost model inputs;
- processes for dealing with externally imposed cost or schedule constraints in order to ensure the integrity of the estimating process; and
- data collection and feedback processes that foster capturing and correctly interpreting data from work performed.

[1]High-Risk Series: An Overview (GAO/HR-95-1, Feb. 1995).

[2]Executive Guide: Improving Mission Performance Through Strategic Information Management and Technology (GAO/AIMD-94-115, May 1994).

[3]Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations (CMU/SEI-95-SR-005, Jan. 1995).

Additionally, SEI, along with other experts in systems and software engineering and project management, advocates the acknowledgement and full disclosure of the inherent imprecision of these estimates. Accordingly, these experts recommend qualifying early project estimates by disclosing the level of uncertainty associated with them, and making the estimate more precise as the project is completed and the uncertainties are eliminated.

Although a recent development, the Statement of Federal Financial Accounting Standards no. 4 (SFFAS 4), Managerial Cost Accounting Concepts and Standards for the Federal Government,[4] which took effect October 1, 1996, requires full cost accounting by federal agencies' reporting entities to support management decision-making. These standards build on the CFO Act of 1990, which requires that agencies develop and maintain integrated accounting and financial management systems in order to develop and report cost information and systematically measure performance, among other functions. In addition, the Federal Managers' Financial Integrity Act of 1982 (FMFIA) requires that agency systems of internal control comply with prescribed standards and provide reasonable assurances that among other things, obligations and costs comply with applicable laws and that revenues and expenditures applicable to agency operations are recorded and accounted for properly.

Results in Brief

FAA's ATC modernization program's cost estimating processes do not satisfy recognized estimating requisites, and its cost accounting practices do not provide for proper accumulation of actual project costs. The result is an absence of reliable project cost and financial information that the Congress has legislatively specified and that leading public-sector and private-sector organizations point to as essential to making fully informed investment decisions among competing ATC projects. Without this information, the likelihood of poor ATC investment decisions is increased, not only when a project is initiated but also throughout its life cycle. It also means that the Congress does not have reliable cost information to use in making funding decisions about FAA. Such a situation is unacceptable when making small investments, but it is especially egregious when making multimillion or billion dollar investments in mission-critical ATC systems.

[4]The Federal Accounting Standards Advisory Board (FASAB) recommends federal accounting standards to the Director of OMB, the Secretary of the Treasury, and the Comptroller General. Once approved, the standards are issued by OMB and GAO.

With respect to cost estimating, FAA fails to meet five of the six process requisites that SEI's Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations says should be institutionally entrenched and consistently used for information technology projects. In the absence of such institutional policies to guide ATC project cost estimating, FAA has adopted a cost estimating process that allows each ATC project to approach cost estimating in whatever manner its estimators choose. The result is inconsistency in the rigor and discipline with which ATC project cost estimates are derived, which in turn means estimates of varying degrees of reliability. In fact, when comparing the approaches that six ATC projects used to derive their current official life cycle cost estimates to SEI's project-specific criteria entitled, A Manager's Checklist for Validating Software Cost and Schedule Estimates,[5] GAO found that two were too poorly documented to permit any comparative analysis, while none of the remaining four satisfied all of the criteria SEI associates with highly credible estimates.[6] Compounding these estimating process weaknesses is FAA's practice of presenting cost estimates as precise, point estimates. By doing so, FAA fails to disclose the estimates' inherent uncertainty and risks, thus further limiting the estimates' decision-making value and credibility.

With respect to cost accounting, FAA is not accumulating all ATC project costs. In fact, FAA does not have a cost accounting system for capturing and reporting the full cost of its ATC projects. Instead, FAA decisionmakers use accounting and financial management systems that omit relevant project costs, such as those associated with FAA project management. The result is that FAA cannot reliably measure the ATC projects' actual cost performance against established baselines, and cannot reliably use information relating to actual cost experiences to improve future cost estimating efforts.

[5]CMU/SEI-95-SR-004, Jan. 1995.

[6]Since the focus of this effort is to assess FAA's cost estimating processes and not to validate the accuracy or completeness of the estimates, we did not evaluate the quality of the estimates.

Principal Findings

Weak Cost Estimating Processes and Practices Undermine FAA's Ability to Make Informed Investment Decisions

The effectiveness of FAA's investment management process is in part a function of the quality of the cost estimates used in the process. Accordingly, GAO assessed FAA's cost estimating processes and practices at two levels. First, on an institutional level, FAA's cost estimating processes for ATC systems partially meet one and do not meet the remaining five institutional process requisites that experts say are embedded in leading information technology development and acquisition organizations.[7] These six requisites, which are listed in table 1, are the product of SEI's research of leading government and private-sector estimating practices. Table 1 also provides a summary assessment of the degree to which FAA satisfies each requisite. According to SEI, an organization must address all six requisites in order to produce reliable estimates. The Clinger-Cohen Act emphasizes the need for reliable cost estimates to allow effective information technology investment decision-making.

Table 1: Summary of FAA's Satisfaction of SEI's Institutional Requisites

SEI requisites	FAA institutional policies and practices
Corporate memory	No
Sizing and reuse structure	No
Extrapolation using actual performance	No
Audit trails	Partial
Integrity in the face of dictated limits	No
Data collection and feedback on actual performance	No

Second, on a project level, GAO reviewed six ATC projects (five of the largest ATC projects and one small project) as case studies to determine how these projects' current official life cycle cost estimates were derived in the absence of any institutional processes for estimating ATC projects' costs. To do so, GAO compared the cost estimating approaches used on each project to SEI criteria developed expressly for project managers to use in deciding whether or not to rely on an estimate.[8] GAO found that two of the six projects had little or no documentation supporting the derivation of their estimates. The four remaining projects' estimating approaches were documented, but none satisfied all the SEI criteria. Of these four, one

[7]This evaluation was performed using SEI's Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations.

[8]This evaluation was performed using SEI's A Manager's Checklist for Validating Software Cost and Schedule Estimates.

satisfied most of the criteria SEI associates with a credible cost estimate. The other three failed to satisfy most of the SEI criteria. To FAA's credit, however, estimators on two of the projects that failed to satisfy most of SEI's criteria are revising life cycle cost estimates using more rigorous approaches.

FAA's estimating process weaknesses are exacerbated by its portrayal of ATC projects' cost estimates as firm, point estimates. According to software engineering experts, cost estimates are by definition imprecise, particularly early in a system's development cycle, and should be qualified to fully disclose this uncertainty. By choosing to present its ATC projects' cost estimates as discrete points, FAA is improperly implying a level of precision that cannot be supported, thereby further limiting the value of the estimates to congressional and agency investment decisionmakers and potentially misleading them.

During the course of GAO's review, FAA organizations initiated several efforts to improve ATC cost estimating processes. Specifically, FAA's program assessment organization is exploring the possibility of integrating cost estimating functions across FAA, and is advocating FAA adoption of a standard tool for recording cost model data. Another group is testing a system for tracking a project's actual operations and maintenance (O&M) costs. The group's goal is to eventually use this system's historical data to help estimate future projects' O&M costs. However, these separate initiatives are not coordinated, relatively new, and not endorsed or institutionalized by FAA.

Shortcomings in Project Cost Accounting Impede FAA's Ability to Effectively Manage ATC Investments and Improve Cost Estimating

The effectiveness of FAA's investment management process, including its cost estimating process, also relies heavily on the quality of actual project cost information. However, FAA does not adequately accumulate all project cost information needed by federal decisionmakers to make fully informed decisions about the billions of dollars being spent on ATC projects. Reliable financial information includes the full cost of a project, including direct and indirect costs. Without this information, an organization does not know how much is being spent on various ATC projects and, therefore, does not have a basis for managing current costs or reliably estimating future costs. Accountability for such costs is required by FMFIA and the CFO Act.

Because FAA does not have a cost accounting system for ATC modernization projects, project and corporate management as well as FAA oversight

agencies and institutions, such as OMB and the Congress, rely on information produced by an assortment of financial systems. None of these financial systems provide for the systematic accumulation and reporting of all relevant project costs.

In August 1996, FAA set up an organization and subsequently initiated an effort to acquire a cost accounting system. FAA has thus far specified general functional requirements and plans to procure an off-the-shelf system that can be tailored to FAA's needs. FAA plans to have this cost accounting system in place by October 1, 1997.

Recommendations

Because the success of FAA's investment analysis and decision-making process depends in large measure on the reliability of ATC project cost information, GAO recommends that the Secretary of Transportation direct the FAA Administrator to institutionalize defined processes for estimating ATC projects' costs. At a minimum, these processes should include the following SEI requisites, each of which is described in more detail in this report:

- a corporate memory (or historical database), which includes cost and schedule estimates, revisions, reasons for revisions, actuals, and relevant contextual information;
- structured approaches for estimating software size and the amount and complexity of existing software that can be reused;
- cost models calibrated/tuned to reflect demonstrated accomplishments on past projects;
- audit trails that record and explain all values used as cost model inputs;
- processes for dealing with externally imposed cost or schedule constraints in order to ensure the integrity of the estimating process; and
- data collection and feedback processes that foster capturing and correctly interpreting data from work performed.

GAO also recommends that the Secretary direct the Administrator to immediately begin disclosing the inherent uncertainty and range of imprecision in all ATC projects' official cost estimates presented to executive oversight agencies or the Congress.

Additionally, GAO recommends that the Secretary direct the Administrator to acquire or develop and implement a managerial cost accounting capability that will satisfy the requirements of SFFAS 4, Managerial Cost Accounting Concepts and Standards for the Federal Government. This

system capability should provide the cost accounting and financial management information needed by FAA management and those who make investment decisions. Such information should include full life cycle costs, which include the costs of resources consumed by a project that directly or indirectly contribute to the output and the costs of identifiable supporting services provided by other organizations within the reporting entity.

GAO further recommends that the Secretary report FAA's lack of a cost accounting capability for its ATC modernization as a material internal control weakness in the Department's fiscal year 1996 FMFIA report and in subsequent annual FMFIA reports until the problem is corrected.

Also, GAO recommends that the Secretary direct the Administrator to report to the Secretary and FAA's authorizing and appropriation committees on progress being made on these recommendations as part of the agency's fiscal year 1999 budget submission.

Agency Comments and GAO's Evaluation

GAO received oral comments on a draft of this report from senior Department of Transportation (DOT) and FAA officials, including representatives from the Office of the Secretary of Transportation, the Executive Assistant to the FAA Chief Financial Officer, the FAA Manager of the Cost Accounting System Division, and the FAA Program Director for Investment Analysis and Operations Research. These officials agreed with most of GAO's findings, conclusions, and recommendations. However, they stated that because they plan to have a cost accounting system in place by October 1, 1997, they do not believe that our recommendations for implementing a cost accounting capability and listing the lack of a cost accounting system as a material internal control weakness in the agency's FMFIA report are necessary. While we are encouraged by FAA's recent actions to procure a cost accounting system, we nevertheless believe that our recommendations are still warranted to ensure that FAA's efforts are complete and timely. Until FAA's cost accounting system—which is still very early in its acquisition life cycle—is developed, installed, and operational, the lack of cost accounting information will continue to pose a risk to sound project management and investment decision-making. As such, implementation of this capability warrants aggressive action and disclosure as a material internal control weakness in the agency's FMFIA report until the new system is in place and producing accurate cost information.

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Abbreviations

ACEIT	Automated Cost Estimating Integrated Tools
APO	Office of Aviation Policy and Plans
ARA	Associate Administrator for Research and Acquisitions
ARINC	Aeronautical Radio Incorporated
ASD-400	Investment Analysis and Operations Research
ASR-9	Airport Surveillance Radar-9
ATC	air traffic control
ATS	Associate Administrator for Air Traffic Services
CASE	Computer-Aided Software Engineering
CBAS	Cost Benefit Analysis System
CFO	Chief Financial Officer
CMM	Capability Maturity Model
COPS	Cost of Performance System
CPMS	Cost Performance Management System

DAFIS	Departmental Accounting and Financial Information System
DCCR	Display Channel Complex Rehost
DOT	Department of Transportation
DSR	Display System Replacement
FAA	Federal Aviation Administration
FASAB	Federal Accounting Standards Advisory Board
FMFIA	Federal Managers' Financial Integrity Act of 1982
FMS	Financial Management System
F&E	Facilities and Equipment
GPS	Global Positioning System
IPDS	Integrated Product Development System
IPT	Integrated Product Team
ISSS	Initial Sector Suite System
JRC	Joint Resources Council
OIG	Office of the Inspector General
OMB	Office of Management and Budget
O&M	Operations and Maintenance
PCB&T	Personnel Compensation, Benefits, and Travel
RE&D	Research, Engineering, and Development
REDMACS	Research, Engineering, and Development Monitoring, Analysis, and Control System
SEI	Software Engineering Institute
SFFAS 4	Statement of Federal Financial Accounting Standards no. 4
SLIM	Software Life Cycle Intermediate Model
STARS	Standard Terminal Automation Replacement System
TRACON	Terminal Radar Approach Control
VSCS	Voice Switching and Control System
WAAS	Wide Area Augmentation System

Introduction

The Federal Aviation Administration's (FAA) primary mission is to ensure safe, orderly, and efficient air travel throughout the United States. FAA's ability to fulfill this mission depends on the adequacy and reliability of the nation's air traffic control (ATC) system, a vast network of computer hardware, software, and communications equipment. Sustained growth in air traffic and aging equipment have strained the current ATC system, limiting the efficiency of ATC operations. To combat these trends, in 1981 FAA embarked on an ambitious ATC modernization program. FAA estimates that it will spend about $34 billion on the program between 1982 and 2003.

