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**February 2012**

# AIR TRAFFIC CONTROL MODERNIZATION

## Management Challenges Associated with Program Costs and Schedules Could Hinder NextGen Implementation

**G A O**Accountability \* Integrity \* Reliability

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## AIR TRAFFIC CONTROL MODERNIZATION

### Management Challenges Associated with Program Costs and Schedules Could Hinder NextGen Implementation

#### Why GAO Did This Study

The Federal Aviation Administration (FAA), partnering with other federal agencies and the aviation industry, is implementing the Next Generation Air Transportation System (NextGen), a new satellite-based air traffic management system that will replace the current radar-based system and is expected to enhance the safety and capacity of the air transport system by 2025. Concurrently, FAA continues to maintain and upgrade existing air traffic control (ATC) systems that will also be needed for NextGen. This involves acquiring and implementing new software and hardware.

GAO was asked to determine (1) how, if at all, costs and schedules of FAA ATC acquisitions programs, including those related to NextGen, have changed since they were first submitted to Congress, (2) the reasons for any such changes, and (3) the extent that selected ATC programs adhere to cost and schedule best practices. To do its work, GAO reviewed 30 programs and conducted cost and schedule analysis on four programs that had an approved baseline and were NextGen related. GAO reviewed acquisition documents and interviewed FAA officials.

#### What GAO Recommends

To better estimate the cost and completion dates for major acquisitions, FAA should, among other things, require cost and schedule risk analysis, independent cost estimates and integrated master schedules. FAA did not comment on whether or not it agreed with the recommendations.

#### What GAO Found

In a review of 30 major ATC acquisition programs, all of which will contribute to the transition to NextGen, GAO found that costs for 11 of the 30 programs have increased from their initial estimates by a total of \$4.2 billion and 15 programs experienced delays. The 11 acquisitions that experienced cost increases account for over 60 percent of FAA's total acquisition costs (\$11 billion of \$17.7 billion) for the 30 programs. The 15 acquisitions that experienced schedule delays, of which 10 also had cost increases, ranged from 2 months to more than 14 years and averaged 48 months.

Cost increases and schedule delays occurred due to several factors, many of which have been longstanding challenges for FAA. Specifically, these have involved (1) additional or unanticipated system requirements; (2) insufficient stakeholder involvement (such as controllers' input) throughout system development; (3) underestimating the complexity of software development; and (4) unanticipated events including funding shortfalls or work stoppages. These challenges, if they persist, will impede the implementation of NextGen, especially in light of the interdependencies among many acquisition programs, where cost increases or delays in one program can affect the costs and schedules of other programs.

For the four programs GAO selected to analyze in depth, FAA is not consistently following the characteristics of high-quality cost estimates and scheduling best practices that GAO previously identified. Regarding cost estimates, GAO found that although all four of the programs generally provided well documented and comprehensive estimates, which are two of the four characteristics, no program fully met the two other characteristics. Specifically, each program estimate was not credible because each lacked an independent cost estimate, which provides a check against FAA's estimate and three programs lacked risk or uncertainty analysis. The estimates also lacked accuracy because they were not updated regularly or based on comparable programs. Regarding scheduling practices, most programs did not substantially or fully meet the majority of the 9 best practices GAO previously identified including developing a fully integrated master schedule of all program activities and performing a schedule risk analysis. For example, without a schedule risk analysis, FAA is unable to predict, with any degree of confidence, if the estimated completion dates are realistic. FAA is implementing new processes and organizational changes to better manage acquisitions. However, by not consistently following the characteristics of high-quality cost estimate and scheduling best practices, FAA cannot provide reasonable assurance to Congress and other stakeholders that NextGen and other ATC programs will avoid additional cost increases or schedule delays.

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## Abbreviations

ABRR	Airborne Reroute Execution
ADS-B	Automatic Dependent Surveillance-Broadcast
AirNav	Airports and Navigations Aids database
AMS	Acquisition Management System
APB	acquisition planning baseline
APTS	Automated Procedures Tracking System
ASDP	Advanced Signal Data Processor
ASOS	Automated Surface Observing System
ASR	Airport Surveillance Radar
ASWON	Aviation Surface Weather Observation Network
ATC	air traffic control
ATCBI-6	Air Traffic Control Radar Beacon Interrogator
ATCSCC	Air Traffic Control System Command Center
ATO	Air Traffic Organization
ATOP	Advanced Technologies and Oceanic Procedures
AUM	Arrival Uncertainty Management
CACR	Collaborative Airspace Constraint Resolution
CATMT	Collaborative Air Traffic Management Technologies
CIP	Capital Investment Plan
Cost Guide	GAO Cost Estimating and Assessment Guide
DataComm	Data Communications
DOD	Department of Defense
EBUS	Enhanced Back-up Surveillance
ECG	En Route Communication Gateway
ERAM	En Route Automation Modernization
ERIDS	En Route Information Display System
FAA	Federal Aviation Administration
F&E	facilities and equipment
I2I	Idea to In-Service Management
IDA	Investment Decision Authority
IDS	Integrated Display Systems
IFIA	International Flight Inspection Aircraft
IFP	Instrument Flight Procedures
IFPA	Instrument Flight Procedure Automation

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IP&A	Investment Planning and Analysis
IPDS	Instrument Procedure Development System
IT	information technology
ITWS	Integrated Terminal Weather System
JRC	Joint Resources Council
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NEXCOM	Next Generation Air/Ground Communication System
NEXRAD	Next Generation Weather Radar
OE	Obstacle Evaluation
OMB	Office of Management and Budget
P3I	Pre-Planned Product Improvements
PAMRI	Peripheral Adapter Module Replacement Item
PS3	Power Systems Sustained Support
RCISS	Regulation and Certification Infrastructure for System Safety
RWSL	Runway Status Lights
SIP	SWIM implementation program
SLEP	Service Life Extension Program
SRA	schedule risk analysis
STARS	Standard Terminal Area Replacement System
SWIM	System Wide Information Management
TAMR	Terminal Automation Modernization and Replacement
TDWR	Terminal Doppler Weather Radar
Tech Center	FAA Technical Center
TERPS	Terminal Instrument Procedures
TFM	Traffic Flow Management
TFMS	Traffic Flow Management System
TRACON	Terminal Radar Approach Control
UHF	Ultra High Frequency
VRRP	Next Generation Voice Recorder Replacement Program
VSCS	Voice Switching and Control Switching System
WAAS	Wide Area Augmentation System
WAM	Colorado Wide Area Multilateration
WARP	Weather and Radar Processor
WCP	Weather Camera Program
WP2	Work Package 2
WP3	Work Package 3

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United States Government Accountability Office  
Washington, DC 20548

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## Congressional Committees

To accommodate anticipated increases in air passenger traffic over time,<sup>1</sup> the Federal Aviation Administration (FAA) has expanded its acquisitions program to sustain current—or legacy—air traffic control (ATC) facilities and systems while simultaneously replacing or supplementing those systems through transition to the satellite-based Next Generation Air Transportation System (NextGen). This modernization effort involves acquiring and implementing new, advanced air traffic management systems, including hardware and software, to dramatically change the way the current aviation system is operated. As the agency transitions to NextGen, which has significantly increased the number, cost, and complexity of FAA's acquisition programs, it is imperative that these programs remain on time and within budget, particularly given current budget constraints and the interdependencies of many NextGen-related ATC programs. FAA has taken several steps to improve its acquisition management—including implementing a cost estimating methodology, a cost accounting system, and a business process, and developing an enterprise architecture—which resulted in the removal of its acquisition management from the GAO High-Risk list in 2009.<sup>2</sup> However, recent cost and scheduling problems among some major acquisition programs, such as the En Route Automation Modernization (ERAM), which is integral to ATC modernization, have renewed concerns about the agency's ability to manage complex multibillion-dollar procurement programs.

In response to your request, this report (1) describes how, if at all, the planned costs and schedules of current FAA ATC acquisition programs, including those related to NextGen, have changed since they were first submitted to Congress, (2) examines the reasons for any changes in planned costs and schedules, and (3) assesses the extent to which

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<sup>1</sup>The nation's air traffic control system handles almost 30 million flights per year. FAA predicts that by 2025, the number of passengers will increase from about 700 million to about 1.1 billion per year, and the number of flights will increase from about 80,000 to more than 95,000 every 24 hours.

<sup>2</sup>GAO, *High Risk Series: An Update*, [GAO-09-271](#) (Washington, D.C.: January 2009).



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selected ATC programs adhere to best practices for determining acquisition costs and schedules.

To determine the changes, if any, in the costs and schedules of FAA's ATC programs, we gathered and analyzed agency data on the estimated costs and schedules of the 30 ATC programs<sup>3</sup> that had baselines—that is, those programs whose estimated budget and schedule had received FAA executive approval.<sup>4</sup> Eighteen of these programs are directly related to the implementation of NextGen, and all are needed to maintain and modernize the existing ATC system in order for it to operate in the NextGen environment. We also drew upon past GAO work in which we undertook detailed reviews of the status of ATC and other acquisition programs<sup>5</sup> and obtained updated documentation as necessary from FAA. We interviewed FAA officials to obtain information on their programs' past and current challenges and current status and summarized the status of all 30 ATC programs, including their original and current cost estimates and completion dates. For each program, we compared its initial estimated cost at the time of its submission to Congress for approval against its current cost estimate and compared its planned and actual schedules.

To examine the reasons contributing to any changes in cost estimates and schedules in the 30 baselined ATC programs, we interviewed FAA officials and contractors and reviewed program documentation. We analyzed information on cost increases and delays for the 30 baselined programs to determine the factors that contributed to cost and schedule changes.

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<sup>3</sup>We requested the information on the programs in August 2010.

<sup>4</sup>According to FAA, baselined programs are acquisition programs with an agreed-to description of the attributes and estimated costs at a particular point in time. The baseline is a formal, management-approved document that serves as a starting point for tracking any changes in the program as it is developed and implemented for performance accountability.

<sup>5</sup>GAO, *Department of Homeland Security: Assessments of Selected Complex Acquisitions*, [GAO-10-588SP](#), (Washington, D.C.: June 30, 2010); *Defense Acquisitions: Assessments of Selected Weapon Programs*, [GAO-10-388SP](#) (Washington, D.C.: Mar. 30, 2010); *Air Traffic Control: FAA Reports FAA Reports Progress in System Acquisitions, but Changes in Performance Measurement Could Improve Usefulness of Information*, [GAO-08-42](#) (Washington, D.C.: Dec. 18, 2007); and *National Airspace System: FAA Has Made Progress but Continues to Face Challenges in Acquiring Major Air Traffic Control Systems*, [GAO-05-331](#) (Washington, D.C.: June 10, 2005).

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To assess the extent to which FAA's cost estimating and scheduling processes aligned with best practices, we conducted an in-depth review of 4 of the 30 baselined programs: the Automatic Dependent Surveillance-Broadcast (ADS-B) system, the Collaborative Air Traffic Management Technologies (CATMT) system, the System Wide Information Management (SWIM) system, and the Wide Area Augmentation System (WAAS).<sup>6</sup> We selected these programs based on the following criteria: the program had reached sufficient maturity such that risks could be identified and the program was key to the modernization of the air traffic control system. We conducted in-depth interviews with FAA acquisition program managers for the programs selected. In addition to interviews, we obtained and analyzed the most current cost and schedule estimates for these programs. To assess the extent to which FAA's acquisition practices for these programs were consistent with best practices, we used the 2009 *GAO Cost Estimating and Assessment Guide* (Cost Guide).<sup>7</sup> In assessing each program's cost estimate, we used the Cost Guide to evaluate FAA's estimating methodologies, assumptions, and results to determine whether the cost estimate was well-documented, comprehensive, accurate, and credible. We also determined the extent to which the schedule was prepared in accordance with best practices that are fundamental to having a reliable schedule. In addition, we performed a schedule risk analysis on a WAAS schedule prepared by the contractor to determine the high-priority risks that the program may encounter that could affect the schedule and the likelihood of the program finishing on time. We selected the WAAS contractor schedule because we determined that it was the only schedule of the four programs we reviewed in detail that was sufficiently reliable for a risk analysis to be performed.

We conducted this performance audit from August 2010 to February 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and

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<sup>6</sup>The four initial cost estimates we reviewed were developed at various points in the past.

<sup>7</sup>GAO, *GAO Cost Estimating and Assessment Guide: Best Practices for Developing and Managing Capital Program Costs*, [GAO-09-3SP](#) (Washington, D.C.: March 2009).

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conclusions based on our audit objectives. Appendix I contains more detailed information on our objectives, scope, and methodology.

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## Background

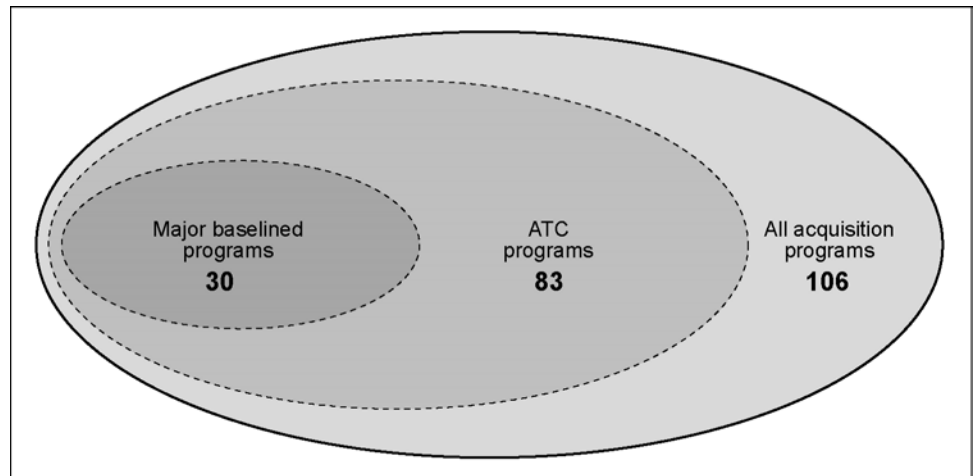
FAA catalogs its acquisition programs in its annually updated Capital Investment Plan (CIP). The CIP identifies planned capital investment in the National Airspace System (NAS) for the next 5 years consistent with the amount requested in the agency's annual budget submission. Appendix C of the CIP, which identifies the anticipated budget line items, is divided into five activities: (1) Engineering, Development, Test, and Evaluation; (2) ATC Facilities and Equipment; (3) Non-ATC Facilities and Equipment; (4) Facilities and Equipment Mission Support; and (5) Personnel Compensation, Benefits and Travel. The CIP for fiscal years 2012 through 2016 contains 106 funded acquisition programs with estimated total budgets (through 2016) of more than \$14 billion. Of these 83 acquisition programs FAA considers ATC related, 18 involve Engineering, Development, Test and Evaluation and 65 involve ATC Facilities and Equipment. The 83 programs include 30 that have had program baselines approved by FAA's Joint Resources Council (JRC),<sup>8</sup> which is responsible for approving major programs.<sup>9</sup> These 30 baselined programs include communications, navigation, and surveillance systems that are key to ATC operations. FAA considers 5 of the programs to be foundational parts of NextGen, and all are key to modernizing the existing ATC system. Figure 1 illustrates the universe of FAA acquisitions for fiscal years 2012-2016.

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<sup>8</sup>The JRC is an FAA executive body consisting of associate and assistant administrators, acquisition program executives, the Chief Financial Officer, the Chief Information Officer, and legal counsel. The JRC makes executive-level decisions, including those that determine whether a program meets a mission need and should proceed.

<sup>9</sup>As defined in Office of Management and Budget Circular A-11, Part 7, major programs are assets that require special management attention because of their importance to the agency's mission. These include high development, operating, or maintenance costs; high risk; high return; or a significant role in the administration of agency programs, finances, property, or other resources.

**Figure 1: Acquisition Programs Reported by FAA in the CIP for 2012 through 2016**



Source: GAO analysis of FAA data.

FAA has developed and uses its Acquisition Management System (AMS) to provide policies and guidance for managing ATC system programs through all phases of the programs' life cycles (see table 1). The Air Traffic Organization (ATO) within FAA is responsible for operating, maintaining, and modernizing the nation's current ATC system.<sup>10</sup>

<sup>10</sup>FAA is implementing a reorganization of ATO that may alter the current alignment of program acquisition responsibilities within ATO.

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**Table 1: FAA Acquisition Life Cycle**

Phase/activity	What occurs during this phase or activity
<b>Needs and solution identification</b>	
Mission analysis	FAA identifies a capability shortfall and determines that it needs an investment to better carry out its mission. Recently, FAA began analyzing its mission needs within the context of its overall goals for the NAS.
Investment analysis	FAA, using an investment analysis team, evaluates alternatives, selects practical and affordable solutions, and develops a baseline of cost, schedule, and performance requirements. This document is called the acquisition program baseline.
<b>Solution implementation</b>	
System integration	Both hardware and software components and subsystems are integrated into a product. Also, intra- and inter-system compatibility are tested and analyzed.
System demonstration	Tests show that the product can work as required and be manufactured within targets.
System production	All activities are carried out to produce needed quantities. Each end item is tested before it leaves the factory to verify that it conforms to specifications and is free from manufacturing defects.
In-service management	All required activities are carried out, including directly operating, providing maintenance functions (both scheduled and unscheduled), and furnishing technical and logistics requirements.
Decommission	All unneeded assets are decommissioned and removed from service at the end of their service lives.

Source: FAA.

The acquisition program baseline defines the cost, schedule and performance baselines for the investment program. The JRC which determines whether to approve a cost and schedule baseline also approves rebaselining, through which the agency documents and approves major changes to a program's previously approved budget or schedule. Rebaselining resets the estimated costs and schedule used to determine how the program will be held accountable and can occur before the program is deployed. Once a program is rebaselined, FAA reports on the performance of the program based on the revised cost and schedule. Although the rationale for rebaselining can be reasonable, as, for example, when a program's scope has been expanded, reporting a

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program's performance based on a rebaselined cost or schedule can also skew or conceal from Congress and other stakeholders the program's actual total costs or overall timeline. We previously reported<sup>11</sup> that the absence of this information on rebaselining in ATO's performance reporting could cause managers and other stakeholders, including Congress, to think that performance was better than it actually was. We recommended that FAA regularly report on the overall, long-term performance in acquiring ATC systems by providing in FAA's annual Performance and Accountability Report the original budget and schedule baselines for each rebaselined program and the reasons for the rebaselining. In response to our recommendation, FAA currently provides this information in Appendix D of its CIP, where it details baseline cost and schedule information for major acquisition programs.

NextGen involves changes to every aspect of air transportation (see fig. 2). NextGen requires the acquisition of new integrated systems (both software and hardware), flight procedures, aircraft performance capabilities, and supporting infrastructure to transform the current air transportation system into one that uses satellite-based surveillance and navigation operations instead of ground-based radar.<sup>12</sup> These changes are intended to increase the efficiency and capacity of the air transportation system while maintaining safety and accommodating anticipated future growth. The planning for NextGen began in 2003<sup>13</sup> and is now focused on implementing improvements in the midterm (by 2018) and in the far term (by 2025).<sup>14</sup>

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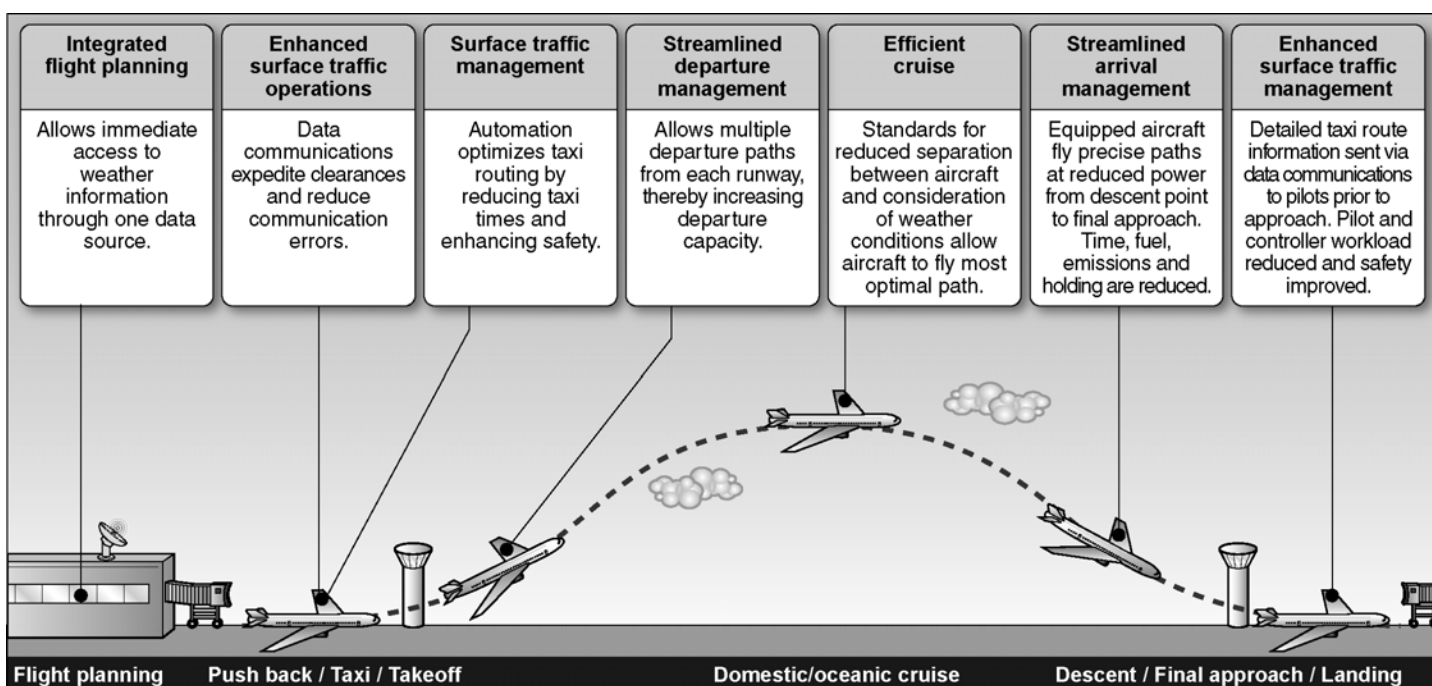
<sup>11</sup>[GAO-08-42](#).

<sup>12</sup>GAO, *Next Generation Air Transportation System: Challenges with Partner Agency and FAA Coordination Continue, and Efforts to Integrate Near, Mid-, and Long-term Activities Are Ongoing*, [GAO-10-649T](#) (Washington, D.C.: Apr. 21, 2010).

<sup>13</sup>Pub. L. No. 108-176, Vision 100—Century of Aviation Reauthorization Act Pub. L. No. 108-176, §§ 709-710, 117 Stat. 2490, 2582 (2003) authorized FAA to begin the NextGen initiative.

<sup>14</sup>Midterm includes capabilities that are planned to be implemented by 2018, such as improved aircraft operational procedures and automated data communication between aircraft and controllers. Far term refers to the complete implementation of NextGen.

**Figure 2: Improvements to Phases of Flight Expected under NextGen**



Source: GAO analysis of FAA information.

As noted previously, we selected 4 programs for in-depth review to determine the extent to which their cost estimates and schedules aligned with best practices:

- ADS-B will enable aircraft to continually broadcast flight data such as position, air speed, and altitude, among other types of information, to air traffic controllers and other aircraft. The program was baselined in 2007, and FAA is currently installing the hardware and software at approximately 800 sites across the nation. The program is scheduled to be completed in 2014.
- CATMT will provide new functionality and other enhancements to the existing Traffic Flow Management System (TFMS), such as automated reroutes and improved data exchanges between ATC facilities. CATMT was first baselined in 2008 and is scheduled to be completed in 2015.
- SWIM will provide an information technology infrastructure that will enable the multiple systems that make up the NAS to share

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information. As such, SWIM is a portfolio of capabilities that will be implemented by other systems. SWIM was first baselined in 2009 and is scheduled to be completed in 2020.

- WAAS will provide aircraft with more accurate aircraft position information to facilitate more direct flight paths and precision approaches to airports. The initial WAAS program was baselined in 1998. The third segment of the program is scheduled to be completed in 2013.

Successful acquisition program management depends, in part, upon effective cost estimation. The cost estimate is the basis for establishing a program's detailed schedule (see following discussion of schedules), as well as identifying the bounds for how much program costs can be expected to vary. We have defined cost estimates as the summation of individual cost elements, using established methods and valid data, to estimate future program costs based on what is currently known.<sup>15</sup> As such, cost estimating requires both science and judgment because answers are seldom—if ever—entirely precise. The goal is to find a reasonable estimate.<sup>16</sup> Reliable cost estimating is a critical function without which agencies are at risk of experiencing cost overruns, missed deadlines, and performance shortfalls.

Our Cost Guide identifies 12 steps consistently applied by cost-estimating organizations throughout the federal government and industry and considered best practices for developing cost estimates. For the purposes of this review, we grouped these steps into four characteristics of high-quality and reliable estimates: well-documented; comprehensive; accurate, and credible. (See table 2.)

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<sup>15</sup>GAO-09-3SP.