Our work over the years has chronicled many FAA failures in meeting ATC projects' cost, schedule, and performance goals.[1] As a result, we designated FAA's ATC modernization as a high-risk information technology initiative in our 1995 report series on high-risk programs.

ATC at a Glance

Automated information processing and display, communication, navigation, surveillance, and weather resources permit air traffic controllers to view key information, such as aircraft location, aircraft flight plans, and prevailing weather conditions, and to communicate with pilots. These resources reside at, or are associated with, several ATC facilities—flight service stations, air traffic control towers, terminal radar approach control (TRACON) facilities, and air route traffic control centers (en route centers). These facilities' ATC functions are described below.

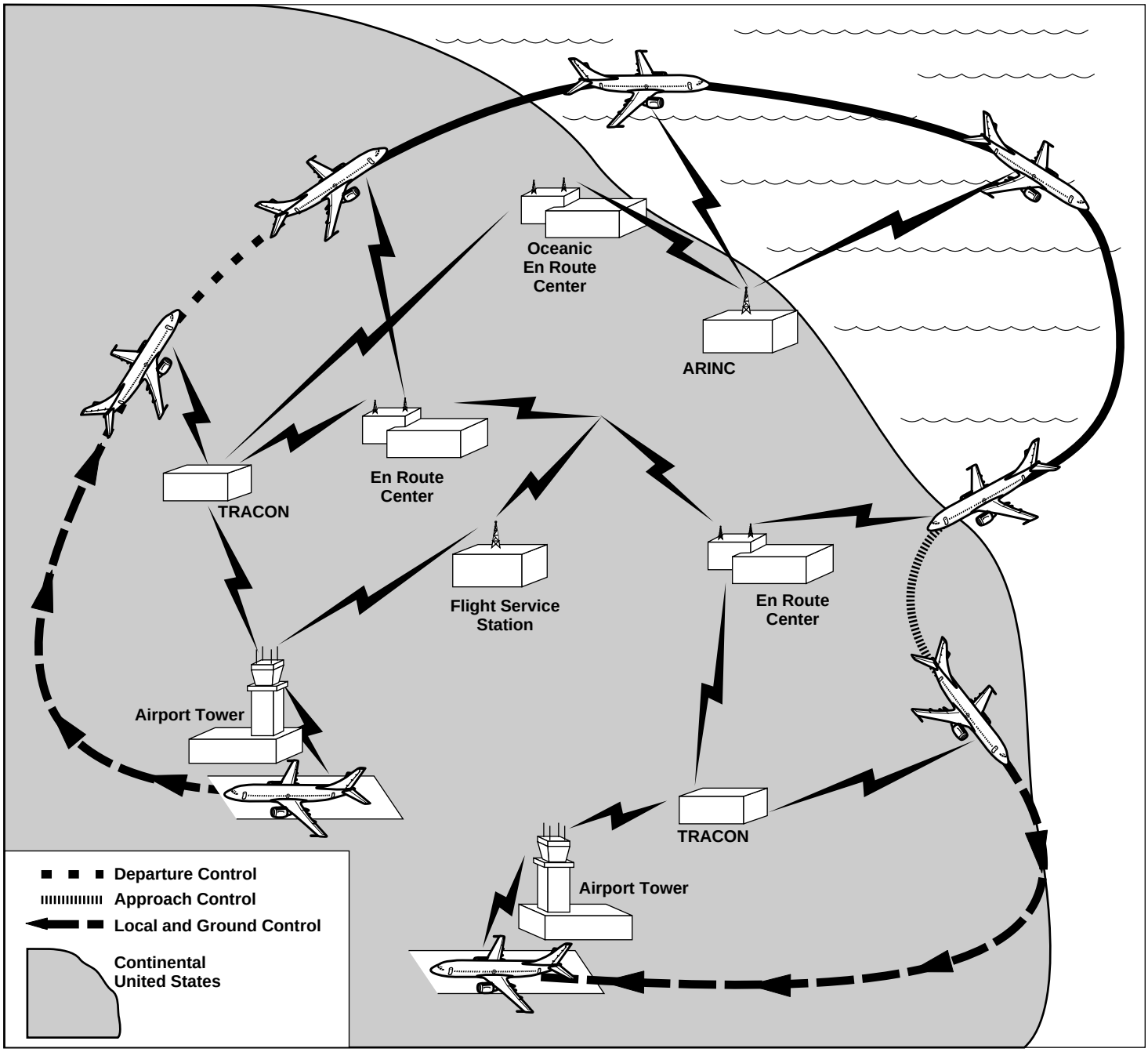
- About 90 flight service stations provide pre-flight and in-flight services, such as flight plan filing and weather report updates, primarily for general aviation aircraft.
- Airport towers control aircraft on the ground and before landing and after take-off when they are within about 5 nautical miles of the airport, and up to 3,000 feet above the airport. Air traffic controllers rely on a combination of technology and visual surveillance to direct aircraft departures and approaches; maintain safe distances between aircraft; and communicate weather-related information, clearances, and other instructions to pilots and other personnel.
- Approximately 180 TRACONs sequence and separate aircraft as they approach and leave busy airports, beginning about 5 nautical miles and ending about 50 nautical miles from the airport, and generally up to 10,000 feet above the ground, where en route centers' control begins.

[1] Air Traffic Control: Status of FAA's Modernization Program (GAO/RCED-95-175FS, May 26, 1995); Air Traffic Control: Status of FAA's Modernization Program (GAO/RCED-94-167FS, Apr. 15, 1994); and Air Traffic Control: Status of FAA's Modernization Program (GAO/RCED-93-121FS, Apr. 16, 1993).

- Twenty en route centers control planes over the continental United States in transit and during approaches to some airports. Each en route center handles a different region of airspace, passing control from one to another as respective borders are reached until the aircraft reaches TRACON airspace. En route center controlled airspace usually extends above 18,000 feet for commercial aircraft. En route centers also handle lower altitudes when dealing directly with a tower, or when agreed upon with a TRACON.
- Two en route centers—Oakland and New York—also control aircraft over the ocean. Controlling aircraft over oceans is radically different from controlling aircraft over land because radar surveillance only extends 175 to 225 miles offshore. Beyond the radars' sight, controllers must rely on periodic radio communications through a third party—Aeronautical Radio Incorporated (ARINC), a private organization funded by the airlines and FAA to operate radio stations—to determine aircraft locations.

See figure 1.1 for a visual summary of the processes for controlling aircraft over the continental United States and oceans.

Figure 1.1: Summary of ATC Over the Continental United States and Oceans



Overview of the ATC Modernization Program

The ATC system of the late 1970s was a blend of several generations of automated and manual equipment, much of it labor-intensive and obsolete. FAA recognized that it could increase ATC operating efficiency by increasing automation. Additionally, FAA forecasted increased future demand for air travel, brought on by airline deregulation of the late 1970s. It also anticipated that meeting the demand safely and efficiently would require improved and expanded services, additional facilities and equipment, improved workforce productivity, and the orderly replacement of aging equipment. Accordingly, in December 1981, FAA initiated its plan to modernize, automate, and consolidate the existing ATC system by the year 2000.

This ambitious modernization program includes the acquisition of new radars and automated data processing, navigation, and communication equipment in addition to new facilities and support equipment. FAA estimates that the modernization will cost over $34 billion through the year 2003 and total over 200 separate projects. ATC information systems make up a large portion of this total, accounting for 169 projects costing $20.7 billion. The Congress will have provided FAA with approximately $14.7 billion of the $20.7 billion through fiscal year 1997.

Over the past 15 years, FAA's modernization projects have experienced substantial cost overruns, lengthy schedule delays, and significant performance shortfalls. To illustrate, the long-time centerpiece of this modernization program—the Advanced Automation System—was restructured in 1994 after estimated costs tripled from $2.5 billion to $7.6 billion and delays in putting significantly less-than-promised system capabilities into operation were expected to run 8 years or more. Similarly, increases in per-unit costs for five other major ATC projects[2] have ranged from 50 to 511 percent, and schedule delays have averaged almost 4 years.

Our past work on the ATC modernization raised a number of concerns, including concerns about the reliability of projects' cost estimates. For example, our review of FAA's Oceanic Display and Planning System found that cost and schedule estimates were questionable because they were based solely on managers' judgments and were not revised to reflect changing project demands and conditions.[3] Also, our work on AAS

[2]The five projects and their respective percentage change in unit costs are the Voice Switching and Control System (511 percent), the Integrated Terminal Weather System (129 percent), the Airport Surface Detection Equipment (56 percent), the Aviation Weather Observing System (51 percent), and the Terminal Doppler Weather Radar (50 percent).

[3]Air Traffic Control: FAA Needs to Justify Further Investment in Its Oceanic Display System (GAO/IMTEC-92-80, Sept. 30, 1992).

highlighted that FAA underestimated the complexity of the system development and relied on its contractor's deficient cost estimating systems.[4] Most recently, we reported that the organizational culture intrinsic to FAA has been to deflate realistic estimates of cost and schedule in order to gain funding approval.[5] In its internal risk management guidance, FAA acknowledges that it has a history of unreliable project cost estimates, attributing some of its unenviable record in ATC projects' cost growth to setting unrealistically low cost estimates, either because of poor cost estimating processes or inadequate system descriptions.[6]

ATC Modernization and Maintenance Management Structure

Two major FAA organizations play key roles in the modernization and evolution of ATC systems—the Office of the Associate Administrator for Research and Acquisitions (ARA) and the Office of the Associate Administrator for Air Traffic Services (ATS). The first, ARA, manages the research, development, and acquisition of modernization projects. Within ARA, two groups are responsible for acquiring systems, while the others handle cross-cutting management functions (e.g., budget formulation, cost estimation, and program evaluation). Also, the William J. Hughes Technical Center is the ATC system test and evaluation facility and supports ATC systems' research, engineering, and development.

ARA employs an Integrated Product Development System (IPDS) approach. A key component of IPDS is the use of Integrated Product Teams (IPT), which are cross-functional teams aligned with major business and functional areas (i.e., en route, terminal, weather and flight services, air traffic management, oceanic, communications, navigation, surveillance, infrastructure, and information systems). IPT members include systems and specialty engineers, logistics personnel, lawyers, contract specialists, and representatives from the organization responsible for the system's operations and maintenance. IPTs are responsible for systems research, development, acquisition, and installation. Product teams within these IPTs are responsible for individual ATC system acquisitions or projects. For example, the en route IPT has product teams for the Display Channel Complex Rehost, the Display System Replacement, the Voice Switching and Control System, and several other en route systems.