<sup>16</sup>GAO-09-3SP.



**Table 2: Characteristics of High-Quality Cost Estimates and Steps Related to Each Characteristic**

Characteristic	Explanation	Step identified in Cost Guide
Well-documented	The documentation should address the purpose of the estimate, the program background, a description of the system, the system's schedule, the scope of the estimate (in terms of time and what is and is not included), the ground rules and assumptions, all data sources, the estimating and rationale, the results of the risk analysis, and a conclusion about whether the cost estimate is reasonable. Therefore, a good cost estimate—while taking the form of a single number—is supported by detailed documentation that describes how it was derived and how the expected funding will be spent in order to achieve a given objective. For example, the documentation should capture in writing such things as the source data used and their significance, the calculations performed and their results, and the rationale for choosing a particular estimating method or reference. Moreover, this information should be captured in such a way that the data used to derive the estimate can be traced back to and verified against their sources, allowing for the estimate to be easily replicated and updated. Finally, the cost estimate should be reviewed and accepted by management to ensure that there is a high level of confidence in the estimating process and in the estimate itself.	Step 1: Define the estimate's purpose, scope, and schedule Step 3: Define the program characteristics Step 5: Identify ground rules and assumptions Step 6: Obtain the data Step 10: Document the estimate Step 11: Present the estimate to management for approval
Comprehensive	The cost estimates should include both government and contractor costs of the program over its full life cycle, from inception through design, development, deployment, and operation and maintenance to retirement. The estimates should also completely define the program, reflect its current schedule, and be technically reasonable. Comprehensive cost estimates should provide a level of detail appropriate to ensure that cost elements are neither omitted nor double-counted, and they should document all cost-influencing ground rules and assumptions. Establishing a product-oriented work breakdown structure is a best practice because it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component.	Step 2: Develop the estimating plan Step 4: Determine the estimating structure Step 5: Identify ground rules and assumptions
Accurate	The cost estimates should provide for results that are unbiased, and they should not be overly conservative or optimistic. Estimates are accurate when they are based on an assessment of most likely costs, adjusted properly for inflation, and contain few, if any, minor mistakes. In addition, the estimates should be updated regularly to reflect material changes in the program, such as when schedules or other assumptions change, and actual costs so that the estimate is always reflecting the program's current status. Among other things, the estimate should be grounded in documented assumptions and a historical record of cost estimating and actual experiences on other comparable programs.	Step 7: Develop the point estimate Step 12: Update the estimate to reflect actual costs and changes

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Characteristic	Explanation	Step identified in Cost Guide
Credible	The cost estimates should discuss any limitations of the analysis because of uncertainty or biases surrounding data or assumptions. Major assumptions should be varied, and other outcomes recomputed to determine how sensitive they are to changes in the assumptions. Risk and uncertainty analysis should be performed to determine the level of risk associated with the estimate. Furthermore, the estimate's results should be crosschecked, and an independent cost estimate conducted by a group outside the acquiring organization should be developed to determine whether other estimating methods produce similar results. For management to make good decisions, the program estimate must reflect the degree of uncertainty, so that a level of confidence can be given about the estimate. Having a range of costs around a point estimate is more useful to decision makers because it conveys the level of confidence in achieving the most likely cost and also informs them on cost, schedule, and technical risks.	Step 7: Compare the point estimate to an independent cost estimate Step 8: Conduct sensitivity analysis Step 9: Conduct risk and uncertainty analysis

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Source: GAO.

The success of a program also depends in part on having an integrated and reliable schedule, which defines, among other things, when work activities will occur, how long they will take, and how they are related to one another. As such, the program schedule not only provides a road map for systematic program execution, but also provides the means by which to gauge progress, identify and address potential problems, and promote accountability. Accordingly, a schedule helps ensure that all stakeholders understand both the dates for major milestones and the activities that drive the schedule. If changes occur within a program, the schedule helps decision makers analyze how those changes affect the program. We have previously identified nine best practices that help ensure a reliable program schedule (these best practices are discussed later in this report). The reliability of the schedule will determine the credibility of the program's forecasted dates, which are used for decision making. FAA is currently developing an integrated master schedule<sup>17</sup> for the NextGen initiative that will be built in part on individual program schedules. The NextGen integrated master schedule is intended to be a comprehensive framework to support planned and actual work, providing decision makers with the information needed to manage the overall effort effectively.

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<sup>17</sup>An integrated master schedule is required at the acquisition program level in order to meet our best practices, which we discuss later in this report.

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## Most Ongoing ATC Programs Remain within Budget and on Schedule, but a Few Have Significantly Exceeded Initial Estimates

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### Most Cost Estimates Remain on Target, but Cost Overruns for Three Key Programs in Total Exceeded \$4 Billion

Of the 30 baselined FAA ATC programs we reviewed, 19 have not increased in cost, but 11 have experienced cost increases ranging from \$2 million to over \$2 billion. And of the 19 programs whose costs have not increased, 7 experienced a cost decrease while the remainder have not changed significantly.<sup>18</sup> However, the 11 programs that exceeded their initial estimated costs account for over 60 percent of total program costs for the 30 baselined programs—\$11 billion of \$17.7 billion. These 11 programs are among the most complex of FAA's major acquisitions in that each involves a large amount of software engineering. (See table 3.)

The 3 programs with the largest cost increases—totaling more than \$4 billion—are key to ATC modernization. Several factors contributed to cost overruns for the Standard Terminal Automation Replacement System (STARS), WAAS, and ERAM programs and required additional congressional appropriations or reductions in program scope.

- Our previous work disclosed that the near tripling of the STARS's budget resulted from insufficient involvement of stakeholders and requirements growth.<sup>19</sup>

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<sup>18</sup>Some programs had neither cost increases nor schedule delays, including: En route Communication Gateway, Integrated Display System, Regulation and Certification Infrastructure for System Safety, Time Based Flow Manager, and Weather and Radar Program.

<sup>19</sup>[GAO-08-42](#).

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- The WAAS program began in 1998 with an initial cost estimate of \$1 billion<sup>20</sup> and a current estimate of \$3 billion. We reported previously that FAA's lack of scientific and technical expertise resulted in unplanned work and contributed to cost increases as well as delays in the deployment schedule. Additionally, FAA changed how it accounted for certain costs in the capital budget in 1999,<sup>21</sup> which further raised the cost estimate to \$3.3 billion. FAA recently revised that estimate down to the current \$3 billion during the 2009 rebaselining because, according to FAA officials, they had met certain program requirements in 2006.
  - As previously mentioned, ERAM is a key modernization system and will be the backbone of the NextGen system. FAA originally submitted to Congress an estimated cost of \$2.1 billion in 2003, and the program is now expected to cost about \$2.4 billion—an increase of about \$330 million. According to FAA, various software issues (e.g., unsuccessful transmission messages and inaccurate data pairing of aircraft and traffic display), as well as problems interfacing with other facilities and systems, have contributed to the cost increases and delays. The extent to which unanticipated requirements, unplanned work, and underestimates of the complexity of software development, among other factors, have contributed to other FAA ATC acquisition program cost overruns and scheduling delays is discussed later in this report.

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<sup>20</sup>In [GAO-05-331](#), we noted that the original estimate for WAAS was \$509 million for a terminated contract with Wilcox Electric. Subsequent estimates and baselines consider only the interim contract awarded to Hughes Aircraft in 1996.

<sup>21</sup>FAA changed how it accounted for the costs of satellite leases from the operations account to the facilities and equipment account.

**Table 3: Eleven ATC Programs That Have Experienced Cost Increases as of August 2011**

Dollars in millions

Program	Original start date	Initial estimate	Current estimate	Cost increase	Percentage increases
Wide Area Augmentation System <sup>a</sup>	1998	\$1,001	\$3,008	\$2,007	199%
Standard Terminal Automation Replacement System	1996	\$940	\$2,719	\$1,779	189%
En route Automation Modernization	2003	\$2,154	\$2,484	\$330	15%
Automated Dependant Surveillance—Broadcast <sup>c</sup>	2007	\$1,682	\$1,726	\$44	3%
Aviation Surface Observation Weather Network <sup>d</sup>	2001	\$351	\$384	\$33	10%
Runway Status Lights	2010	\$327	\$352	\$25	8%
UHF Replacement	2002	\$85	\$93	\$8	9%
International Flight Inspection Aircraft <sup>b</sup>	2003	\$27	\$34	\$6	23%
Integrated Terminal Weather System <sup>b</sup>	1997	\$276	\$282	\$6	2%
Terminal Doppler Weather Radar	2003	\$75	\$77	\$2	3%
Tower Training Simulators	2007	\$34	\$36	\$2	7%
<b>Total</b>		<b>\$6,952</b>	<b>\$11,195</b>	<b>\$4,243</b>	

Source: GAO analysis of FAA data.

<sup>a</sup>According to FAA, the WAAS program is currently divided into three phases—two have been completed and the third is projected to be completed by 2013. However, in the CIP for fiscal years 2012 through 2016, the WAAS program is listed as a single program costing \$3 billion.

<sup>b</sup>Program completed during GAO review.

<sup>c</sup>According to the FAA, the ADS-B current revised budget includes congressional directed spending of \$9.4 million in fiscal year 2008 and \$6.8 million in fiscal year 2009.

<sup>d</sup>This program includes the ongoing pre planned product improvement segment.

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## Schedules for Roughly Half of ATC Programs Are on Track, but Half of ATC Programs Are Delayed

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### Half of ATC Programs Are on or Ahead of Schedule and Half Are Delayed

We found that 15 of the 30 baselined programs either have experienced no change in schedule or were completed early or on time; however, the other 15 programs are projected to be completed later than originally estimated. These delayed programs range from the Integrated Display System, which will consolidate information from several weather subsystems into a single display, which FAA expects to be completed 2 months after its initial estimated completion date, to WAAS, which FAA estimates will be completed in 2013—more than 14 years after its initial estimated completion date (see table 4). Ten of the 15 programs with schedule delays also experienced cost increases. However, even if a schedule delay does not result in a direct cost increase to that program, the delay can lead to increased costs for FAA because FAA staff must continue to manage the acquisition over the longer term as it is being implemented, as well as maintain any legacy system that the program is replacing. Because of program interdependencies, a schedule delay can also affect how and when other programs will be implemented.

**Table 4: Fifteen ATC Programs That Have Experienced Delays Based on Original Scheduled Completion Date**

<b>Program</b>	<b>Original start date</b>	<b>Original planned completion date</b>	<b>Projected completion date</b>	<b>Delay or projected delay (in months)</b>
Wide Area Augmentation System <sup>a</sup>	January 1998	August 1999	September 2013	169
Air Traffic Control Beacon Interrogator-6	August 1997	September 2004	January 2012	88
Integrated Terminal Weather System <sup>b</sup>	June 1997	July 2003	Aug 2010	85
Next Generation Air/Ground Communication System Segment 1	September 1998	September 2008	September 2013	60
Airport Surveillance Radar- 11 <sup>d</sup>	November 1997	September 2005	June 2010	57
Terminal Doppler Weather Radar	February 2003	December 2013	September 2017	4
En route Automation Modernization	June 2003	December 2010	August 2014	44
Aviation Surface Weather Observation Network <sup>c</sup>	August 2001	September 2009	September 2012	36
UHF Replacement	November 2002	September 2010	September 2013	36
International Flight Inspection Aircraft	December 2003	August 2009	May 2012	33
Voice Switching and Control System (Tech Refresh) Phase 2	August 2006	June 2012	December 2014	30
Standard Terminal Automation Replacement System	February 1996	October 2005	June 2007	20
Tower Training Simulator <sup>b</sup>	December 2007	September 2009	August 2010	11
Runway Status Lights	January 2010	October 2015	June 2016	8
Integrated Display System Replacement	September 2008	October 2015	December 2015	2

Source: GAO analysis of FAA data.

<sup>a</sup>According to FAA, the WAAS program is divided into three phases—two have been completed and the third is projected to be completed by 2013. However, in the CIP for fiscal years 2012 through 2016, the WAAS program is listed as a single program costing \$3 billion.

<sup>b</sup>Program completed during GAO review.

<sup>c</sup>Program includes the ongoing pre planned product improvement segment.

<sup>d</sup>The ASR-11 Program was re-baselined in September 2005 with a planned completion of September 2009.

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## Several Factors Contributed to Cost Increases and Schedule Delays, and Some Could Hamper NextGen Implementation

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### A Number of Factors Have Contributed to Cost Increases and Delays

Cost increases and schedule delays occurred because of several factors, all of which have been long-standing challenges for FAA and some of which continue to affect programs despite FAA efforts to mitigate the factors. Specifically, these factors include (1) additional, unanticipated system requirements work; (2) insufficient stakeholder involvement throughout system development; (3) underestimates of the complexity of software development; and (4) unanticipated events, including funding decreases or work stoppages (see table 5). Of the 30 programs we reviewed, 15 experienced cost increases, schedule delays, or both,<sup>22</sup> and we were able to determine that cost increases or schedule delays for 11 were attributable to one or more of these factors.<sup>23</sup>

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<sup>22</sup>Ten programs experienced cost delays and schedule delays, and five programs only experienced schedule delays.

<sup>23</sup>We did not categorize, or have available information for, the remaining four programs.



**Table 5: Key Factors Contributing to Cost Growth, Schedule Delays, or Both for ATC Systems**

Name of ATC system	Unanticipated requirements or unplanned work	Insufficient stakeholder involvement	Underestimating the complexity of software development	Unanticipated events
Airport Surveillance Radar-11	✓			✓
EnRoute Automation Modernization	✓	✓	✓	
Next Generation Air-Ground Communications	✓			✓
Runway Status Lights				✓
Voice Switching and Control System- Tech Refresh Phase 2	✓			✓
Air Traffic Control Beacon Interrogator-6	✓			✓
Integrated Weather System	✓		✓	✓
International Flight Inspection Aircraft	✓			
Wide Area Augmentation System	✓	✓	✓	
Standard Terminal Automation Replacement System	✓	✓		
UHF Radio Replacement				✓

Source: GAO analysis of FAA data.

Following are some examples of how these contributing factors led to cost increases or schedule delays in some of FAA's ATC baselined programs:

- Unanticipated requirements or work:* For nine of the programs in table 5, FAA has had to undertake substantially more development work than planned because FAA program officials originally misjudged the extent to which commercial off-the-shelf nondevelopmental solutions, such as those procured by another agency, would meet FAA's needs. For example, although WAAS was being developed by an integrated product team that included representatives from several FAA offices, the team did not effectively resolve problems in meeting a required performance capability—that pilots be warned in a timely manner when a system may be providing them with potentially misleading and possibly hazardous information. These actions resulted in unanticipated work and contributed to the rise in WAAS's cost from the original estimate of \$509 million in 1994 to about \$2 billion in 2005.

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- *Insufficient stakeholder involvement:* As we previously reported,<sup>24</sup> ERAM was designed at a time when air traffic controllers did not participate in efforts to design and test new systems. Because active users of the system from different locations could not provide insight early on, issues that could have been addressed early in the design phase were not addressed. In response, FAA has taken steps to improve the testing of new systems in order to reduce the likelihood of larger-than-anticipated software issues arising during system implementation. For example, FAA and the controllers' union recently entered into a memorandum of understanding to bring controllers into the testing and evaluation phase of ERAM.<sup>25</sup> Under this agreement, the controllers' union will have ERAM technical, evaluation, and training representatives, as well as a team of 16 controllers (including 12 from en route facilities and 4 from terminal facilities), who will be detailed to test and validate software fixes with contractor engineers at the FAA Technical Center (Tech Center). In addition, our previous work disclosed that the near tripling of the Standard Terminal Automation Replacement System's budget resulted from insufficient involvement of stakeholders and requirements growth—two systemic factors that we found led to acquisitions missing their budget and schedule targets. This, in turn, contributed to cost growth, schedule delays, and eventually a reduction in the number of systems to be deployed.<sup>26</sup>
  - *Underestimates of the complexity of software development:* This factor contributed to cost increases and schedule delays for ERAM, as well as issues with costs, scheduling, or both for two other programs. In 2010, FAA tested ERAM at two key sites (the Seattle and Salt Lake en route centers) on live air traffic, usually late at night when air traffic volume was low. During this testing, FAA encountered both anticipated and unanticipated software issues, which prompted the test sites, at times, to revert to using FAA's legacy en route computer system. Specifically, software instructions to a controller in one sector to hand off control of an aircraft to a controller in an

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<sup>24</sup>GAO, *Next Generation Air Transportation System: FAA's Metrics Can Be Used to Report on Status of Individual Programs, but Not of Overall NextGen Implementation or Outcomes*, [GAO-10-629](#) (Washington, D.C.: July 27, 2010).

<sup>25</sup>Under the new contract between FAA and the controllers union, the union is to have full participation in the development and implementation of air traffic modernization systems.

<sup>26</sup>[GAO-08-42](#).

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adjacent sector failed, and flight data were lost or reassigned to another flight. While some testing at FAA's Tech Center preceded testing at the two key sites, the Tech Center could only test limited scenarios, and none of the scenario testing identified this software error. In addition, as discussed earlier, ERAM was designed during a time when air traffic controllers did not participate in efforts to design and initially test new systems. FAA anticipated the potential for software issues at the outset of the program and initially scheduled approximately 6 to 9 months of contingency time between the time it achieved initial operating capability<sup>27</sup> and operational readiness demonstrations at these sites, leaving little buffer for any potential delays. FAA worked with its contractor to correct a number of software issues, but further testing on live air traffic at the two test sites continued to produce critical safety errors. As a result, in March 2010, FAA decided, with the support of the air traffic controllers' union, to halt all ERAM testing on live traffic and to revise the deployment schedule. The program was rebaselined in June 2011, and the program's completion date was extended from December 2010 to August 2014. As a result of the schedule delays, the rebaselined cost estimate increased from \$ 2.1 billion to \$2.4 billion.<sup>28</sup>

- *Unanticipated events:* Unanticipated events at implementation sites and unanticipated funding issues have delayed several programs' schedules and increased costs. For example, Airport Surveillance Radar-11 was originally scheduled to be completed in June 2009 but was delayed to June 2010. FAA reports indicated that the delay was due to an unusually protracted real estate acquisition at one site and issues involving validating performance during seasonal radar operations from other another site. Similarly, FAA's Runway Status Lights program—which involves installing airport lighting equipment that visually signals to pilots when it is unsafe to enter, cross, or begin takeoff on a runway—has experienced schedule delays because of construction issues at five sites (Charlotte, North Carolina; Fort Lauderdale, Florida; Las Vegas; Minneapolis; and Washington-Dulles). FAA officials attributed some of these delays to the furlough

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<sup>27</sup>Initial operating capability is the declaration by site personnel that the system is ready for conditional operational use in the NAS.

<sup>28</sup>Recent reports from the Department of Transportation Inspector General and MITRE (a not-for profit organization chartered to work in the public interest) indicate that these cost and schedule estimates may be underestimated.

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of some FAA employees in July 2011 and a freeze on contractor funding during the furlough, which resulted in work stoppage orders for several projects—including Runway Status Lights. FAA program managers will need to assess the impact of the furlough on other programs that had experienced work stoppage orders, including ADS-B, the Standard Terminal Automation Replacement System, SWIM, WAAS, and various weather programs.<sup>29</sup>

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### Interdependencies among NextGen ATC Programs Could Slow NextGen Implementation

The interdependencies of ATC acquisition programs have become more prominent as the NextGen program shifts from planning to implementation, so that cost increases and schedule delays in one program could have a cascading effect on other programs. As discussed earlier, due to the integrated nature of NextGen, the development and delivery of many of its component programs are mutually dependent on the development and delivery of one or more other programs. For example, ERAM, FAA's new en route computer system, is critical to the delivery of ADS-B capabilities such as broadcasting flight information. ERAM is also pivotal to the on-time implementation of two other key NextGen programs—Data Communications (DataComm),<sup>30</sup> which is estimated to cost about \$3 billion, and the NextGen information technology architecture, SWIM, which is estimated to cost over \$550 million. Due in part to ERAM's delay, FAA was forced to delay the Data Communications baseline date by approximately 6 months, rebaseline SWIM segment 1, and delay the SWIM segment 2 baseline date to 2012. The longer-term effects of these delays are unclear, but certain SWIM capabilities could be delayed for several years, and the progress of other programs that are dependent on SWIM's system integration could be hindered, as well. Thus, looking more broadly, the implementation of NextGen—both midterm (now through 2018) and far-term (2019-2025) schedules—will be affected by how well FAA manages program interdependencies.

As we reported in 2010,<sup>31</sup> individual FAA program offices understand their programs' dependence on ERAM's implementation, but FAA has not

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<sup>29</sup><http://www.faa.gov/news/media/workstop/>.

<sup>30</sup>DataComm is planned provide capabilities for pilots and controllers to transmit digital messages and will eventually replace the analog voice communication system currently in use.

<sup>31</sup>GAO-10-629.

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developed a full listing of how ERAM schedule slippages, or slippages in other programs that are critical to NextGen, could either affect other programs' implementation schedules or delay the implementation of capabilities and improvements.<sup>32</sup> In 2008, we recommended that FAA improve the usefulness of ATO's acquisition performance reporting by including information in the agency's Performance and Accountability report or elsewhere on the potential effect of any budget or schedule slippages on the overall transition to NextGen.<sup>33</sup> This recommendation remains open, as FAA has not definitively indicated how it will track slippages that will affect other dependent NextGen programs. FAA's acquisition management system was not designed for managing NextGen programs in an integrated way. To assist in managing NextGen portfolios, FAA is starting to monitor all the activities of a particular operational improvement to ensure integration is on track. As we noted in the 2010 report, as this approach is more fully implemented, it will likely clarify the impact of slippages in one program's schedule on the implementation status of other NextGen programs and operational capabilities. In addition, as we will discuss in the next section, FAA is developing an Integrated Master Schedule for the entire NextGen initiative that is, in part, intended to show how changes in program schedules affect other programs and the timelines for the NextGen initiative as a whole. However, as we discuss later, the schedules for the four programs we reviewed in detail are not reliable. Reliable schedules at the program level will be needed to develop a reliable Integrated Master Schedule for NextGen.

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## Program Management Changes Are Aimed at Addressing Past Challenges

According to FAA, it is taking actions to address the factors that have contributed to cost increases and schedule delays. In 2011, FAA assessed the NextGen effort as part of its Foundation for Success initiative<sup>34</sup> and has implemented the "Idea to In-Service Management" (I2I) process, which it believes will result in improvements in the way the

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<sup>32</sup>FAA's Enterprise Architecture for the national airspace system shows the interdependencies and capabilities that may be affected by various programs, but this document cannot indicate specific milestones that could be affected.

<sup>33</sup>[GAO-08-42](#).

<sup>34</sup>The Foundation for Success initiative is aimed at improving certain governance, shared services, human capital, and NextGen management structures to better manage FAA functions.

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FAA develops, acquires, and implements new NextGen capabilities from conception through implementation. The I2I concept is intended to improve collaboration early in the acquisition process, resulting in better defined capabilities and an early indication of cost and benefits. These enhancements are intended to resolve many of the challenges associated with overall program management and enable FAA to focus on program management best practices. FAA believes that I2I will also result in improvements in specific areas that have presented challenges in the past, such as cost estimating, anticipating requirements and work, stakeholder collaboration, software development, and systems integration.

Also in 2011, FAA implemented a reorganization of the NextGen Operations and Planning Office and ATO which FAA believes will support the I2I process and improve acquisitions of NextGen programs. Specifically, FAA created a NAS Lifecycle Planning Division within the NextGen Operations and Planning Office to focus the integration of NextGen programs from a cost, schedule, and systems capability perspective. Within ATO, FAA established a new Program Management Office, which puts the responsibility for the program management of all NextGen and other major ATC acquisitions within a single organization. By combining program managers into one organization, FAA hopes to create a stronger acquisition program and improve the consistency and implementation of best practices. According to FAA, these organizational changes allow responsibilities for acquisitions to be better defined to more efficiently set strategic direction, define operational requirements, ensure system integration, oversee implementation processes, and ensure accountability throughout the acquisition life cycle.

To improve the acquisitions management process, FAA has also divided large acquisition programs into segments. A segmented or phased approach is being taken with programs like SWIM and CATMT. This approach breaks a larger program into smaller and more manageable pieces to lower the risk. In the past, we noted that this approach can improve management by providing for midcourse corrections and, thus, help FAA avoid costly late-stage changes. However, this approach can also increase the duration and possibly the cost of the program.<sup>35</sup>

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<sup>35</sup>GAO, Air Traffic Control: *FAA's Modernization Efforts Past, Present, and Future*, [GAO-04-227T](#) (Washington, D.C.: Oct. 30, 2003).

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According to FAA officials, a segmented approach allows the agency to more effectively manage acquisitions at both the program and enterprise architecture level. An enterprise architecture approach provides the structure to relate organizational mission, vision, and goals to business processes and the technical or information technology infrastructure required to execute them. FAA officials stated that many of the factors we identified that contributed to cost increases and schedule delays highlight the need for an enterprise-level perspective throughout the acquisition process. The I2I process is intended to provide an enterprise-level focus and improve collaboration across related programs.