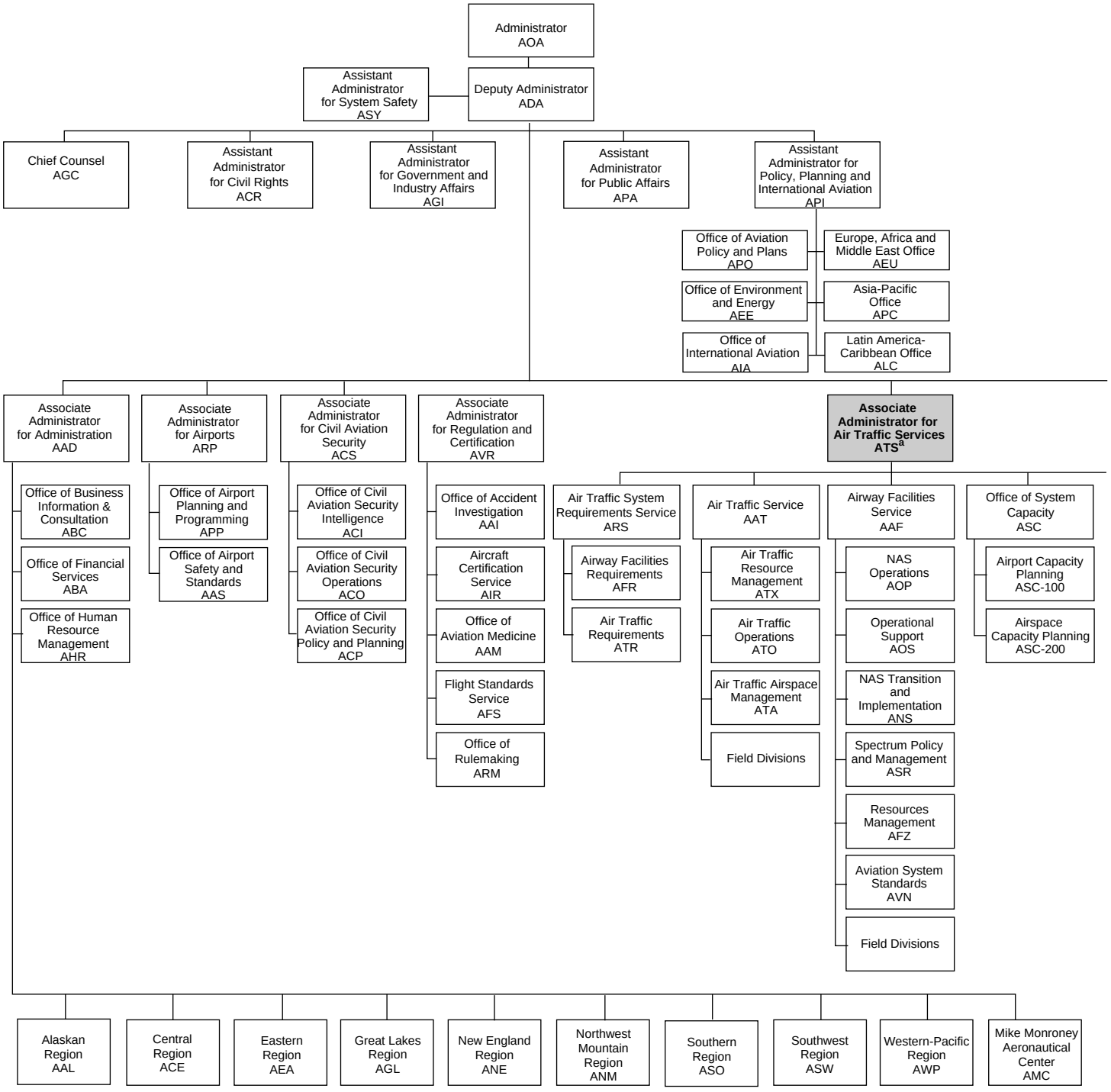
[4]Air Traffic Control: Status of FAA's Modernization Program (GAO/RCED-94-167FS, Apr. 15, 1994).

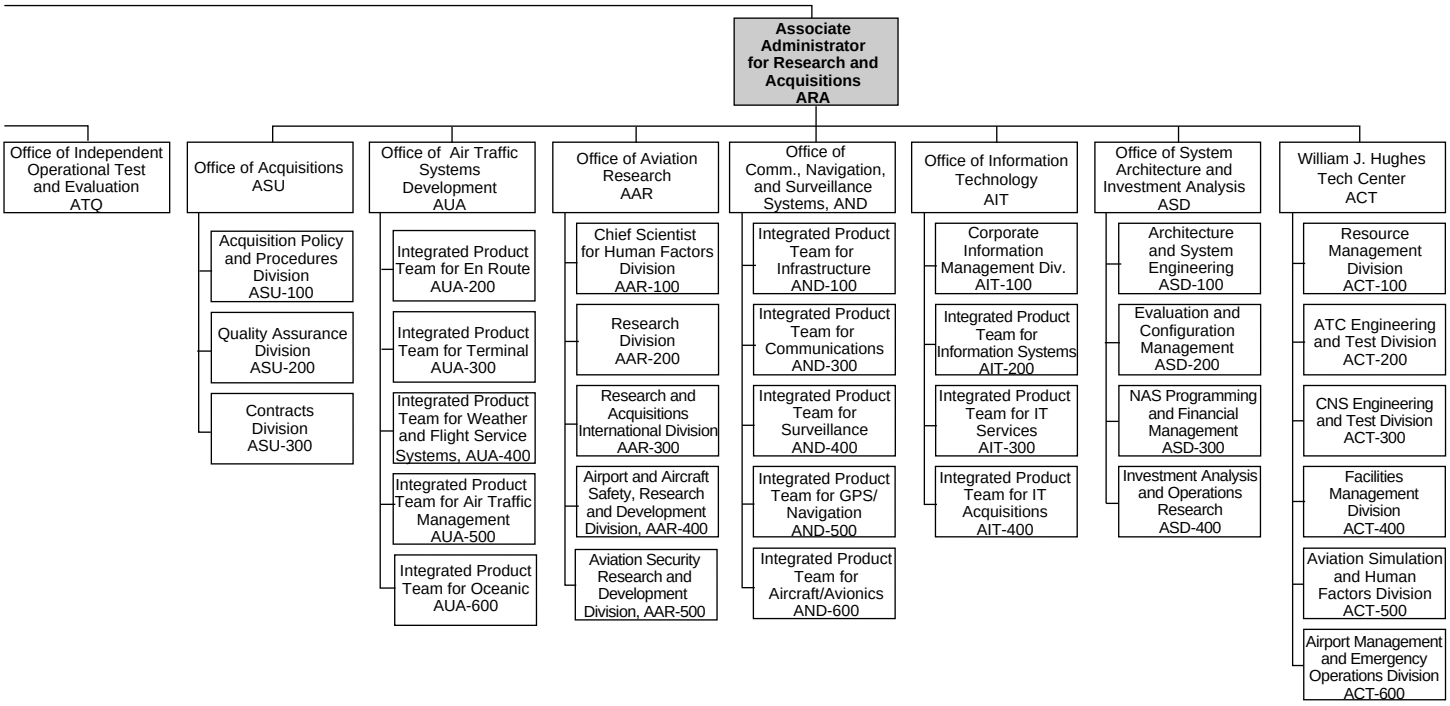
[5]Aviation Acquisition: A Comprehensive Strategy Is Needed for Cultural Change at FAA (GAO/RCED-96-159, Aug. 22, 1996).

[6]Cost growth can occur for various reasons, including changing requirements, unstable funding streams, poor project and/or contract management, and poor estimates.

The second major organization involved with ATC systems is ATS. ATS is responsible for directing, coordinating, controlling, and ensuring the safe and efficient utilization of the national airspace system. Organizations within ATS are responsible for planning, operating, and maintaining ATC systems. Responsibility for managing ATC systems is transferred from the IPT to ATS once the systems have been installed and are operational. See figure 1.2 for a visual summary of the ATC modernization and maintenance management structure.

Figure 1.2: Organizational Chart Highlighting ATC Modernization and Maintenance Management Structure





[a]ATS is currently being reorganized

During our review, we assessed six major modernization projects. These projects were the

- **Voice Switching and Control System** (VSCS), which provides air-to-ground voice communication services and ground-to-ground voice communication services between controllers, other ATC personnel, and others at the same and different en route centers and other ATC facilities;
- **Standard Terminal Automation Replacement System** (STARS), which is to replace critical air traffic control computers with new traffic computers, displays, and software in TRACON facilities and towers;
- **Display System Replacement** (DSR), which is to replace air traffic controllers' existing display-related systems in each of the en route centers;
- **Airport Surveillance Radar-9** (ASR-9), which monitors aircraft movement and position within a radius of 60 miles of an airport terminal;
- **Wide Area Augmentation System** (WAAS) for the Global Positioning System (GPS), which is to provide augmentations to the Department of Defense's GPS in order to allow improved navigation on domestic and oceanic air routes; and
- **Display Channel Complex Rehost** (DCCR), which is an interim replacement to the mainframe computer system that processes radar and other data into displayable images on controllers' screens.

Roles and Responsibilities for Project Cost Estimating

The FAA organization responsible for estimating costs on the projects we assessed varied depending on the project's stage in its life cycle. According to FAA acquisition rules in place when the latest life cycle cost estimate for the projects we assessed were developed, FAA's Investment Analysis and Operations Research organization (ASD-400), which is one of the groups within ARA that handles cross-cutting management functions, developed life cycle cost estimates early in the project life cycle—both when mission needs were evaluated and again when evaluating the costs, benefits, and feasibility of project alternatives. Once the decision was made to invest in a given alternative, the IPTs assumed responsibility for updating the cost estimates. However, IPTs could also choose to develop their own cost estimates prior to the investment decision point, rather than have ASD prepare them.

Of the six projects we reviewed, four used ASD-400 at some point in the project's life cycle. The other two did not. In addition, some project managers updated the acquisition phase portion of the life cycle cost

estimates periodically between the times that the full life cycle cost estimates were revised.

FAA's organizational responsibilities for cost estimating have recently changed. In October 1995, the Congress instructed FAA to develop and implement a new acquisition management system, which would not be subject to various existing acquisition laws. On November 15, 1995, the President signed this bill into law.[7] FAA began implementing this new acquisition management system in April 1996 with the issuance of broad policies, guiding principles, and internal procedures.[8] While not yet fully implemented, these specify that two key decisions be made at the corporate level by the Joint Resources Council (JRC), a newly formed body comprised of the associate administrators for operations and acquisitions as well as officials responsible for acquisitions, financial services, and legal counsel. These decisions are (1) whether mission needs warrant entry into investment analysis and (2) whether to invest in the project at the conclusion of investment analysis. FAA identified the latter as the most important decision in the life cycle acquisition management process. Accordingly, FAA plans to establish a "center of excellence" for investment analysis with experts in cost estimating, risk assessment, market analysis, and affordability analysis.

Under this new scenario, investment analysis will be conducted as a joint enterprise by the FAA organization sponsoring the system (i.e., ATS) and the FAA organization responsible for acquiring it (i.e., ARA). The purpose is threefold: to ensure that (1) users buy into the solution, (2) acquisition specialists have a voice in the cost, schedule, and performance baselines they will have to live with, and (3) the investment analysis staff understands the concerns of the operations and acquisitions organizations. Under this approach, the sponsoring organization, with technical support from the investment analysis staff, develops and approves its requirements in the form of a Requirements Document. The investment analysis staff leads the effort to identify and analyze candidate solutions through market surveys, alternatives analysis, and affordability assessments, with support from the sponsoring organization and the ARA IPT responsible for acquiring it. This effort culminates in the Investment Analysis Report, which is to contain comprehensive quantitative data for each alternative, such as life cycle cost, cost-benefit ratios, and risk. The IPTs use this information to generate cost and schedule baselines for each alternative in the form of an Acquisition Program Baseline. At the investment decision point, the JRC

[7]1996 DOT Appropriations Act (Public Law 104-50), Section 348.

[8]Federal Aviation Administration Acquisition Management System, Apr. 1, 1996.

decides on an alternative; baselines the project's requirements, costs, schedules, performance, and benefits; and commits the agency to full funding of the program. Thereafter, any changes to these baselines must be approved by the JRC. In fact, no funding may be committed or obligated that would exceed the program cost baseline until the increase is approved by the JRC and included in agency plans and budgets.

The success of FAA's new investment analysis and decision-making approach depends on many factors, not the least of which is the reliability of ATC project cost information discussed in this report.

Sound Investment Decisions Require Reliable Cost Estimating and Accounting Practices and Data

Reliable cost estimates and monitoring of actual costs are essential to informed investment decision-making throughout the development and maintenance of capital items, such as ATC systems. In the case of FAA, they are cornerstones to its aforementioned investment analysis and decision-making processes.

In 1994, we reported on how leading organizations improved mission performance through information technology. Among other things, we reported that successful organizations manage information system projects as investments, and continually assess the quality of projects' estimated costs and carefully monitor projects' actual costs against these estimates. Furthering this initiative, OMB's 1995 guidance, Evaluating Information Technology Investments, calls for selecting information technology project investments on the basis of cost, benefit, risk, and return; controlling projects by comparing ongoing actual results being achieved with projected costs, benefits, and risks; and, finally, evaluating projects after they have been implemented to determine actual cost, benefits, risks, and returns, and modifying the selection and control processes based on lessons learned. This guidance has since been embodied in (1) the Clinger-Cohen Act of 1996, which requires the selection of information technology investments on the basis of competing projects' estimated costs, benefits, and risks, and (2) the Chief Financial Officers (CFO) Act of 1990, which requires federal agencies to maintain integrated accounting and financial management systems that permit systematic and reliable measurement of projects' cost and performance. Additionally, OMB Circular A-11, Part 3, requires agencies to request full up-front budget authority for all ongoing and new fixed assets (including information technology) in their fiscal year 1998 budget submission. This circular also requires a fixed asset plan and justification for major

acquisitions, including, among other items, an analysis of full life cycle costs and an estimate of the risk and uncertainty in meeting project goals.