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## For Programs We Reviewed, FAA Did Not Consistently Meet All Characteristics of Quality Cost Estimates or Schedule Best Practices

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### Selected Cost Estimates Were Generally Comprehensive and Well-Documented, but Accuracy and Credibility Need to Be Improved

Our review of the ADS-B, CATMT, SWIM, and WAAS cost estimates showed that while each program followed at least some of the four characteristics of high-quality and reliable cost estimates—well-documented, comprehensive, accurate, and credible—none of the programs adhered closely enough to those characteristics to create a reliable cost estimate. As previously noted, these characteristics incorporate the 12 steps consistently applied by cost-estimating organizations throughout the federal government and industry and considered best practices for developing cost estimates. The results of our review of the ADS-B, CATMT, SWIM, and WAAS cost estimates, which are summarized in table 6, show that they were most aligned with the characteristic of comprehensive cost estimates but need improvement in the other three areas, particularly with the characteristics of accurate and credible estimates. Imprecise estimates can result in Congress unnecessarily authorizing and appropriating millions of dollars for programs. As noted, in some cases, FAA, in order to stay within the original cost estimate, modified a program's requirements and Congress






had to appropriate more funds or reduce the scope to allow FAA to finish the program.

FAA could better ensure that the cost estimates for these four programs, as well as its other major acquisition programs, are reliable. Our work shows that an assessment of these cost estimates for these programs, as well as FAA's other major acquisition programs, would allow FAA to better understand if its cost estimation guidelines and our characteristics of high-quality cost estimates are in fact being followed (See table 6).

**Table 6: GAO Analysis of the Extent FAA Acquisition Cost Estimates Met the Characteristics of High-Quality and Reliable Cost Estimates**

Characteristic	Characteristic description	ADS-B	CATMT	SWIM	WAAS
Well-documented	The cost estimate should be supported by detailed documentation that describes the purpose of the estimate, the program background and system description, the scope of the estimate, the ground rules and assumptions, all data sources, estimating methodology and rationale, and the results of the risk analysis. Moreover, this information should be captured in such a way that the data used to derive the estimate can be traced back to, and verified against, the sources.				
Comprehensive	The cost estimates should include costs of the program over its full life cycle, provide a level of detail appropriate to ensure that cost elements are neither omitted nor double counted, and document all cost-influencing ground rules and assumptions.				
Accurate	The cost estimate should be based on an assessment of most likely costs (adjusted for inflation), documented assumptions, historical cost estimates, and actual experiences on other comparable programs. Estimates should be cross-checked against an independent cost estimate for accuracy, double counting, and omissions. In addition, the estimate should be updated to reflect any changes.				
Credible	The cost estimates should discuss any limitations of the analysis because of uncertainty, or biases surrounding data or assumptions. Risk and uncertainty analysis should be performed to determine the level of risk associated with the estimate. Further, the estimate's results should be cross-checked against an independent estimate.				

Source: GAO analysis of FAA documents.

-  Met
-  Substantially met
-  Partially met
-  Minimally met
-  Not met

Note: "Not met" means the program provided no evidence that satisfies any of the best practice criteria. "Minimally met" means the program provided evidence that satisfies a small portion of the criteria. "Partially met" means the program provided evidence that satisfies about half of the criteria. "Substantially met" means the program provided evidence that satisfies a large portion of the criteria. "Met" means the program provided evidence that completely satisfies the criteria.



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Because the four programs were generally similar in the extent to which they met each of the four characteristics, the following discussion summarizes the strengths and weaknesses we found for each characteristic across the four programs. A more detailed discussion of our findings is contained in appendix IV.

- *Well-documented.* Two of the four cost estimates we analyzed substantially met the characteristic of being well-documented; the other two partially met this characteristic. A well-documented cost estimate is thoroughly documented, including identifying specific source data and their significance, detailing calculations and results, and explaining why particular cost estimating methods were chosen. In other words, sufficient documentation exists such that an unfamiliar analyst could recreate the cost estimate and arrive at the same results. For example, the SWIM estimate provided detailed documentation describing the program, in addition to the methodology, calculations, and quantities used to develop the estimate. However, none of the four estimates sufficiently captured the entire source data used, addressed its reliability, or described how various forms of data from disparate sources were normalized (i.e., the data were described in like terms). For example, the WAAS estimate was based, in part, on actual labor costs from a previous contract, but the program office provided no evidence that these data were evaluated for reliability or accuracy. Similarly, the CATMT estimate routinely relied on subject matter expertise as a source for assumptions, such as the cost of labor, but the estimate did not document the experts' qualifications, background, underlying assumptions, or data sources. Moreover, we noted that three of the four estimates often substantially relied on expert opinion rather than on data. While expert opinion can be useful in the absence of data, it is subjective and generally should be used sparingly for cost estimates. Since data are the foundation of every cost estimate, data quality affects the overall quality of the estimate. In addition, because data are gathered from a variety of sources and take many different forms, normalization helps to improve consistency with other cost information and enable valid comparisons and projections.
- *Comprehensive.* All four cost estimates we analyzed substantially met the characteristic of being comprehensive. For an estimate to be comprehensive, it should include full life-cycle costs, completely define the program with sufficient detail, include cost elements that are traceable to the statement of work or objective to ensure they are neither omitted nor double counted, and document all cost-influencing ground rules and assumptions. We found that the ADS-B, CATMT,

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and SWIM cost estimates included all life-cycle costs, regardless of program phase or funding source, and the ADS-B and SWIM cost estimates completely defined the program with an appropriate level of detail. In particular, the ADS-B cost estimate included cost estimates for both government and contractor costs, and the WAAS cost estimate thoroughly defined the program and reflected the current schedule. The four estimates did not fully meet the comprehensive characteristic because they lacked evidence that all cost influencing ground rules and assumptions were considered.

- *Accurate.* None of the four cost estimates met or substantially met the characteristic of being accurate. The estimates generally adjusted costs for inflation and contained few computation or mathematical mistakes, but they were not regularly updated to reflect schedule and requirement changes, did not provide evidence of documenting or reviewing differences between planned and actual costs, and were not based on historical cost data from comparable programs. For example, the ADS-B, CATMT, and SWIM cost estimates provided no evidence that they were updated to reflect program changes, such as schedule slippages or varying assumptions, and did not include the current actual costs of the program. Although the WAAS estimate included evidence that it was updated to reflect major changes in technical and program requirements, such as the four rebaselining the program has undergone since its 1998 inception, it did not include evidence that estimated costs were replaced with actual costs as the program advanced. Cost estimates that are not regularly updated with current information cannot provide decision makers with accurate information that is necessary, for example, when new system requirements are called for under tight budget conditions. In addition, comparing planned and actual costs enables cost estimators to measure the accuracy of their estimates and refine their processes. In addition, none of the four programs more than minimally used historical data to develop their cost estimates. Had historical data been used, the estimators would have had additional insight into actual costs on programs that used similar technologies, which could be used, for example, to challenge overly optimistic assumptions and bring more realism to the cost estimate.
- *Credible.* None of the four cost estimates met or substantially met the characteristic of being credible, which includes obtaining an independent cost estimate from a group outside the acquiring organization, and cross-checking the major cost elements in that estimate against cost drivers identified through sensitivity and risk analyses. The ADS-B, CATMT, SWIM, and WAAS estimates lacked

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credibility largely because FAA did not obtain an independent cost estimate for any of the programs. In addition the CATMT, SWIM, and WAAS estimates provided little evidence that it conducted sensitivity or risk analyses. Instead, each program received independent cost reviews as part of the investment decision process—even though such reviews are not required by FAA policy. FAA stated that the Investment, Planning and Analysis (IP&A) Office in the FAA Finance Organization does not prepare independent estimates, but it is organizationally independent of the acquisition programs and conducts independent reviews of all cost estimates. However, an independent cost review is less rigorous than an independent cost estimate. According to our cost guide, an independent cost estimate is often more accurate because the estimating team is further removed from the program office and less prone to accept overly optimistic assumptions or be burdened by organizational bias.<sup>36</sup> Other federal agencies, including the Department of Defense, require independent cost estimates. Had an independent cost estimate been completed, the estimating team and program team could have identified the major differences between their estimates, reconciled those differences where possible, and provided a synopsis of the two estimates and their differences to acquisition program management. In addition, without sensitivity and risk analyses, cost estimators cannot measure the effects of varying assumptions, and managers cannot determine, for example, the rational level of contingency reserves necessary to cover increased costs that may result from uncertainties such as unexpected design complexity, changes in requirements, or budget shortfalls—all of which FAA ATC programs, and in particular NextGen programs, have experienced in recent years. We found evidence that some level of risk analysis was conducted for ADS-B, CATMT, and SWIM, although the analysis was not sufficiently robust. For example, key cost drivers were not identified, and additional context about how the estimate could be affected by software design and development issues was not included.

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<sup>36</sup>An independent cost estimate can be done by an independent cost estimating office within an organization or by an outside contractor.

Selected Schedules Did Not Substantially Meet Most Best Practices and Are, Therefore, Unreliable






We determined that the schedules for the four programs we reviewed are unreliable because none met or substantially met all nine of the best practices for developing a reliable schedule. (see table 7). For example, none of the schedules fully met best practices for capturing all activities in an integrated master schedule, identifying critical paths and reasonable float for all activities, or assigning resources to those activities. Moreover, none of the schedules had documentation that provided more than minimal evidence that they conducted a schedule risk analysis. As was the case with our review of cost estimates for the four programs, our work regarding the schedules for these programs shows that an assessment of the schedules, as well as schedules for FAA's other major acquisition programs, would allow FAA to understand if the nine best practices for reliable schedules are being followed.

Table 7: Extent Program Schedules Met Best Practices

Best practice	Description	ADS-B (FAA prepared)	CATMT (contractor prepared)	SWIM (FAA prepared)	WAAS (FAA prepared)	WAAS (contractor prepared)
1. Capturing all activities	A schedule should reflect all activities defined in the program’s work breakdown structure and include all activities to be performed by the government and contractor.					
2. Sequencing all activities	The schedule should be planned so that all activities are logically sequenced in the order they are to be carried out.					
3. Assigning resources to all activities	The schedule should realistically reflect the resources (i.e., labor material and overhead) needed to do the work, whether all required resources will be available when needed, and whether any funding or time constraints exist.					
4. Establishing the duration of all activities	The schedule should reflect how long each activity will take to execute.					
5. Integrating schedule activities horizontally and vertically	The schedule should be horizontally and vertically integrated—that is, it should link already sequenced activities with outcomes while also delineating the relation of supporting tasks and subtasks to upper-level milestones. Such mapping among levels enables different groups to work to the same master schedule.					

6. Establishing the critical path	The schedule should identify the critical path, or those activities that, if delayed, will negatively impact the overall project completion date. The critical path enables analysis of the effect delays may have on the overall schedule.					
7. Identifying reasonable float	The schedule should identify float—the amount of time an activity can slip in the schedule before it affects other activities—so that flexibility in the schedule can be determined. As a general rule, activities along the critical path typically have the least amount of float.					
8. Conducting a schedule risk analysis	The schedule should include a schedule risk analysis that uses statistical techniques to predict the probability of meeting a completion date. A schedule risk analysis can help management identify and understand the most important risks and focus on mitigating them.					
9. Updating the schedule using logic and durations to determine dates	The schedule should use realistic durations for activities and be monitored to determine when forecasted completion dates differ from the planned dates. This analysis can be used to assess whether schedule variances will affect future work.					

Source: GAO analysis of FAA documents.

-  Met
-  Substantially met
-  Partially met
-  Minimally met
-  Not met

Note: “Not met” means the program provided no evidence that satisfies any of the best practice criteria. “Minimally met” means the program provided evidence that satisfies a small portion of the criteria. “Partially met” means the program provided evidence that satisfies about half of the criteria. “Substantially met” means the program provided evidence that satisfies a large portion of the criteria. “Met” means the program provided evidence that completely satisfies the criteria.

Because the scheduling best practices are interrelated in such a way that deficiencies in one best practice will cause deficiencies in the others, a schedule must meet or substantially meet all nine practices to be reliable. For example, preparing a schedule that is program-wide—including an integrated breakdown of the work to be performed by both the government and its contractors over the expected life of the program—is

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a best practice. If the schedule does not capture all activities, then there will be uncertainty about whether activities are sequenced correctly or if the schedule properly reflects the resources needed to accomplish the work, which is also a best practice. Logic and durations (that is, the time it takes to complete a specific activity) should be used and maintained to ensure realistic start and completion dates and to reflect the true status of the project—a necessary condition for conducting follow-on schedule risk analyses. Moreover, if activities are not properly sequenced with logical links, it will not be certain if the critical path—which represents the chain of dependent activities with the longest total duration—is valid. Collectively, the weaknesses in not fully meeting or substantially meeting all nine key practices increases the risk of schedule slippages and cost overruns since a well-defined schedule helps to identify the amount of human capital and fiscal resources that are needed to execute the program. Therefore, by not having reliable schedules, FAA cannot conduct meaningful oversight of an acquisition program's progress or determine whether the program is achieving the desired results.