Experts Advocate Key Estimating Process Requisites

The Software Engineering Institute's (SEI) Capability Maturity Model (CMM), the standard used by government and industry to determine the maturity of an organizations' software development processes, also highlights the need for good estimates and good estimating processes.[9] Three of the CMM's key process areas for level 2 (repeatable) process maturity are project planning, project tracking, and subcontract management. These process areas must have reliable estimates for size, effort, schedule, and cost if they are to be performed successfully. The CMM further requires that the procedures that implement these key process areas be documented.

To improve the state of practice for software cost and schedule estimating, SEI developed and published (1) criteria for establishing sound estimating processes and (2) a guide for managers to use in validating an individual project's estimate.[10] These documents, in effect, describe "best practices" used in industry and government for estimating software costs and schedules. However, SEI found that the "best practices" are equally applicable to hardware and integrated systems projects, and therefore allows for substituting the word "system" for "software" throughout its guides and checklists. SEI also noted that while the criteria target the acquisition/development phase of a project's life cycle, the concepts are also applicable to other phases of the life cycle.

According to SEI's Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations, in order to have sound estimating processes, an organization should have six attributes, or requisites, institutionally embedded in its policies and procedures. These include (1) a corporate memory, or historical database(s), for cataloging cost estimates, revisions, reasons for revisions, actuals, and other contextual information, (2) structured processes for estimating software size and the amount and complexity of existing software that can be reused, (3) cost models calibrated/tuned to reflect demonstrated accomplishments on similar past projects, (4) audit trails that record and explain values used as cost model inputs, (5) processes for

[9]Capability Maturity Model for Software, Version 1.1 (CMU/SEI-93-TR-24).

[10]Checklists and Criteria for Evaluating the Cost and Schedule Estimating Capabilities of Software Organizations (CMU/SEI-95-SR-005, Jan. 1995) and A Manager's Checklist for Validating Software Cost and Schedule Estimates (CMU/SEI-95-SR-004, Jan. 1995).

dealing with externally imposed cost or schedule constraints in order to ensure the integrity of the estimating process, and (6) data collection and feedback processes that foster capturing and correctly interpreting data from work performed. SEI provides detailed checklists for assessing an organization's satisfaction of each requisite.

These same six requisites are interwoven through seven questions SEI poses in A Manager's Checklist for Validating Software Cost and Schedule Estimates. The seven questions are (1) Are the objectives of the estimate clear and correct? (2) Has the task been appropriately sized? (3) Are the estimated cost and schedule consistent with demonstrated accomplishments on past projects? (4) Have the factors that affect the estimate been identified and explained? (5) Have steps been taken to ensure the integrity of the estimating process? (6) Is the estimate based on reliable evidence of the organization's past performance? and (7) Has the situation remained unchanged since the estimate was prepared? Once again, SEI provides detailed checklists for addressing these seven questions. These SEI publications are further discussed in chapter 2 and in appendixes I, II, and III.

Cost Accounting Requirements

Requirements for agency cost accounting have been evolving for decades. In a 1985 report, the Comptroller General presented a framework for strengthening agencies' financial management structure.[11] This report called for the integration of accounting and budgeting systems to better monitor progress against estimates and to better estimate future program costs. More specifically, it states that actual costs must be maintained and monitored in order to effectively manage programs and control costs. This approach was embodied in the CFO Act of 1990, which requires agencies to develop and maintain integrated accounting and financial management systems which provide for (1) the development and reporting of cost information and (2) the systematic measurement of performance.

Most recently, the Statement of Federal Financial Accounting Standards no. 4 (SFFAS 4), Managerial Cost Accounting Concepts and Standards for the Federal Government, effective for fiscal years beginning after September 30, 1996, was issued. This standard requires reporting entities to regularly accumulate and report the full cost (including all direct, indirect, and supporting costs) of its activities. These cost accounting standards are further discussed in chapter 3.

[11]Managing the Cost of Government: Building An Effective Financial Management Structure (GAO/AFMD-85-35 and GAO/AFMD-85-35-A, Feb. 1985).

Objectives, Scope, and Methodology

The objectives of our review were to determine if (1) FAA's project cost estimates are based on good estimating policies and practices and (2) the actual costs of ATC modernization projects are being properly accumulated.

To determine if FAA's estimates were based on good policies and practices, we

- researched current literature and interviewed project estimating experts to identify the key components of good cost estimating practices;
- obtained and analyzed FAA's policies and practices for estimating costs to determine what criteria (directives, orders, instructions, and implementing procedures), if any, FAA has in place to guide managers in developing projects' cost estimates;
- assessed FAA's cost estimating policies, practices, tools, and techniques to determine if they incorporate the key components of good cost and schedule estimating practices advocated by SEI and other experts; and
- selected FAA's five largest (based on latest life cycle cost estimates) ongoing ATC modernization projects and one project that was the subject of another GAO review, and interviewed project managers and assessed project documentation on these six projects to determine (1) how the current life cycle cost baseline was estimated and (2) how this estimating approach compared to the SEI project-level questions.[12] To do this, we compared each projects' documentation to SEI's detailed checklists for each question; determined if the project satisfied, partially satisfied, or did not satisfy each checklist item and assigned points accordingly (1, .5, or 0 points, respectively); and then summed the points and presented them as a portion of the total points available (e.g., 4/10). Because the focus of this effort is to assess FAA's cost estimating processes and not to validate the accuracy or completeness of the estimates, we did not evaluate the quality of the estimates.

To determine whether the actual costs of ATC modernization projects are being properly accumulated, we

- obtained and reviewed (1) selected reports and testimonies issued by GAO, the Department of Transportation's Office of the Inspector General, and the Defense Contract Auditing Agency, (2) related policies and procedures issued by the Department of Transportation, (3) applicable accounting standards and guidance, and (4) applicable OMB directives;

[12]A Manager's Checklist for Validating Software Cost and Schedule Estimates (CMU/SEI-95-SR-004, Jan. 1995).

- reviewed FAA's policies and procedures governing ATC financial management and interviewed program managers and financial accounting staff to determine (1) their roles and responsibilities for recording and managing ATC cost information and (2) the financial processes used to accumulate and record ATC costs; and
- reviewed available information for the five largest (based on life cycle cost estimates) ongoing ATC projects and determined if costs are properly accumulated by (1) obtaining available financial information on the projects and identifying the cost elements included and excluded and (2) assessing reconciliation procedures among varying sources of information.

We requested comments on a draft of this product from the Secretary of Transportation. On December 10, 1996, we obtained oral comments from Transportation and FAA officials, including representatives from the Office of the Secretary of Transportation, the Executive Assistant to the FAA Chief Financial Officer, the FAA Manager of the Cost Accounting System Division, and the FAA Program Director for Investment Analysis and Operations Research. Their comments are presented and addressed in chapters 2 and 3 of this report.

We performed our work at the Federal Aviation Administration in Washington, D.C., and the Software Engineering Institute in Pittsburgh, Pennsylvania, between February and December 1996. Our work was performed in accordance with generally accepted government auditing standards.

ATC Modernization Lacks the Institutional Capacity to Produce Reliable Cost Estimates

Reliable estimates of projects' expected costs are essential to decide among alternative investments. According to SEI, consistently producing them requires defined institutional processes for deriving estimates, archiving them, and measuring actual performance against these estimates. FAA's cost estimating processes used on its ATC modernization projects do not meet SEI criteria. These weaknesses are exacerbated by FAA's practice of presenting cost estimates as precise, point estimates. By doing so, FAA obscures the estimates' inherent uncertainty and may mislead decisionmakers.

Policies and Practices for Estimating Costs Do Not Satisfy "Best Practices" Requisites

FAA's institutional processes for estimating ATC projects' costs do not fully satisfy any of the six SEI requisites. According to SEI, all six must be satisfied to produce credible estimates. The six requisites are described below, along with our analysis showing that FAA's institutional policies and practices fail to meet them. (See appendixes I and II for more detail.) We shared this analysis with FAA's cost estimating authority, who agreed that FAA's policies and practices do not meet SEI's process requirements.

Requisite 1: A Corporate Memory

According to SEI, estimating organizations should have a process for organizing and retaining project cost and schedule information in a historical database, and for using it as an integral part of the estimating process. This database should contain detailed information on projects' original estimates, revised estimates, reasons for revisions, and actual performance against the estimates. It should also contain descriptive contextual information that enables people to understand and correctly interpret the data in the database.

FAA has no institutional corporate memory, or historical database, on ATC projects' cost and schedule estimates and performance. While FAA has a number of stand-alone databases within different groups, none provide a complete picture of estimates, assumptions that make up the estimates, revisions, and actual performance on projects. For example, the Cost Benefit Analysis System (CBAS) is a database that contains some information on projects' cost estimates and planned budget levels. However, it contains no information on how and why estimates are revised, why budget streams differ from estimates, or what projects actually cost.

Further, what limited information is available on actual cost performance is not an integral part of the project estimating process, and the

information on cost estimates that is retained by the central estimating organization is not readily available to the project personnel that are responsible for updating estimates after the initial investment decision has been made.

Requisite 2: Structured Processes for Estimating Product Size and the Amount and Complexity of Existing Software That Can Be Reused

According to SEI, estimating organizations should follow well-defined, structured processes for estimating product size and the amount and complexity of existing software that can be reused. It should be clear what is included and what is excluded from size estimates, and new estimates should be checked by comparing them to measured sizes of existing software products.

FAA has no institutional process for estimating product size and the amount of existing software that can be reused. Each project manager decides to estimate software size and reuse as he or she chooses. Among ATC projects, these processes range from simple lines-of-code estimates using an individual's personal knowledge of similar systems' sizes to sophisticated analysis based on project-unique variables. For example, the original software size estimates for the Standard Terminal Automation Replacement System (STARS) was a rough approximation based on the number of lines of code in a predecessor system. A more recent, though not yet official, estimating effort established size estimates for each desired STARS software function and then compared the estimates to known sizes of similar functions on two other completed projects. This effort also used a checklist to ensure that no desired functions were overlooked and accounted for differences between STARS and its predecessor system. The latter, more careful size estimate is over three times the original estimate for new and modified software.

Requisite 3: Mechanisms for Extrapolating From Demonstrated Accomplishments on Past Projects

According to SEI, estimating organizations should have documented processes for extrapolating from past experiences. These processes should include the use of cost models that are calibrated and validated on the basis of actual experience. Further, differences between cost models' outputs should be analyzed and explained.

FAA's estimating guidance recommends 10 different cost models as acceptable estimating tools; however, there is no requirement for project estimators to use these models or to collect and use past experience to calibrate these models. As a result, projects' use and calibration of the models is inconsistent. For example, estimators on three of the six

projects we assessed did not use cost models in their estimates whereas Display System Replacement (DSR) officials not only used four cost models, but also calibrated them to past experiences on a predecessor system.

Requisite 4: Audit Trails

According to SEI, estimating organizations should prepare adequate audit trails of inputs to the estimates, including parameters used in cost models and their rationales.

FAA estimating guidance requires that cost estimates be documented and reproducible. However, the degree of documentation and the extent of any accompanying explanation is left to the discretion of each project's estimators. As a result, the detail and quality of the audit trails on ATC projects is inconsistent. For example, only handwritten notes document how the Display Channel Complex Rehost (DCCR) estimate was derived. On the other hand, the DSR estimate and the ongoing STARS estimating effort are supported by volumes of documentation delineating the assumptions, processes, and model inputs used.

Requisite 5: Integrity in Dealing With Dictated Costs or Schedules

According to SEI, organizations should ensure that the effects of dictated, or externally imposed, costs or schedules are determined and explicitly presented to management. Estimators should document and managers should approve any changes made to model parameters to accommodate dictated costs or schedules, the rationale for making the changes, and the effect of the changes on other factors—cost, schedule, or risk.

FAA has no institutional process for ensuring integrity in dealing with dictated costs or schedules. As a result, each project manager determines his or her own response to externally imposed constraints. Only one of the projects we assessed acknowledged working under an externally imposed schedule. STARS project officials are preparing a cost estimate that shows the cost of meeting the compressed schedule. However, without an institutional policy requiring such action, there is no assurance that all dictated constraints on all ATC projects will be handled so effectively.

Requisite 6: Data Collection and Feedback Processes That Foster Capturing and Correctly Interpreting Data From Work Performed

According to SEI, organizations should have a defined process for gathering information on ongoing and completed projects (including original estimates, revised estimates, and post-mortem assessments) and entering this information into the historical database.