The following discussion summarizes the extent to which the schedules for the four programs we examined met best practices. More detailed information for each program regarding scheduling best practices is presented in appendix V.

## ADS-B

We reviewed the schedule prepared by FAA and found it did not fully meet any of GAO's nine scheduling best practices, resulting in an unreliable schedule. Evidence provided in the ADS-B schedule indicates that it substantially met three of the nine best practices and partially, minimally, or did not meet the other six. For example, although the ADS-B schedule provided evidence of periodic updating, it did not capture all of the effort currently called for in the approved baseline for the entire ADS-B program and, therefore, was not a fully integrated schedule. Without fully integrating government activities with contractor activities, and thereby capturing all key activities, the schedule will not reliably estimate the program's completion. In addition, the ADS-B schedule we reviewed did not identify critical paths or include a schedule risk analysis, which uses statistical techniques to predict a level of confidence in meeting a program's completion date; did not logically sequence all activities and establish their durations; and had excessive float<sup>37</sup> on a majority of

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<sup>37</sup>The amount of time by which a predecessor activity can slip before the delay affects successor activities.

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current and planned activities. According to program officials, a number of the issues our analysis identified were, in part, the result of the schedule's limited time frame, which covered only a defined transitional period (October 2010 through April 2011) during which responsibility for about a third of the effort passed from the FAA to its prime contractor. Officials also stated that although their schedule contains critical activities, it has not had a traditional critical path since its contractor began managing the deployment of deliverables. The FAA uses contract options to order the scope, sequence, and requirements for key milestones. Within those options, the contractor has the authority to implement the sequence of more discrete activities in the order they deem most appropriate. FAA program officials plan to rectify this problem, noting that with negotiations now completed, they will in the near future identify a critical path to span all program milestones.

## CATMT

Because the CATMT program did not prepare an FAA schedule and instead relied on its contractor schedule, we reviewed the contractor schedule, which we found to be unreliable. Our analysis found that the contractor's CATMT schedule substantially or fully met four of the nine best practices: capturing all activities, assigning resources, establishing the durations, and updating the schedule. For example, the CATMT contractor schedule pertains to the current phase of the program that is being implemented in software releases, or phases. However, there was no overarching FAA government owned schedule that accounts for all software releases for the entire program and would thus delineate the relation of current software release tasks to the upper-level milestones for the overall CATMT program. The CATMT schedule included detailed resource information, and the program office provided evidence that resources are tracked in detailed labor-hour spreadsheets. We also found that 90 percent of the activities were of short duration and that the program office regularly reviews the schedule, which is in line with best practices. On the other hand, five of the nine best practices were either partially, minimally, or not met. Specifically, the CATMT schedule lacked evidence indicating that it established a critical path, accurately identified float between activities, integrated the schedule vertically and horizontally, sequenced all activities, or performed a schedule risk analysis. Regarding the critical path, our analysis determined that the CATMT schedule does not identify a critical path for the entire program.

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Instead, the program is being accomplished multiple 6-month spirals<sup>38</sup>; thus, there is only a critical path for each software release, not for the program as a whole.<sup>39</sup> Without a valid program-wide critical path FAA management cannot determine which tasks, if they slip, will have the most detrimental effects on the project finish date. We also found that 68 percent of the remaining activities to be completed had unreasonably high float exceeding 1,000 days, meaning that those activities could slip about 5 work years<sup>40</sup> without affecting the overall project finish date, a highly unlikely scenario.<sup>41</sup> The accurate identification of critical paths and float are inextricably linked. For example, if the schedule is missing activities or they are not correctly linked, float estimates will be miscalculated, resulting in an invalid critical path. Without a schedule that can produce a true critical path, the program office will neither be positioned to provide reliable timeline estimates nor be able to identify when problems or changes may occur and determine the impact they may have on subsequent work. CATMT program officials acknowledged that the schedule did not include program-wide critical paths but noted that a critical path exist for individual segments of the program. They also noted that a schedule risk analysis was not performed because it was not a contractual deliverable.

## SWIM

Because the SWIM schedule did not fully or substantially meet any of GAO's nine scheduling best practices, we found it to be unreliable. The SWIM program differs from the others in that it is an aggregation of NextGen acquisition programs, each developing an aspect of the SWIM information sharing capability. Because SWIM program managers are reliant on schedule information from a number of other programs, SWIM schedule integration is particularly important. However, our analysis found

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<sup>38</sup>Software spiral development is an incremental approach to reduce risk, so that user needs and requirements are better defined.

<sup>39</sup>FAA officials said that because of the 6-month spiral development approach, the schedule cannot deliver a single critical path for the entire program. Instead, the critical paths are calculated and based by software releases. To calculate a critical path by each software release, the prime contractor uses an end constraint on the key deliverable milestone for each software release. For further explanation, see table 13 in appendix IV.

<sup>40</sup>A work year is approximately 200 days since every organization works to a different calendar.

<sup>41</sup>These float values are due mostly to activities being tied to the project finish milestone, which is constrained to start no earlier than July 1, 2016. For further explanation, see table 13 in appendix IV.



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that the SWIM schedule was not, by any measure, fully integrated because it provided only a synopsis of the individual system implementing program schedules and, thus, did not fully represent the work required to complete the overall SWIM program. This resulted in float calculations that were unrealistic, and the resulting critical path calculations were invalid. In addition, while the many missing activities negatively impacted the schedule logic and the accuracy of durations, it also made the accurate allocation of resources and comprehensive integration of schedule activities, both horizontally and vertically, impossible. We also noted that FAA made no effort to identify a program-wide critical path. Program officials said that because each of the system implementing program schedules has its own critical path, involve disparate capabilities, and are independent of one another their individual critical paths are not accessible through the SWIM schedule software. They therefore are not used for overall SWIM program management. We believe that the SWIM program itself should have its own critical path that includes, at a minimum, acceptance of major deliverables from the system implementing program schedules. Without a program-wide critical path, management does not have a clear picture of the underlying project tasks that must be performed to achieve the overall program target completion date. Finally, although there was no risk analysis conducted on this schedule, our analysis found that this best practice was minimally met because a risk analysis was conducted on a separate but related schedule, and the SWIM program office considered risk to some extent.

## WAAS

Like the other three programs, we found the WAAS program schedule prepared by FAA unreliable because it did not fully or substantially meet any of GAO's nine scheduling best practices; however, we also reviewed the contractor's schedule for the same segment and found it fully or substantially met six best practices.<sup>42</sup> For example, FAA's WAAS program schedule did not fully sequence activities in the order in which they are to be carried out. More specifically, the WAAS program schedule showed nearly half of the remaining activities were missing sequenced logic, causing us to question the calculated dates of activities. Logic is necessary for a schedule to show program managers when activities are expected to start and finish; when logic is missing, activity dates cannot

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<sup>42</sup>We reviewed two schedules for the WAAS program: one produced by the FAA program office and the other produced by its prime contractor. We evaluated the contractor prepared schedule, which was the most current schedule available for the purposes of the schedule risk analysis, which is discussed more fully later in this report.

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adjust correctly to changes in activities. To test the ability of the schedule to dynamically update its dates due to changes, we artificially extended the duration of an activity to 1,500 days, which changed the activity's finish date. However, the duration extension had no effect on successor activities because this activity is not tied to any successor activities. Extending the duration to 1,500 days also pushed the project planned finish date from September 22, 2016, to June 29, 2017; however, because the logic links are not in place, we questioned whether the projected finish date under this scenario is reliable.

Moreover, the WAAS program schedule had too many artificial constraints that were driving the start and finish dates for more than 70 percent of the remaining activities.<sup>43</sup> Constraints are usually substitutes for logic and can mean that the schedule is not well planned or feasible. Constraints also greatly reduce the ability of the program to take advantage of possible time savings. Further, our analysis found that the schedule did not fully capture or assign resources to all government and contractor activities; it also did not accurately allocate resources or consistently establish the duration of activities. In addition, while WAAS program officials told us that the schedule was integrated vertically and horizontally, we did not find evidence of such integration. Furthermore, we found the WAAS program office's schedule did not identify a critical path for the entire program. As noted earlier, critical path and float determinations are closely related. Our analysis of the WAAS program office schedule found that more than half of the remaining activities had float of more than 1,000 working days, which we believe to be unreasonably high. Without proper determination of float, management cannot properly reallocate resources from tasks to other tasks without adversely affecting the overall completion date. Although program officials said that they maintained a risk register listing the potential risks that could impact the schedule and adjusted the schedule for these risks, we did not find evidence that the program office had conducted a risk analysis of its schedule.

While the schedule prepared by the contractor did not fully or substantially meet three of the scheduling best practices, it fully or substantially met six: capturing, sequencing, assigning resources to, and

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<sup>43</sup>A constraint predefines the start, finish, or both dates of an activity. The schedule should use logic and durations in order to reflect realistic start and completion dates for activities.

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establishing the duration of all activities; establishing the critical path; and identifying reasonable float between activities. For example, our analysis found that all activity durations are consistently estimated in days and adhere to a standard 5-day workweek that accounts for holidays, and no activities were scheduled to begin on a weekend. Officials from the contractor said duration estimates for the schedule are based on historical information from past performance, comparable releases, lessons learned, similar work, and other data requirements. In addition, our analysis traced several critical paths in the schedule. Though we found minor interruptions in the various critical paths, the schedule's logic, reasonable durations, and low total float estimates allow the calculation a valid critical path.

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### WAAS Schedule Risk Analysis Indicates Risks That Managers Could Mitigate to Avoid Delays

As noted, FAA did not perform a complete schedule risk analysis for any of the four programs we reviewed and, thus, cannot accurately estimate these programs' completion dates with confidence. A schedule risk analysis, which is one of our best practices for program scheduling, uses statistical techniques to predict a level of confidence in meeting a program's completion date. The objective of the analysis is to develop a probability distribution of possible completion dates that reflect the project and its identified risks. This analysis can help program managers both understand the most important risks to the program and focus on mitigating those risks. Other federal agencies, including the Department of Defense and the National Aeronautics and Space Administration, require schedule risk analysis for major acquisitions; the Department of Veterans Affairs, in response to a GAO recommendation,<sup>44</sup> plans to require schedule risk analysis for major construction projects.

We conducted a schedule risk analysis on the WAAS contractor prepared schedule, which we chose because it was relatively mature, it partially met or substantially met six of the nine best practices (see table 7), and it contained enough information to perform a schedule risk analysis.<sup>45</sup> We reviewed the risk register that the contractor had developed, which

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<sup>44</sup>GAO, *VA Construction: VA Is Working to Improve Initial Project Cost Estimates, but Should Analyze Cost and Schedule Risks*, [GAO-10-189](#) (Washington, D.C.: Dec. 14, 2009).

<sup>45</sup>The other three schedules did not have the required information to conduct a schedule risk analysis.

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showed four potential risks to the project. We then conducted interviews with FAA program and contractor staff and asked them to discuss other potential risks to the project, including how the risk would affect the project's timeline and the likelihood of the risk occurring. Using this information we identified an additional 16 risks for a total of 20 risks. The fact that our interviews identified a relatively large number of new risks could be an indication that the contractor did not systematically analyze the full range of risks when developing the program's risk register. We then consolidated the 20 risks into 14 broader risks and tested how each would impact the duration of specific activities in the schedule. We then ran a Monte Carlo simulation,<sup>46</sup> which consisted of the computer-generated results of 3,000 estimates of the future schedule based on the activities in the schedule, the chance that some of the activities would be affected by some risks and the predicted effect of those risks on the duration of each activity.

We then analyzed the potential impact of risks on the program schedule. Since risks can effect the schedule in various ways—for example, risks can have a large impact on the durations of activities they affect, or they can introduce critical paths that are different from the baseline critical path—we analyzed the marginal impact of each of the risks we identified to determine which would have the greatest effect on the overall schedule. We found the following three key risks to the program, only the first of which (limited WAAS program office resources) was originally identified by the contractor. The three risks are

- limited WAAS program office resources such as staffing;
- delays in software yet to be released and additional changes to software already released and in use; and
- a potentially optimistic schedule completion date.

Our schedule risk analysis showed the completion of the segment of the WAAS program covered by the schedule could slip as much as 2 months. Specifically, the analysis showed that there is less than a 5 percent probability that the program segment would be completed by September 6, 2012, the current baselined date for completion. However, it appears

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<sup>46</sup>A Monte Carlo simulation involves the use of random numbers and probability distributions to examine potential outcomes.