FAA has no institutional process for gathering information on completed projects and entering it in a historical database. Post-mortem reviews are performed rarely, and only on an ad hoc basis. Instead, each project manager determines the type and amount of information retained.

Individual ATC Projects' Cost Estimating Approaches Are Inconsistent and Sometimes Unreliable

Because FAA does not have well-defined, institutional processes for estimating information technology projects' costs, the approaches used and the reliability of the estimates are inconsistent.

To assist management in assessing the credibility of a given project cost estimate, SEI developed seven questions which must be answered. The seven questions are (1) Are the objectives of the estimate clear and correct? (2) Has the task been appropriately sized? (3) Are the estimated cost and schedule consistent with demonstrated accomplishments on other projects? (4) Have the factors that affect the estimate been identified and explained? (5) Have steps been taken to ensure the integrity of the estimating process? (6) Is the estimate based on reliable evidence of the organization's past performance? and (7) Has the situation remained unchanged since the estimate was prepared? SEI developed a detailed checklist to assist in addressing each question. (See appendix III for more information on SEI's questions and checklists.)

We applied this checklist to the most recently baselined life cycle cost estimate on six ATC projects (the five ongoing projects with the largest life cycle cost estimates plus one ongoing project that was the subject of another GAO review). These projects are the Voice Switching and Control System (VSCS), the Standard Terminal Automation Replacement System (STARS), the Display System Replacement (DSR), the Airport Surveillance Radar-9 (ASR-9), the Wide Area Augmentation System for the Global Positioning System (WAAS), and the Display Channel Complex Rehost (DCCR).

Of the six systems, two (ASR-9 and DCCR) could not be assessed because they lacked documentation describing how the latest official life cycle cost estimates were derived. For example, the estimated cost to develop ASR-9 is

$857 million.[1] However, there is no documentation describing how ASR-9 software size estimates were determined or what assumptions were used to estimate costs from these size estimates. As a result, there is no analytical way to determine the credibility of the original estimate or estimating approach. Moreover, without documentation, FAA cannot systematically use its ASR-9 experience in other system estimating endeavors.

Of the remaining four systems, we found that the approaches used on three (STARS, WAAS, and VSCS) satisfied some but not all of SEI's reliability questions. To their credit, officials on two of these projects are currently revising parts of the life cycle cost estimate using more rigorous approaches. For example, the estimating approach used to establish the current STARS life cycle cost estimate was performed very early in the project's life cycle, during the mission needs determination phase. Project officials estimated the project's software size on the basis of a predecessor system's size. However, the predecessor was so different from STARS that its size was not a good indicator of the size of STARS' software. Unlike the predecessor, STARS is being developed to be easily maintainable, portable, and expandable. Additionally, many significant functions, such as support software for configuration management and simulation, were not accounted for in the original software estimate. Project officials agree that the early estimating process was not strong, and in fact, that they underestimated the size and complexity of the software to be developed. In an ongoing estimating effort, STARS estimators have been more thorough and rigorous in estimating the software size and project costs. They defined existing and missing STARS functions, comparing the functions to two completed projects' functions to help determine software size for each function, and refining this estimate based on advice from experts throughout FAA and performance demonstrations by competing vendors. However, even this improved estimating approach falls short of SEI standards. Specifically, STARS estimators did not calibrate the cost estimating models it used to past FAA performance, choosing instead to use the models' default values. Calibrating models to an organization's historical experience (i.e., determining the productivity value of a "man-month" or the time and cost to produce a "line of code" based on the organization's past performance on similar projects, or adding new cost drivers that are specific to an organization's business, such as security or privacy) will provide more accurate estimates.

[1]A project official stated that they have no estimate of what it will cost to operate and maintain ASR-9 over its life cycle.

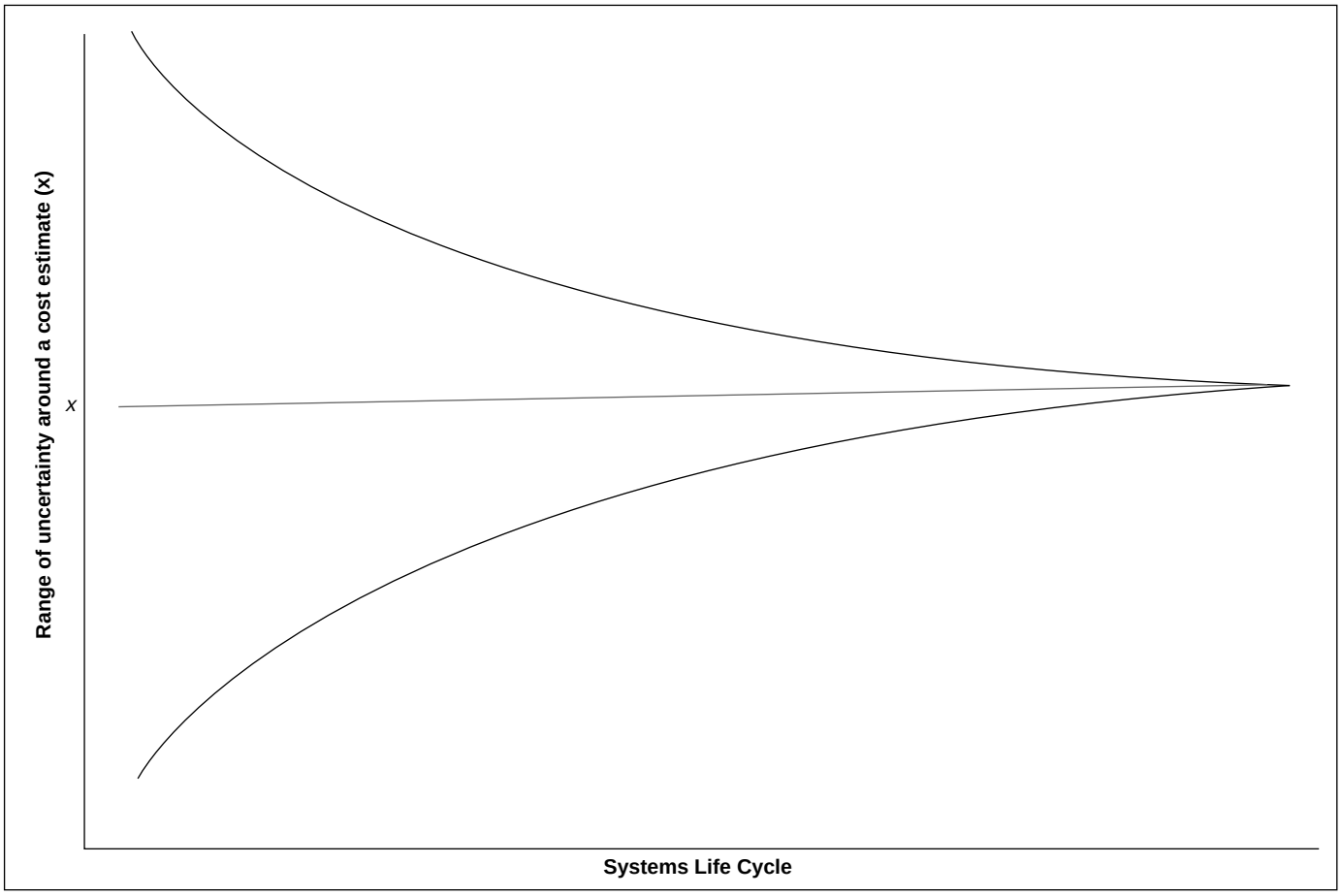
In addition, project estimators derived official WAAS life cycle cost estimates based on experiences with the National Satellite Test Bed, a precursor to the WAAS development. However, little documentation exists on how the original WAAS size estimates were derived and what assumptions and parameters were used to estimate costs. Project officials are currently updating estimates using a published sizing methodology and the Software Life Cycle Intermediate Model (SLIM) cost model, and stated that they believe this is a much more rigorous approach than prior estimating efforts. However, this more structured approach also falls short of SEI requirements. For example, the project software estimator stated that one cost model parameter (input variable) is a ranking of the sophistication of the developer's software environment. The estimator scored the WAAS contractor as very high on this parameter and showed us where this information was captured in the SLIM database. However, the estimator went on to explain that he chose a high score based on the contractor's rating as a level 3 organization on SEI's CMM and the fact that they have and use Computer-Aided Software Engineering (CASE) tools. This explanatory information was not recorded in the SLIM database or in any other documentation, and thus is not available to anyone trying to understand or validate the estimate or learn from this estimating experience.

The current official estimate for the last of the six systems, DSR, was derived using an approach that partially or fully satisfied six of the seven SEI reliability questions. Examples of DSR's adherence to SEI guidance include (1) DSR's software size estimate was developed by identifying needed software functions, and then determining the amount of new code needed and reusable code available for each of these software functions, (2) DSR estimators calibrated cost estimating models to past experience on DSR's predecessor system, the Initial Sector Suite System (ISSS), and (3) estimators used templates to ensure that key cost factors would not be overlooked. However, DSR estimators did not record the rationales for the parameters they used in their cost models or explain differences among cost model results. (See appendix IV for further information on the results of our assessment.)

FAA's Portrayal of ATC Projects' Cost Estimates Implies an Unjustified Level of Precision

Software and systems development experts agree that early project estimates are by definition imprecise, and that this inherent imprecision decreases during the project's life cycle as more information becomes known about the system. Some have described this phenomenon as a "cone of uncertainty" that is widest early in the life cycle and narrows over time as more becomes defined and known about the project. (See figure 2.1.) These experts emphasize that each cost estimate should include an indication of its degree of uncertainty, possibly as an estimated range or qualified by some factor of confidence. For example, a cost estimate of $1 million could be presented as a range from $750,000 to $1.25 million or as $1 million with a confidence level of 90 percent, indicating that there is a 10-percent chance that costs will exceed this estimate.

Figure 2.1: Cost Estimating Accuracy Over Time



FAA does not reveal its estimates' degree of uncertainty to managers involved in investment decisions. Instead, FAA presents its projects' cost estimates as unqualified point estimates, thereby suggesting an element of precision that does not exist. A budget official stated that FAA presents project cost estimates as such because "this is the way OMB and Congress want to see it." Further, he stated that in today's environment of lean budgets, the low-end of the estimate range is all that FAA can afford and all that is salable, and therefore, this is what they present.

By presenting a point estimate instead of a range of estimates or a realistically qualified estimate, FAA is not fully disclosing all relevant information about the projects' potential costs and inherent risk. The result is uninformed, and thus potentially unwise, investment decisions.

FAA Organizations Have Initiated Efforts to Improve Cost Estimating

During the course of our review, FAA organizations initiated several efforts to improve their processes for estimating and archiving cost information. However, these efforts are still relatively new and have not yet been institutionalized. We did not evaluate any of these efforts.

FAA's Office of Investment Analysis and Operations Research (ASD-400), which has historically been responsible for early life cycle cost estimates, has established an informal cost estimating work group to explore the possibility of integrating cost estimating functions across FAA. To date, this group has documented current cost estimating processes and identified the multitude of organizations that participate in different components of the estimating process. The group has also drafted a workbook to guide estimators in developing estimates. However, neither the group nor the workbook has not yet been officially sanctioned by FAA.

Additionally, FAA's Office of Information Technology recently procured an agencywide site license for another cost estimating tool, the Software Life Cycle Intermediate Model (SLIM). This tool is one of several that estimators can use to develop cost estimates.

FAA's Office of Airway Facilities Requirements initiated a "grass roots" effort to standardize on a single cost estimating and tracking tool, called the Automated Cost Estimating Integrated Tools (ACEIT). Officials stated that institutionalizing ACEIT would provide FAA a consistent framework for estimating costs, including a documented audit trail. The group supporting ACEIT is currently briefing other FAA organizations in an attempt to promote adoption of this tool throughout FAA.

The same organization is also testing the Cost and Performance Management System (CPMS) to track operations and maintenance (O&M) costs by project for the first time. An airways facilities manager stated that CPMS will eventually be integrated with ACEIT to allow estimators to use actual project cost information in estimating new projects' O&M costs.

Conclusions

Multimillion dollar, and even billion-dollar, investment decisions on air traffic control modernization projects are being made without reliable information on the projects' estimated and actual costs. FAA does not have well-defined, structured estimating processes that are rigorously followed, and does not disclose the estimates' inherent uncertainty. Without better estimates of cost, FAA's new investment analysis and decision-making processes are unlikely to be effective.

Recommendations

We recommend that the Secretary of Transportation direct the FAA Administrator to institutionalize defined processes for estimating ATC projects' costs. At a minimum, these processes should include the following SEI requisites, each of which are described in more detail in this report:

- a corporate memory (or historical database), which includes cost and schedule estimates, revisions, reasons for revisions, actuals, and relevant contextual information;
- structured approaches for estimating software size and the amount and complexity of existing software that can be reused;
- cost models calibrated/tuned to reflect demonstrated accomplishments on past projects;
- audit trails that record and explain all values used as cost model inputs;
- processes for dealing with externally imposed cost or schedule constraints in order to ensure the integrity of the estimating process; and
- data collection and feedback processes that foster capturing and correctly interpreting data from work performed.

We also recommend that the Secretary direct the Administrator to immediately begin disclosing the inherent uncertainty and range of imprecision in all ATC projects' official cost estimates presented to executive oversight agencies or the Congress.

Additionally, we recommend that the Secretary direct the Administrator to report to the Secretary and FAA's authorizing and appropriation

committees on progress being made on these recommendations as part of the agency's fiscal year 1999 budget submission.

Agency Comments

DOT and FAA officials provided oral comments on a draft of this report. These officials concurred with the report's findings, conclusions, and recommendations on cost estimating. They also stated that this report will be useful as FAA strives to improve its cost estimating capabilities.

FAA Is Not Adequately Accounting for ATC Project Costs

Agencies are required to maintain adequate systems of accounting and internal controls to provide managers and other decisionmakers with reliable financial information to effectively measure performance and make sound investment decisions. In the case of the ATC modernization program, FAA is not satisfying this requirement. Specifically, ATC project information does not include all relevant project costs, including internal personnel compensation, benefits, and travel (PCB&T) costs, because FAA lacks a cost accounting system to accumulate and allocate these costs to specific projects. FAA's internal accounting policies include a requirement for a cost accounting system; however, this policy has not been implemented. As a result, project managers are unable to measure actual costs and their ability to make informed decisions is impaired. Moreover, complete project information is not available to feed back into, and thereby improve, future project cost estimates.

Agencies Are Required to Maintain Adequate Accounting Systems

The Federal Managers' Financial Integrity Act of 1982 (FMFIA) requires that agency systems of internal accounting and administrative control comply with internal control standards prescribed by the Comptroller General and provide reasonable assurance that among other things, obligations and costs comply with applicable law and revenues and expenditures applicable to agency operations are recorded and accounted for properly. FMFIA also requires that agency heads issue an annual report, transmitted to the President and the Congress, detailing whether their internal control systems fully comply with the act's requirements, including the identification of material systems weaknesses and plans for corrective actions.

The Chief Financial Officers (CFO) Act of 1990 requires agencies to develop and maintain integrated agency accounting and financial management systems that comply with applicable accounting principles, standards, and requirements, including

- the preparation of complete, reliable, consistent, uniform, and timely information that is responsive to agency management's financial information needs;
- the development and reporting of cost information;
- the integration of accounting and budgeting information; and
- the systematic measurement of performance.

Recently, the Statement of Federal Financial Accounting Standards no. 4 (SFFAS 4), Managerial Cost Accounting Concepts and Standards for the

Federal Government, was issued, effective for fiscal periods beginning after September 30, 1996. These standards require a reporting entity to accumulate and report the full cost of its activities regularly for management information purposes. The full cost of a project is described as the sum of (1) the costs of resources consumed by the project that directly or indirectly contribute to the output and (2) the costs of identifiable supporting services provided by other organizations within the reporting entity and by other reporting entities. These standards also require that the full costs of resources be assigned to outputs through costing methodologies or cost finding techniques that are most appropriate to the organization's operating environment and that they be followed consistently. While SFFAS 4 has only been effective for a short time, and therefore was not applicable during the period of our review, it provides cost accounting criteria which are now required to be implemented by all agencies.

Additionally, the 104th Congress passed the Federal Financial Management Improvement Act of 1996 which, among other provisions, requires agencies to comply with federal accounting standards.

ATC Project Costs Are Not Being Properly Accumulated

FAA financial systems supporting the ATC modernization program do not accumulate all project costs, and thus, managers do not receive all relevant financial information needed to effectively manage their projects. Of the five projects whose financial information we reviewed, none of the project managers could provide the total of all costs incurred from the project's inception. Instead, they provided:

- contract numbers for their respective projects so that cost data for each contract could be extracted from FAA's Departmental Accounting and Financial Information System (DAFIS) and aggregated to provide total contract costs. However, these contract costs could be understated because project officials could not verify that they provided us all applicable contract numbers.
- incomplete project costs. These costs were not complete because they did not include (1) Personnel Compensation, Benefits, and Travel (PCB&T) costs associated with the Facilities and Equipment (F&E) appropriations account and (2) all costs paid out of the Operations and Maintenance (O&M) appropriations account. PCB&T costs for the F&E appropriation include internal FAA costs that are related to project design, contracting, and contractor oversight. O&M costs are costs associated with the administration, operation, repair, and maintenance of operating FAA

facilities and are generally the single largest component of an information systems life cycle cost. In 1995, total PCB&T costs were approximately $2 billion for all ATC projects. PCB&T and O&M costs are accounted for separately and are not allocated to individual ATC projects. Because these costs are not allocated to specific projects, full life cycle costs of projects cannot be determined and may be significantly understated.

An additional limitation is that FAA does not carry over and report the costs associated with terminated or redirected projects as part of the successor projects' costs, even though successor projects reuse parts of the predecessors' components. As a result, the full costs of "restructured" ATC projects are understated. Accounting for the full costs of projects requires that the costs related to usable portions of terminated or redirected projects be included in the costs of the ongoing projects. In addition, full project cost accounting information would require that costs of unused parts of terminated or redirected projects be separately identifiable within the "corporate memory."

For example, one of the projects we reviewed, the Display System Replacement (DSR), is a follow-on to an earlier terminated project known as the Initial Sector Suite System (ISSS). According to FAA officials, DSR software and hardware salvaged from ISSS accounts for about 19 percent of DSR's cost. However, these costs are not included in DSR's accumulated and reported costs because, according to an FAA official, these costs are considered "sunk costs." The term "sunk costs" is generally used to describe costs that have been incurred in the past and have no relevance to future decision-making. However, we believe these costs should be considered a part of a project's full cost since they would be instructive in reliably estimating costs of similar systems. In addition, information about the amount of costs associated with the unused portions of terminated projects should be retained in the "corporate memory" to provide a full picture of the real cost of development projects.

FAA Lacks a Cost Accounting System for Its ATC Modernization Program

A managerial cost accounting system supports the collection, measurement, accumulation, analysis, interpretation, and communication of cost information to allow users to determine the cost of specific programs and activities and the composition of, and changes in, these costs. As mentioned above, the CFO Act requires agencies to develop and maintain a cost accounting capability that captures both budgetary and financial accounting data and generates performance measures. FAA's internal policies require a cost accounting system and state that the cost

accounting system should be integrated with the general accounting system. However, these policies have not been implemented; thus FAA project managers do not have the capability to fully account for costs being incurred for the ATC modernization program.

Instead of a cost accounting system, several financial management systems account for specific financial accounting and budgetary data, but these systems are not integrated and they do not provide the full cost information necessary for investment decisions. These systems include the following.

- Departmental Accounting and Financial Information System (DAFIS): This system is the Department of Transportation's core accounting system. However, this system is not a cost accounting system because not all cost information is captured by project. In addition, the Department's Office of the Inspector General (OIG) reported that DAFIS data is unreliable and inaccurate.[1] For example, the OIG reported that major balance discrepancies existed between DAFIS accounts and their supporting details. Further, in April 1996, a cost accounting systems consultant reported that DAFIS does not provide all levels of management with timely, accurate, relevant, and meaningful information.
- Financial Management System (FMS): This FAA system is used by ATC project managers to establish quarterly obligation plans under the Facilities and Equipment (F&E) appropriation and to track actual obligations against these plans. However, FMS is not a cost accounting system because it (1) contains only obligation data and (2) does not contain all relevant cost data, such as those for PCB&T.
- Cost of Performance System (COPS): This system is used by FAA organizations responsible for operating and maintaining ATC systems to allocate aggregated O&M obligation data to individual cost centers (that is, field maintenance organizations). COPS is not a cost accounting system because it does not contain information on actual costs. In addition, COPS' O&M cost data is not allocated to and accumulated for individual projects.
- Research, Engineering and Development, Monitoring, Analysis, and Control System (REDMACS): This system is used by FAA organizations responsible for ATC research and development projects to establish quarterly obligation plans for the Research, Engineering, and Development (RE&D) appropriation and to track actual obligations against these plans. REDMACS is not a cost accounting system because it does not contain information on actual costs.

[1]Supplementary Report on Internal Control Systems and Compliance Related to the Airport and Airway Trust Fund Portion of the Federal Aviation Administration FY 1993 Financial Statement (Department of Transportation - Office of Inspector General, AD-FA-5-005, Mar. 29, 1995).

Project managers have also developed their own unique systems to account for F&E and RE&D obligations. These "cuff" systems range from spreadsheets to more sophisticated financial management systems, but do not include O&M costs and generally do not capture actual costs. None of the systems listed above, either individually or combined, constitute a cost accounting system because they do not provide for accumulation and monitoring of total costs.

In recognition of the need for accurate and reliable cost information, FAA's Associate Administrator for Administration established a new Cost Accounting Systems Division in August 1996 and engaged a consultant to assist the agency in defining its cost accounting requirements and in designing and implementing a system to meet these requirements. According to the Manager of the Cost Accounting System Division, this system will use data from several financial management systems, including DAFIS, and is planned to be in place by October 1, 1997.

Conclusions

Reliable project cost information that is both complete and accurate is needed to estimate future project costs, make sound investment decisions, and effectively manage projects. FAA does not have a cost accounting system capable of reliably accumulating full project cost information, and therefore cannot reliably estimate future project costs, ensure that investment decisions are sound, or manage projects effectively. Without better cost information, FAA's new investment analysis and decision-making processes are unlikely to be effective.

Recommendations

In light of FAA's weaknesses in accounting for and reporting ATC project costs, we recommend that the Secretary of Transportation direct the FAA Administrator to acquire or develop and implement a managerial cost accounting capability that will satisfy the requirements of SFFAS 4, Managerial Cost Accounting Concepts and Standards for the Federal Government. This system capability should provide the cost accounting and financial management information needed by FAA management and those who make investment decisions. Such information should include full life cycle costs, which include the costs of resources consumed by a project that directly or indirectly contribute to the output and the costs of identifiable supporting services provided by other organizations within the reporting entity.

We further recommend that the Secretary report FAA's lack of a cost accounting capability for its ATC modernization as a material internal control weakness in the Department's fiscal year 1996 FMFIA report and in subsequent annual FMFIA reports until the problem is corrected.

Also, we recommend that the Secretary direct the Administrator to report to the Secretary and FAA's authorizing and appropriation committees on progress being made on these recommendations as part of the agency's fiscal year 1999 budget submission.

Agency Comments and Our Evaluation

In providing oral comments on a draft of this report, DOT and FAA officials stated that since they are in the process of acquiring a cost accounting system and plan to have an "initial operating capability" by October 1, 1997, they do not agree with our recommendations and consider them unnecessary. While we acknowledge and support FAA's cost accounting organizational and system initiatives, it is important to note that its cost accounting system acquisition is still very early in its acquisition life cycle and much remains to be accomplished before FAA can have the cost accounting capability we recommend. In fact, FAA has yet to develop detailed functional requirements for this system, thereby precluding our analysis at this time of whether its plans will satisfy our recommendation. Additionally, until FAA implements our recommendation and improves the accuracy of underlying data in feeder systems like DAFIS, it will continue to lack adequate cost information needed to effectively manage its ATC system acquisitions. Disclosure of such a management control weakness is one of the objectives of the FMFIA, and therefore we continue to believe that FAA should report its lack of a cost accounting system as a material weakness in its FMFIA reports until the problem is corrected.

Summary Comparison of SEI's Requisites for Reliable Estimating Processes and FAA's Institutional Policies and Practices

Table I.1 identifies SEI's requisites for reliable estimating processes and contrasts these with the institutional policies and practices currently in place at FAA. A more detailed comparison for each requisite is provided in appendix II.