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that the segment will be completed close to the deadline since we found a 50 percent probability that the program segment will be completed by October 23, 2012 (about 1.5 months after the current estimated date for completion); and an 80 percent probability that the program will be completed by November 13, 2012 (about 2.25 months after the current estimated date for completion).

Although we did not conduct a schedule risk analysis for other FAA programs, the result of our analysis provides examples of the types of risks that major acquisition programs face and the impact those risks can have on meeting acquisition program milestones, especially given the interrelation and interdependencies among NextGen acquisitions discussed earlier. More information on our schedule risk analysis can be found in appendix V.

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### **Lack of Reliable Program Schedules Will Hinder Development of an Overall NextGen Integrated Master Schedule**

FAA has begun developing an integrated master schedule for the entire NextGen initiative that would, in part, capture related NextGen program schedules, governance activities, and other performance and financial data to provide real-time monitoring of the overall NextGen effort. However, the unreliability of the four program schedules for programs that are integral to the NextGen initiative puts this high-level master schedule at risk. Having a reliable integrated master schedule would enable FAA to determine how delays in one program impact other programs and the overall NextGen implementation timeline. While it is encouraging that FAA is beginning to develop an integrated NextGen master schedule, the effort could be hampered by the lack of schedule integration at the program level, as well as the failure of individual program schedules to meet best practices. For example, since FAA does not perform schedule risk analysis on individual programs, it cannot predict with certainty if any of the programs will be completed on time. Therefore, the integrated master schedule for NextGen would be built on schedules that may not reflect accurate program completion dates. Similarly, none of the four schedules we reviewed, which were for segments of the entire program, had reflected how tasks for the segment affected milestones for the entire program. Without integrated schedules at the program level, an integrated master schedule at the NextGen initiative level would be problematic.

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## FAA has Taken Steps to Improve Acquisition Program Cost Estimates and Schedules

In response to our review of the extent that the four selected acquisition programs met best practices for cost estimates and schedules, FAA provided information on steps it is taking to improve its processes for both cost estimates and schedules and noted that some of the cost estimates and schedules we reviewed were developed before the improvements were in place. FAA stated that strengthening its cost estimation process is part of the seven key acquisition processes it has developed, including program management, contractor management, requirements, risk management, measurement and analysis, verification and validation, and quality assurance. FAA stated that it has updated its *Guidelines for FAA Cost Estimating* to be consistent with the GAO Cost Guide, filling in gaps that it had identified during a comparison of its practices to those contained in the Cost Guide. As of November 2011, 11 of the 12 best practices are addressed in the guidelines. According to FAA officials, the remaining best practice—involving the creation of independent cost estimates—is unlikely to be implemented at FAA in the foreseeable future because FAA believes the resources required to create independent estimates are prohibitive in current budget environments. FAA has more than tripled the number of cost estimators in the Investment Planning and Analysis organization, many of which work with the acquisition program offices to provide guidance on preparing estimates. Additionally, as part of FAA's effort to improve acquisition certification and training, the agency is preparing to launch a cost estimating certification program. Coupled with a competency-based training program, FAA believes the certification program will enhance and improve consistency of the skills of FAA cost estimators.

In describing its efforts to improve schedules, FAA stated that it views the development and maintenance of integrated schedules as an inherent and critical part of its seven key acquisition functions. FAA noted that included in its standard process for acquisition schedules are toolkits that require programs to develop integrated program schedules that address all nine of GAO's best practices. FAA stated that the current procedures for developing best practices were not fully in place when the four programs we reviewed began the implementation phase.

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## Conclusions

FAA has made improvements in its management of air traffic control modernization acquisitions, and most of the 30 we reviewed are currently within the original cost estimate and half are on schedule. FAA is also taking steps to address past issues to ensure cost estimates and schedules are more accurate in the future, including incorporating best practices in its acquisitions guidance and policies. Nevertheless, our

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review of the FAA acquisitions found that it has yet to fully implement several GAO-identified best practices or follow others. Following best practices is particularly important for FAA, which must manage large, complex, and interdependent acquisitions associated with NextGen. Cost estimates that are imprecise can result in Congress appropriating millions of dollars for projects based on estimates that prove to be inaccurate, and program schedule delays can increase costs and affect the implementation of interdependent programs. In such cases, FAA will be forced to reduce the scope of the programs to stay within the original estimates or Congress will need to appropriate unanticipated funds to complete the programs. Delays and cost increases in individual programs could have a cascading effect on other programs and ultimately affect FAA's timelines and goals for NextGen implementation.

Our analysis of the cost estimates and schedules for the four programs we reviewed indicates that FAA needs to further develop requirements for critical cost estimation and schedule procedures. Independent cost estimates can improve the accuracy and credibility of cost estimates and better ensure that programs will be completed within budget. A schedule risk analysis can help FAA determine the likelihood that a program will be completed on time. FAA stated that it has no immediate plans to conduct independent cost estimates due to current budgetary constraints. We recognize that conducting independent cost estimates and schedule risk analysis takes both financial resources and some time and that it may be appropriate to limit one or both of these analyses to instances where a program is particularly costly, complex, or on a compressed schedule. However, conducting independent cost estimates, schedule risk analyses, and other analyses called for in our best practices can not only help minimize the risk of cost overruns and schedule delays, but also provide FAA, congressional decision makers, and other stakeholders with important information about these critical acquisitions.

It is also important that FAA develop master schedules at the individual acquisition program level. FAA's lack of a fully integrated master schedule for the programs we reviewed hampers its ability to provide accurate information on the schedule for these programs. This information will be needed as FAA simultaneously works to develop an integrated master schedule for the overall NextGen initiative. The use of an integrated master schedule can assist FAA in monitoring a program, identifying problems that could affect later stages of the program's implementation, improving the accuracy of cost estimates and schedules for individual programs, and improving the accuracy of information FAA is compiling to monitor the costs and schedules for the NextGen initiative.

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FAA has incorporated 11 of our 12 steps that are associated with the characteristics of a high-quality and reliable cost estimate into their acquisition guidelines. However, our analysis of the four major programs indicates that FAA has not adequately integrated all of the steps for these programs into its cost estimation processes, and thus the estimates are not reliable. Similarly, although FAA addresses our nine scheduling best practices in its acquisition guidelines, our analysis of the schedules for the four programs indicates that the schedules are not adequately following these best practices and are not reliable. Although the cost estimates and schedules for some of the four programs were developed prior to FAA's revision of acquisition guidelines, our work shows that FAA needs to assess its major acquisition programs to understand if its guidelines and other best practices are, in fact, being followed. Such an assessment would then allow FAA to better ensure that best practices for cost estimates and schedules are being applied.

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## Recommendations for Executive Action

To improve cost estimates and schedules for NextGen and other major air traffic control acquisition programs, GAO recommends that the Secretary of Transportation direct FAA to take the following three actions when appropriate for major acquisition programs based on a program's cost, schedule, complexity, and risk:

- Conduct independent cost estimates and schedule risk analysis for major acquisition programs.
- Require a fully integrated master schedule for each major acquisition program, including those that are components of NextGen. An integrated master schedule should horizontally and vertically link all program activities and milestones, including government and contractor schedules and program segments.
- Conduct an assessment of major acquisition programs to ensure they meet all of the established best practices for cost estimates and schedules contained in GAO guidance.

Given constrained budgets, FAA should determine which programs should be subject to these recommendations, such as those that are particularly costly, complex, or on a compressed schedule.



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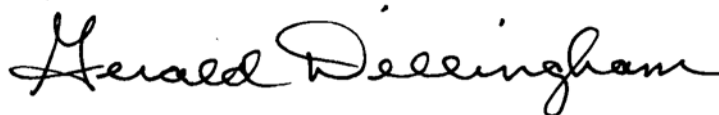
## Agency Comments

We provided a draft of this report to the Department of Transportation for review and comment. DOT and FAA responded by email and did not comment whether or not they agreed or disagreed with our recommendations. DOT provided comments on the results of our analysis of the cost estimates and schedules for the four programs we reviewed in depth. In response to our finding that the ADS-B, CATMT, SWIM, and WAAS estimates lacked credibility largely because FAA did not obtain an independent cost estimate for any of the cost estimates, and provided little evidence that they conducted sensitivity or risk analyses, FAA stated it is not convinced that an independent organization will reduce the uncertainty of cost estimates. FAA noted that it does not have an independent organization such as the Department of the Navy's Center for Cost Analysis. However, FAA stated that the Finance Organization within ATO assessed the ADS-B program office's Basis of Estimate as part of the JRC Decision and that this level of independence, combined with specific entry and exit criteria, allowed the program offices to manage these acquisitions so that costs were controlled, risks mitigated, and technical parameters achieved, while adhering to the planned milestone schedule. We agree that the Finance Organization assessment of the two cost estimates provided some degree of independence and may have improved the accuracy of the ADS-B estimates, but it is not clear that such an independent review will guarantee similar results for other programs. As we stated in the report, such an independent cost review is less rigorous than an independent cost estimate. According to our cost guide, an independent cost estimate is often more accurate because the estimating team is further removed from the program office and less prone to accept overly optimistic assumptions or be burdened by organizational bias. DOT also provided technical clarifications, which we incorporated into the report as appropriate.

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We are sending copies of this report to interested congressional committees, the Secretary of Transportation, and the Acting Administrator of FAA. In addition, the report is available at no charge on the GAO website at <http://www.gao.gov>.

If you or your staff have any questions about this report, please contact me at (202) 512-2834 or [dillinghamg@gao.gov](mailto:dillinghamg@gao.gov). Contact points for our Offices of Congressional Relations and Public Affairs may be found on the last page of this report. GAO staff who made key contributions to this report are listed in appendix V.

A handwritten signature in black ink that reads "Gerald Dillingham". The signature is written in a cursive style with a large, stylized "G" and "D".

Gerald L. Dillingham, Ph.D.  
Director, Physical Infrastructure Issues

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*List of Committees*

The Honorable Jay Rockefeller  
Chairman  
The Honorable Kay Bailey Hutchison  
Ranking Member  
Committee on Commerce, Science, and Transportation  
United States Senate

The Honorable Ralph Hall  
Chairman  
The Honorable Eddie Bernice Johnson  
Ranking Member  
Committee on Science, Space, and Technology  
House of Representatives

The Honorable Thomas Petri  
Chairman  
The Honorable Jerry Costello  
Ranking Member  
Subcommittee on Aviation  
Committee on Transportation and Infrastructure  
House of Representatives

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# Appendix I: Objectives, Scope and Methodology

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In response to a congressional request, we examined the Federal Aviation Administration's (FAA) ability to modernize, upgrade, and replace the National Airspace System's (NAS) facilities and equipment to meet projected increases in traffic volumes, enhance the system's safety, and increase the efficiency of the air traffic control (ATC) system—a principal component of the NAS. FAA's ATC acquisitions are critical to maintaining the NAS and transitioning to the Next Generation Air Transportation System (NextGen) over the next 10 years. Given that some key legacy and NextGen acquisitions have experienced schedule delays and cost overruns, which may risk the timely implementation of NextGen, we (1) determined whether the planned costs and schedules of current FAA ATC acquisition programs have changed since they were first submitted to Congress; (2) examined the reasons for any changes in planned costs and schedules; and (3) assessed the extent to which select ATC programs adhered to best practices for determining acquisition costs and schedules.

To describe any changes in costs and schedules of the current 30 FAA capital ATC acquisitions, we gathered and analyzed agency data on the estimated cost and schedules of these ATC acquisitions.<sup>1</sup> We drew upon past work in which we undertook detailed reviews of the status of ATC and other acquisition programs<sup>2</sup> and obtained updated documentation as necessary from FAA. We interviewed FAA officials to obtain information on FAA's acquisition process and summarized the status of all acquisitions, including FAA's original and current cost estimates and completion dates. For baselined acquisitions,<sup>3</sup> we compared estimated costs when they were submitted to Congress for approval against their current estimates, and we analyzed planned and actual schedules.

To determine the reasons for changes in cost estimates and schedules, we interviewed FAA officials and FAA contractors and reviewed

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<sup>1</sup>We requested the information on the programs in August 2010.

<sup>2</sup>[GAO-10-588SP](#), [GAO-10-388SP](#), [GAO-08-42](#), and [GAO-05-331](#).

<sup>3</sup>According to FAA, baselined acquisitions, as opposed to nonbaselined acquisitions, are an agreed-to description of the attributes of a product, at a point in time, that serves as a basis for defining change; an approved and released document, or a set of documents, each of a specific revision—the purpose of which is to provide a defined basis for managing change; the currently approved and released configuration documentation; or a released set of files consisting of a software version and associated configuration documentation.

acquisition documentation. We analyzed information on cost increases and delays to determine if systematic issues exist that have effects on other FAA acquisitions.