Table I.1: Comparison of SEI's Requisites for Reliable Estimating Processes and FAA Policies and Practices for ATC Projects

	FAA	
SEI requisites	**Institutional policies**	**Actual practice**
A corporate memory (historical database) containing original and revised cost and schedule estimates and actual costs and schedules on completed projects to be used as an integral part of the estimating process for new/updated projects. (See appendix II, table II.1 for more details.)	None.	Some information on project estimates and budgets are maintained in different, unrelated databases. None of these databases, however, provide sufficient data to support these estimates and assumptions and to document revisions to estimates and actual performance against estimates. Projects vary in the type and extent of historical information used. The limited information available on actual project cost is not used as part of the estimating process.
Structured processes for estimating product size and reuse. (See appendix II, table II.2 for more details.)	None.	Project teams follow whatever approach they choose for estimating product size and reuse. As a result, size and reuse practices vary.
Mechanisms for extrapolating from demonstrated accomplishments on past projects—that is, tools for forecasting costs and schedules that are calibrated to past experience. (See appendix II, table II.3 for more details.)	FAA policy approves parametric modeling as one of five acceptable cost estimating methodologies. FAA guidance recommends, but does not require, using various estimating tools/models. FAA does not have a policy regarding the calibration/tuning of the models using demonstrated accomplishments.	Project teams use a variety of models or none at all. The extent to which they use historical information varies depending on their awareness of and access to such information.
Audit trails detailing and explaining values used for the cost model parameters. (See appendix II, table II.4 for more details.)	FAA guidance states that cost estimates be documented and reproducible, but does not specify what that entails.	Audit trails vary among projects, ranging from handwritten notes to detailed volumes.
Integrity in dealing with dictated costs and schedules. (See appendix II, table II.5 for more details.)	None.	Project teams determine how they deal with imposed cost and schedule objectives. The effect of imposed cost and schedule constraints is not always explicitly presented.
Data collection and feedback processes that foster capturing and correctly interpreting data from work performed and entering them into the historical database. (See appendix II, table II.6 for more details.)	FAA policies require projects to identify and analyze differences from earlier estimates. FAA does not have a policy regarding data collection and feedback.	Project teams determine the type and amount of information they retain. Thus, the type of information and its location varies among projects.

Detailed Comparison of SEI's Checklist for Each Requisite and FAA Practices for ATC Projects

The following tables provide a detailed comparison of FAA's practices to the six SEI requisites' components that were summarized in appendix I.

Table II.1: A Corporate Memory

Evidence of maturity	FAA practices
The organization has a process for organizing and retaining information on completed projects (a historical database).	FAA does not have an institutional process for creating, maintaining, and using a historical database(s) on ATC projects. FAA has several processes for retaining different subsets of the full set of information on completed project estimates and actuals. That is, it has processes for populating several databases that organize and retain some project information for use within certain groups.[a] These individual processes are not coordinated with or part of an institutional process for organizing and retaining all relevant information on completed projects' estimates and actuals. None of these databases (either individually or combined) provide a comprehensive cradle-to-grave understanding of a project's history from early estimates, through revisions, and to ultimate completion. Furthermore, the information catalogued in the existing databases is limited to the perceived needs of the group that manages it. That is, it is not always known and accessible to, or usable by, estimators outside each group.

Evidence of maturity	FAA practices		
	FAA does not have an institutional historical database.[b] The databases noted above provide the following information:		
The information on completed projects includes:	CBAS	F&E	DAFIS
1. the life cycle model used together with the portion covered by the recorded schedule and costs	yes	no	no
2. original size estimate	yes	no	no
3. changes in size resulting from changes in requirements	yes[c]	no	no
4. the original cost and schedule estimate, together with the values and rationales used for cost model parameters	y/n[d]	no	no
5. re-estimates and estimates-to-complete	yes	yes	no
6. reasons for re-estimates	no	no	no
7. actual costs and schedules	no	no	y/n[e]
8. actual size of delivered code	no	no	no
9. staffing profile	no	no	no
10. labor mix	no	no	yes[f]
11. skill level of the project team, measured relative to the skill level of the organization's typical team	no	no	no
12. nonlabor costs	no	no	no
13. management costs	no	no	no
14. system integration costs	no	no	no
15. an estimate at completion	no	yes	yes
16. extenuating circumstances or reasons for the differences between the original and final estimates	no	yes[g]	no
17. a work breakdown structure or alternative description of the tasks included in the recorded costs	no	no	no
18. a work-flow schematic for the software process	no	no	no
19. a summary of significant deliverables produced by the project (software, documentation, etc.)	no	no	no
20. a summary of any unusual issues or contract factors that affected cost or schedule	no	yes	no
21. if multiple builds or releases were used, the size, cost, schedule, and characteristics of each build or release	no	no	no

Evidence of maturity	FAA practices
The historical database is treated as an integral part of the estimating process, and estimators have active roles in specifying and sustaining the information it contains.	Because FAA does not have an institutional historical database, it is not an integral part of the estimating process. With the exception of the CBAS database, none of the individual databases are used in the estimating process. CBAS is used at the discretion of the ASD-400 estimators if they are involved in developing a project's cost estimate. With the exception of the ASD-400 estimators, estimators are not active in defining the information in the respective databases.
The database contains a useful set of completed projects.	FAA does not have an institutional historical database. Each of the individual databases contains a useful set of projects.
The elements included in (and excluded from) effort, cost, schedule, size, and reuse measures are clearly identified.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. None of the individual databases provide this level of detail. The CBAS database provides a reference to documentation supporting the cost estimate, which includes information on cost and schedule elements, but not the elements included in effort, size, and reuse measures. Individual projects may have this information in their project files.
Schedule milestones (start and finish dates) are described in terms of criteria for initiation or completion.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. None of the individual databases provide this level of detail. Individual projects may have this information in their project files.
Effort and cost data clearly indicate which parts of the life cycle and which activities are covered by the different categories of hours or costs recorded.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. None of the individual databases provide this level of detail. Individual projects may have this information in their project files.
Records for projects indicate whether unpaid overtime was used.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. None of the individual databases provide this level of detail. Further, none of the projects we reviewed recorded unpaid overtime.
Unpaid overtime, if used, is quantified, so that recorded data provide a valid basis for estimating future effort.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. None of the individual databases provide this level of detail. Further, none of the projects we reviewed recorded unpaid overtime.
Cost models are used to provide a consistent framework (standard terms and parameters) for recording historical data.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. FAA endorses a number of cost models, thus permitting differences among projects in the data that are recorded. Of the individual databases, only the CBAS database references models used by estimators. These models, however, are not used to record actual performance data on completed projects.

(continued)

Evidence of maturity	FAA practices
Historical data have been examined to identify inconsistencies, and anomalies have been corrected or explained. (This is best done with the same cost models used for estimating.)	Because FAA does not have an institutional historical database, this type of information is not recorded therein. Thus, these data are not examined for anomalies. None of the individual databases provide this level of detail. Individual projects may have this information in their project files and may correct anomalies.
Workflow schematics are used to describe similarities and differences among projects.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. None of the individual databases provide this level of detail. Individual projects may have this information in their project files.

[a]The databases include:

—the Cost Benefit Analysis System (CBAS), which catalogues project estimates and provides a reference to the location of supporting documentation in a repository. It is only accessible by estimators in the Investment Analysis and Operations Research Division (ASD-400) of the Office of Systems Architecture and Investment Analysis;

—the Facilities and Equipment Database, which tracks changes in F&E estimates over time, but whose supporting documentation is located in a number of places. It is used by one individual to answer ad hoc FAA and congressional management and oversight questions on how estimates have changed over time; and

—several financial management systems, including REDMACS, DAFIS, FMS, and COPS, which provide budgetary performance information to project teams.

[b]Individual projects may contain some of this information in their project files.

[c]Only if a new cost estimate is generated.

[d]The database repository contains cost and schedule estimates, but not the values and rationales used for cost model parameters.

[e]DAFIS can provide actual costs, but no schedule information.

[f]This information could be pulled, with effort, from DAFIS.

[g]The database provides a marker to when, or how, the estimate changed (i.e., at a major acquisition review), not the reason for the change.

Table II.2: Structured Processes for Estimating Software Size and Reuse

Evidence of maturity	FAA practices
The estimating processes for size and reuse are documented.	FAA does not have a documented institutional process for estimating size and reuse. Project teams are permitted to follow whatever approach they choose for estimating product size and reuse.
The estimating processes for size and reuse are followed.	Because FAA does not have a documented institutional process for estimating size and reuse, project teams do not follow such a process. Project teams are permitted to follow whatever approach they choose for estimating product size and reuse.
The descriptions of size and reuse identify what has been included in (and excluded from) the size and reuse measures.	Because FAA does not have a documented institutional process for estimating size and reuse, project approaches differ in the extent to which they describe what has been included and excluded from size and reuse measures.
The measures of reuse distinguish between code that will be modified and code that will be integrated as is into the system.	Because FAA does not have a documented institutional process for estimating size and reuse, project approaches differ in how reuse measures are described.
Size estimates are checked by relating them to measured sizes of other software products or components.	Because FAA does not have a documented institutional process for estimating size and reuse, project approaches differ in how size estimates are checked.
The size estimating process is checked periodically by comparing its predictive capabilities with measured sizes of completed products.	Because FAA does not have a documented institutional process for estimating size and reuse, project approaches differ in how size estimating approaches are checked.
Because size estimating is often the weakest link in cost and schedule estimating, the organization has a continuing effort that focuses on improving its size estimating process.	FAA does not have any ongoing efforts that focus on improving its size estimating process. Project-specific efforts may exist.

Table II.3: Mechanisms for Extrapolating From Demonstrated Accomplishments on Past Projects

Evidence of maturity	FAA practices
The extrapolation process is documented.	FAA does not have a documented institutional process requiring, or describing how to go about, extrapolation from past projects. Project teams are permitted to follow whatever approach they choose for their extrapolations, if in fact they choose to extrapolate.
Cost models and other tools have been acquired or developed to assist estimators.	FAA recommends a number of cost models to assist estimators. However, it does not provide these models—estimators are allowed to pick any model they choose, if any, and are individually responsible for obtaining any needed licenses.
The cost models have been calibrated to relevant historical data.	Because FAA does not have a documented institutional process for extrapolating from past projects, project approaches differ based on if, and how, cost models are calibrated.
Cost model calibrations are up to date.	Because FAA does not have a documented institutional process for extrapolating from past projects, project approaches differ based on if, and how, cost models are calibrated.
The cost and schedule models are used to quantify demonstrated organizational performance in ways that normalize for differences among software products and projects.	Because FAA does not have a documented institutional process for extrapolating from past projects, project approaches differ in the extent to which they use cost models to quantify demonstrated organizational performance.
The consistency that estimators achieve when fitting cost models to historical data is measured and tracked.	Because FAA does not have a documented institutional process for extrapolating from past projects, project approaches differ in the extent to which they track cost model performance.
Values used for cost model parameters are validated by comparisons with past projects.	Because FAA does not have a documented institutional process for extrapolating from past projects, project approaches differ in the extent to which they validate cost model parameters.
The methods used to account for reuse recognize that reuse is not free.	Because FAA does not have a documented institutional process for extrapolating from past projects, project approaches differ in their recognition of software reuse costs.
Extrapolations from past projects incorporate measured trends in technology improvement, either within the cost models themselves or as inputs to them.	Because FAA does not have a documented institutional process for extrapolating from past projects, project teams are permitted to determine if they extrapolate from past projects, and what this extrapolation incorporates.
Estimators work jointly with project managers and experienced technical people to identify how the new work compares to work the organization or others have done before.	If used by the project team, ASD-400 or contract estimators work jointly with project managers and technical personnel to identify similarities between current and prior systems.
More than one cost model or estimating approach is used, and differences among results are analyzed and explained.	FAA policies require use of one or more approved cost estimating approaches. However, FAA does not require that estimators analyze and explain differences in estimates. Project teams are permitted to determine if and how extensively they assess any differences among estimates.
Trends in the organization's process and performance parameters are tracked to identify their effects on cost model calibrations.	Because FAA does not have a documented institutional process for extrapolating from past project, project teams are permitted to determine if and how they will track and identify the effects of trends in organizational parameters on cost model calibrations.

Table II.4: An Audit Trail

Evidence of maturity	FAA practices
The organization's process documentation identifies who is responsible for preparing the audit trail for software estimates.	FAA does not have an institutional process identifying who is responsible for preparing an audit trail for software estimates. Project teams are permitted to determine who documents the audit trail and the extent of this documentation.
A list of parameter values and their rationales accompanies each estimate.	FAA does not have an institutional process requiring estimators to list all parameter values and their rationales. Project teams are permitted to determine the extent to which estimators document parameter values and their rationales.
A template or format is used to record the values of cost model parameters and their rationales.	FAA does not have an institutional process for recording cost model parameters and their rationales. Project teams are permitted to determine how they will record the values of cost model parameters and their rationales.
Uncertainties in parameter values are identified and quantified.	FAA does not have an institutional process for dealing with uncertainties in parameter values. Project teams are permitted to determine the extent to which they identify and quantify uncertainties in parameter values.
The lists of parameter values and their rationales are retained in the organization's historical database.	Because FAA does not have an institutional historical database, this type of information is not retained therein. None of the individual databases provide this level of detail.

Table II.5: Integrity in Dealing With Dictated Costs and Schedules

Evidence of maturity	FAA practices
Management reviews and agrees to parameter values and rationales before costs are estimated.	FAA does not have an institutional policy requiring managers to review and agree to parameter values and rationales before costs are estimated. Project teams are permitted to determine if and when management approval is needed in developing cost estimates. FAA's Office of Aviation Policy and Plans (APO) is responsible for reviewing the methodological soundness of cost estimates. However, APO does not evaluate parameter values and their rationales.
Reasons for changing parameter values from those identified in the calibration set are documented.	FAA does not have an institutional process on changing parameter values. Project teams are permitted to determine which parameter values they will use.
Adjustments to cost model parameters to meet desired costs or schedules are accompanied by management actions that make the parameter values realistic.	FAA does not have an institutional process on dealing with imposed costs and schedules. Project teams are permitted to determine how they will deal with cost or schedule objectives.
The actions that the organization intends to take to make its adjusted cost model parameters valid are spelled out in the project plan.	Because FAA does not have an institutional process on dealing with imposed costs and schedules, it does not require projects to justify how to make adjusted cost model parameters valid. Project teams are permitted to determine how they will deal with cost and schedule objectives.

Table II.6: Data Collection and Feedback Processes That Foster Capturing and Correctly Interpreting Data From Work Performed

Evidence of maturity	FAA practices
There is a defined process for gathering information on completed projects and entering it into the historical database.	Because FAA does not have an institutional historical database, it does not have a process for gathering information on completed projects and entering it into the historical database. Of the individual databases, only the financial databases have information on completed projects, and this information is strictly budgetary. Individual project teams may have this information in their project files.
Postmortems are held at the completion of each project to ensure that (1) recorded data are valid and (2) events that affected cost or schedule get recorded and described while they are still fresh in people's minds.	FAA does not have an institutional process for holding postmortem assessments at the completion of each project. FAA performs project postmortem reviews on an ad hoc basis.
Estimates used for original project planning are saved and entered into the historical database.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. Estimates for original project planning are retained by ASD-400, and filed in the CBAS system.
Re-estimates and estimates for changes to the product or process are recorded and saved in the historical database.	Because FAA does not have an institutional historical database, this type of information is not recorded therein. Project teams are required to file updated cost estimates with ASD-400, for input into the CBAS database.
Pilots and prototypes of new software processes are measured and tracked to capture information that can guide estimates for full-scale processes.	FAA does not have an institutional process for incorporating full-scale software process improvements into its estimating approaches.
Organizations that acquire software receive and save copies of the developer's postmortem reports.	FAA does not have an institutional process for receiving and saving copies of the developer's postmortem reports. Project teams are permitted to determine the extent of the documentation they require from contractors and retain it.
There is a structured process for capturing data on effort and cost from ongoing and completed projects.	FAA policies require monitoring actual program cost, schedule,and technical achievement. Additionally, all major project teams require contractors to submit contract performance reports detailing progress against cost, schedule, and technical goals. This information is reported at formal acquisition review meetings and retained by the project office.
The capturing of data for cost estimating and planning is integrated with the measurement processes used for project tracking and oversight and process improvement.	FAA does not have an institutional process for integrating its estimating/planning functions with its measurement processes used for tracking, oversight, and process improvement on individual projects. Individual project teams may incorporate project tracking information in their re-estimates.
Estimates-to-complete are updated and reviewed at regularly scheduled intervals (e.g., monthly).	FAA requires that estimates-to-complete be updated at major acquisition reviews.
Estimates-to-complete are updated and reviewed whenever there is a major change to requirements, resources, priorities, commitments, assumptions, or understanding of the project.	FAA requires project managers to monitor project performance against the cost, schedule, and technical boundaries in the acquisition program baseline and to promptly report any anticipated breaches to the acquisition executive.
The processes for capturing, collecting, and disseminating measurement results and descriptive data are supported by automation, so that opportunities for misinformation, sloppiness, and indifference are minimized.	FAA does not have institutional processes for the automated capture, collection, and dissemination of measurement results and descriptive data.

SEI Checklist for Validating the Reliability of a Project's Cost Estimate

Table III.1 provides a summary of the checklist items supporting each SEI question.

Table III.1: SEI Checklist for Validating the Reliability of a Project's Cost Estimate

SEI questions	Checklist items
Are the objectives of the estimate clear and correct?	The objectives of the estimate are stated in writing. The life cycle to which the estimate applies is clearly defined. The tasks and activities included in (and excluded from) the estimate are clearly identified. The tasks and activities included in the estimate are consistent with the objectives of the estimate.
Has the task been appropriately sized?	A structured process has been used to estimate and describe the size of the software product. A structured process has been used to estimate and describe the extent of reuse. The processes for estimating size and reuse are documented. The descriptions of size and reuse identify what is included in (and excluded from) the size and reuse measures used. The measures of reuse distinguish between code that will be modified and code that will be integrated as is into the system. The definitions, measures, and rules used to describe size and reuse are consistent with the requirements (and calibrations) of the models used to estimate cost and schedule. The size estimate was checked by relating it to measured sizes of other software products or components. The size estimating process was checked by testing its predictive capabilities against measured sizes of completed products.

(continued)

SEI questions	Checklist items
Are the estimated cost and schedule consistent with demonstrated accomplishments on other projects?	The organization has a structured process for relating estimates to actual costs and schedules of completed work. —The process is documented. —The process was followed. The cost and schedule models that were used have been calibrated to relevant historical data. (Models of some sort are needed to provide consistent rules for extrapolating from previous experience.) The cost and schedule models quantify demonstrated organizational performance in ways that normalize for differences among software products and projects. (So that a simple, unnormalized, lines-of-code per staff-month extrapolation is NOT the basis for the estimate.) The consistency achieved when fitting the cost and schedule models to historical data has been measured and reported. The values used for cost and schedule model parameters appear valid when compared to values that fit the models well to past projects. The calibration of cost and schedule models was done with the same versions of the models that were used to prepare the estimate. The methods used to account for reuse recognize that reuse is not free. (The estimate accounts for activities such as interface design, modification, integration, testing, and documentation that are associated with effective reuse.) Extrapolations from past projects account for differences in application technology. (For example, data from projects that implemented traditional mainframe applications require adjustments if used as a basis for estimating client-server implementation. Some cost models provide capabilities for this, others do not.) Extrapolations from past projects account for observed, long-term trends in software technology improvement. (Although some cost models attempt this internally, the best methods are usually based on extrapolating measured trends in calibrated organizational performance.) Extrapolations from past projects account for the effects of introducing new software technology or processes. (Introducing a new technology or process can initially reduce an organizations's productivity.) Work-flow schematics have been used to evaluate how this project is similar to (and how it differs from) projects used to characterize the organization's past performance.
Have the factors that affect the estimate been identified and explained?	A written summary of parameter values and their rationales accompanies the estimate. Assumptions have been identified and explained. A structured process such as a template or format has been used to ensure that key factors have not been overlooked. Uncertainties in parameter values have been identified and quantified. A risk analysis has been performed, and risks that affect cost or schedule have been identified and documented. (Elements addressed include issues such as probability of occurrence, effects on parameter values, cost impacts, schedule impacts, and interactions with other organizations.)

(continued)

SEI questions	Checklist items
Have steps been taken to ensure the integrity of the estimating process?	Management reviewed and agreed to the values for all descriptive parameters before costs were estimated. Adjustments to parameter values to meet a desired cost or schedule have been documented. If a dictated schedule has been imposed, the estimate is accompanied by an estimate of (1) the normal schedule and (2) the additional expenditures required to meet the dictated schedule. Adjustments to parameter values to meet a desired cost or schedule are accompanied by management action that makes the values realistic. More than one cost model or estimating approach has been used, and the differences in results have been analyzed and explained. People from related but different projects or disciplines were involved in preparing the estimate. At least one member of the estimating team is an experienced estimator, trained in the cost models that were used. Estimators independent of the performing organization concur with the reasonableness of the parameter values and estimating methodology. The groups that will be doing the work accept the estimate as an achievable target. Memorandums of agreement have been completed and signed with the other organizations whose contributions affect cost or schedule.

(continued)

SEI questions	Checklist items
Is the estimate based on reliable evidence of the organization's past performance?	The estimating organization has a method for organizing and retaining information on completed projects (a historical database). The database contains a useful set of completed projects. Elements included in (and excluded from) the effort, cost, schedule, size, and reuse measures in the database are clearly identified. (See, for example, the SEI checklist for defining effort, schedule, and size measures.) Schedule milestones (start and finish dates) are described in terms of criteria for initiation or completion, so that work accomplished between milestones is clearly bounded. Records for completed projects indicate whether unpaid overtime was used. Unpaid overtime, if used, has been quantified so that recorded data provide a valid basis for estimating future effort. Cost models that were used for estimating also have been used to provide consistent frameworks for recording historical data. (This helps ensure that comparable terms and parameters are used across all projects, and that recorded data are suitable for use in the estimating models.) The data in the historical database have been examined to identify inconsistencies, and anomalies have been corrected or explained. (This is best done with the same cost models used for estimating.) The organization has a structured process for capturing effort and cost data from ongoing projects. The producing organization holds postmortems at the completion of its projects to (1) ensure that recorded data are valid and (2) ensure that events that affected costs or schedules get recorded and described while they are still fresh in people's minds. Information on completed projects includes —the life-cycle model used, together with the portion covered by the recorded cost and schedule; —actual (measured) size, cost and schedule; —the actual staffing profile; —an estimate at completion, together with the values for cost model parameters that map the estimate to the actual cost and schedule; —a work breakdown structure or alternative description of the tasks included in the recorded cost; —a work-flow schematic that illustrates the software process used; —nonlabor costs; —management costs; —a summary or list of significant deliverables (software and documentation) produced by the project; and —a summary of any unusual issues that affected cost or schedule. Evolution in the organization's work-flow schematics shows steady improvement in the understanding and measurement of its software processes.
Has the situation remained unchanged since the estimate was prepared?	The estimate has not been invalidated by recent events, changing requirements, or management action (or inaction). The estimate is being used as the basis for assigning resources, deploying schedules, and making commitments. The estimate is the current baseline for project tracking and oversight.

Six ATC Projects' Cost Estimates' Satisfaction of SEI's Checklist

Table IV.1 provides a summary comparison of six ATC projects' estimates against SEI's questions for assessing an estimate's reliability. SEI provides detailed checklists for addressing these seven questions (see appendix III for a summary of the detailed checklists). We compared official project life cycle estimates to the detailed checklists to determine how well the projects satisfied each question. The fraction in each block shows the number of satisfactory (worth 1 point) or partially satisfactory responses (worth .5 points) to checklist items divided by the total number of items. Projects with insufficient documentation to support an assessment were given a "No Basis" rating, indicating that there was no basis for an evaluation. Because SEI checklists focus on key processes, we did not evaluate project cost estimates to determine if all applicable costs are included.

An SEI expert agreed that this method was an acceptable and conservative approach to scoring projects. However, he cautioned that a project with an extremely high score could lack the one checklist item that is critical to that specific project, thus rendering the estimate unreliable.

Table IV.1: Six ATC Projects' Cost Estimates' Satisfaction of SEI's Checklist

Projects SEI Questions	VSCS	DSR	STARS	ASR-9	WAAS	DCCR
Are the objectives of the estimate clear and correct?	4/4	4/4	3/4	No Basis[a]	4/4	No Basis
Has the task been appropriately sized?	No Basis	5.5/8	2/8	No Basis	No Basis	No Basis
Are the estimated cost and schedule consistent with demonstrated accomplishments on other projects?	No Basis	4.5/10	0.5/10	No Basis	2/10	No Basis
Have the factors that affect the estimate been identified and explained?	2/5	3.5/5	1/5	No Basis	3/5	No Basis
Have steps been taken to ensure the integrity of the estimating process?	5.5/7	5.5/7	2.5/7	No Basis	3/7	No Basis
Is the estimate based on reliable evidence of the organization's past performance?	1.5/12	2.5/12	0.5/12	No Basis	1/12	No Basis
Has the situation remained unchanged since the estimate was prepared?	1/3	3/3	0/3	No Basis	0/3	No Basis

[a]No basis for an evaluation.

Major Contributors to This Report

Accounting and Information Management Division, Washington D.C.

Linda M. Calbom, Director
Randolph C. Hite, Senior Assistant Director
John C. Fretwell, Assistant Director
Keith A. Rhodes Technical Assistant Director
Madhav S. Panwar, Senior Technical Advisor
Colleen M. Phillips, Senior Information Systems Analyst
Tomas Ramirez, Jr., Senior Business Process Analyst
Cynthia Jackson, Senior Auditor
Deborah R. Peay, Staff Auditor

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