To determine the extent to which select ATC programs adhered to best practices for determining acquisition costs and schedules, we conducted an in-depth review of 4 of the 30 acquisitions programs: The Automatic Dependent Surveillance-Broadcast (ADS-B) system, the Collaborative Air Traffic Management Technologies (CATMT) system, the System Wide Information Management (SWIM) system, and the Wide Area Augmentation System (WAAS). We selected these four acquisitions based on the following criteria: (1) existence of baselining, (2) the acquisition is at a point in the acquisition process where risks can be identified, and (3) the acquisition is key to NextGen and legacy systems. In addition to interviews, we collected documentation, and we analyzed and summarized the views and information collected. We also identified best practices that FAA could adopt or strengthen to improve its acquisitions cost estimation and scheduling and ensured that acquisitions follow cost and schedule best practices outlined in our Cost Estimating and Assessment Guide.<sup>4</sup> We also performed a schedule risk analysis of the WAAS program to determine the likelihood of the project finishing on schedule.

We used our *Cost Estimating and Assessment Guide*<sup>5</sup> (Cost Guide) as a source of criteria for analyzing cost estimates. As noted earlier in our report, our Cost Guide identifies 12 steps consistently applied by cost-estimating organizations throughout the federal government and industry and considered best practices for developing cost estimates. For the purposes of this review, we grouped these steps into four characteristics of high-quality and reliable estimates—well-documented, comprehensive, accurate, and credible—which can be summarized as follows:

**Well-documented:** The documentation should address the purpose of the estimate, the project background and system description, its schedule, the scope of the estimate (in terms of time and what is and is not included), the ground rules and assumptions, all data sources, the estimating methodology and rationale, the results of the risk analysis, and

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<sup>4</sup>GAO-09-3SP.

<sup>5</sup>GAO-09-3SP.

a conclusion about whether the cost estimate is reasonable. Therefore, a good cost estimate—while taking the form of a single number—is supported by detailed documentation that describes how it was derived and how the expected funding will be spent in order to achieve a given objective. For example, the documentation should capture in writing such things as the source data used and their significance, the calculations performed and their results, and the rationale for choosing a particular estimating method or reference. Moreover, this information should be captured in such a way that the data used to derive the estimate can be traced back to and verified against their sources. Finally, the cost estimate should be reviewed and accepted by management to ensure there is a high level of confidence in the estimate and the estimating process.

**Comprehensive:** The cost estimates should include both government and contractor costs of the project over its full life cycle, from inception through design, development, deployment, operation, and maintenance to retirement of the project. The cost estimate should be structured in sufficient detail to ensure that cost elements are neither omitted nor double counted, and they should document all cost-influencing ground rules and assumptions.

**Accurate:** The cost estimates should provide for results that are unbiased, and they should not be overly conservative or optimistic. Estimates are accurate when they are based on an assessment of most likely costs, adjusted properly for inflation, and contain few, if any, minor mistakes. In addition, the estimates should be updated regularly to reflect material changes in the project, such as when schedules or other assumptions change so that the estimate is always reflecting the project's current status. Among other things, the estimate should be grounded in documented assumptions and a historical record of cost estimating and actual experiences on other comparable projects.

**Credible:** The cost estimates should discuss any limitations of the analysis because of uncertainty or biases surrounding data or assumptions. Major assumptions should be varied, and other outcomes recomputed to determine how sensitive they are to changes in the assumptions. Risk and uncertainty analysis should be performed to determine the level of risk associated with the estimate. Furthermore, the estimate's results should be cross-checked, and an independent cost estimate conducted by a group outside the acquiring organization should be developed to determine whether other estimating methods produce similar results.

After reviewing documentation submitted by FAA and information obtained during interviews, we determined the extent to which the cost estimates met the characteristics of cost-estimating best practices for the four projects we reviewed.

Our review of project schedules was based on research that identified a range of best practices associated with effective schedule estimating. In addition, we obtained the consulting services of David Hulett, Ph.D.,<sup>6</sup> to assist in our risk analysis of the WAAS project schedule.<sup>7</sup> We also conducted multiple interviews with project managers, contractors, and schedulers to determine the extent to which current project schedules met the best practices criteria. These nine practices are:

**Capturing all activities:** The schedule should reflect all activities (steps, events, outcomes, and other factors) as defined in the project's work breakdown structure, including activities to be performed by both the government and its contractors.

**Sequencing all activities:** The schedule should be planned so that it can meet project-critical dates. To meet this objective, activities need to be logically sequenced in the order that they are to be carried out. In particular, activities that must finish prior to the start of other activities (i.e., predecessor activities) and activities that cannot begin until other activities are completed (i.e., successor activities) should be identified. Identifying interdependencies among activities that collectively lead to the accomplishment of events or milestones can be used as a basis for guiding work and measuring progress.

**Assigning resources to all activities:** The schedule should realistically reflect what resources (i.e., labor, material, and overhead) are needed to do the work, whether all required resources will be available when they are needed, and whether any funding or time constraints exist.

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<sup>6</sup>Hulett & Associates, LLC Los Angeles. Dr. Hulett is the author of "Practical Schedule Risk Analysis."

<sup>7</sup>The WAAS contractor schedule was found reliable enough to conduct a schedule risk analysis. Because we found the other three schedules were unreliable, a schedule risk analysis could not be performed.

**Establishing the duration of all activities:** The schedule should reflect how long each activity will take to execute. In determining the duration of each activity, the same rationale, data, and assumptions used for cost estimating should be used for preparing the schedule. Furthermore, these durations should be as short as possible and should have specific start and end dates. Excessively long periods needed to execute an activity should prompt further decomposition of the activity so that shorter execution durations will result.

**Integrating schedule activities horizontally and vertically:** The schedule should be horizontally integrated, meaning that it should link the products and outcomes associated with already sequenced activities. These links are commonly referred to as “hand-offs” and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. The schedule should also be vertically integrated, meaning that traceability exists among varying levels of activities and supporting tasks and subtasks. Such mapping or alignment among levels can enable different groups to work to the same master schedule.

**Establishing the critical path for all activities:** With the use of scheduling software, the critical path—the longest-duration path through the sequenced list of activities—should be identified. The establishment of a project’s critical path is necessary for examining the effects of delays in any activity along this path. Potential problems that may occur on or near the critical path should also be identified and reflected in the scheduling of the time for high-risk activities (see the next activity, “Identifying float”).

**Identifying reasonable float:** The schedule should identify float—the time that a predecessor activity can slip before the delay affects successor activities—so that schedule flexibility can be determined. As a general rule, activities along the critical path typically have the least amount of float.

**Conducting a schedule risk analysis:** A schedule risk analysis uses a good critical path method schedule and data about project schedule risks, as well as Monte Carlo simulation techniques, to predict the level of confidence in meeting a project’s completion date, the amount of time contingency needed for a level of confidence, and the identification of high-priority risks. This analysis should focus not only on critical path activities but also on other schedule paths that may become critical. A schedule/cost risk assessment recognizes the interrelationship between schedule and cost and captures the risk that schedule durations and cost



estimates may vary for a variety of reasons, including limited data, optimistic estimating, technical challenges, lack of qualified personnel, and other external factors. As a result, the baseline schedule should include a buffer or a reserve of extra time. A reserve of extra time for contingencies should be calculated by performing a schedule risk analysis. As a general rule, the reserve should be held by the project manager and applied as needed to those activities that take longer than scheduled because of the identified risks. Reserves of time should not be apportioned in advance to any specific activity since the risks that will actually occur and the magnitude of their impact are not known in advance.

**Updating the schedule using logic and durations to determine the dates:** The schedule should use logic and durations in order to reflect realistic start and completion dates for project activities. The schedule should be continually monitored to determine when forecasted completion dates differ from the planned dates. This information can be used to determine whether schedule variances will affect downstream work. Maintaining the integrity of the schedule logic is not only necessary to reflect the project's true status but is also required before conducting a schedule risk analysis. The schedule should avoid logic overrides and artificial constraint dates that are chosen to create a certain result on paper. Individuals trained in critical path method scheduling should be responsible for updating the schedule.

Based on our work, we determined the extent to which estimates and schedules for the four projects we selected met each best practices criterion:

- Not Met—project officials provided no evidence that satisfies any portion of the criterion.
- Minimally Met—project officials provided evidence that satisfies a small portion of the criterion.
- Partially Met—project officials provided evidence that satisfies about half of the criterion.
- Substantially Met—project officials provided evidence that satisfies a large portion of the criterion.
- Met—project officials provided evidence that satisfies the entire criterion.

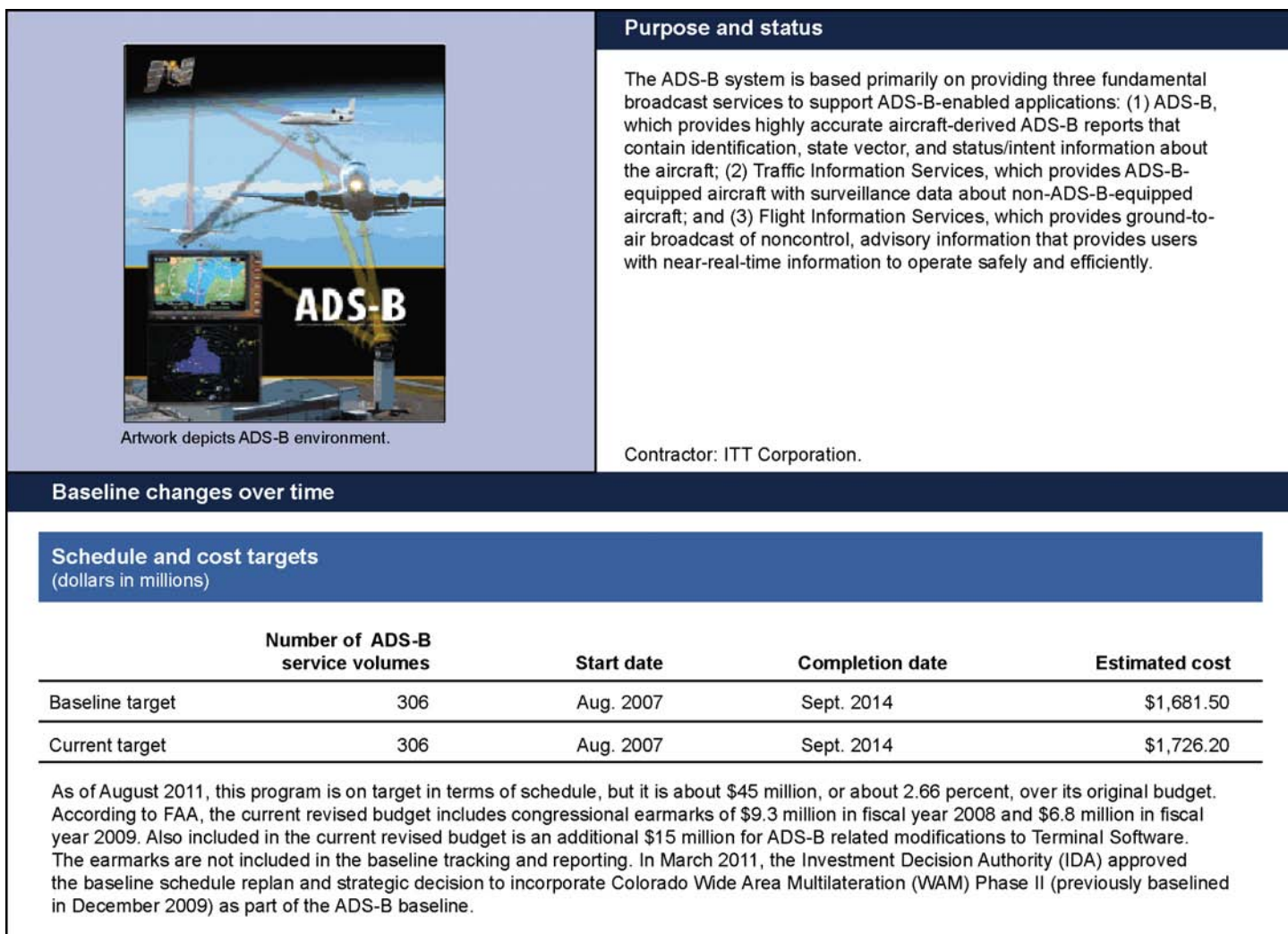
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We conducted this performance audit from August 2010 to February 2012 in accordance with generally accepted government auditing standards. Those standards require that we plan and perform the audit to obtain sufficient, appropriate evidence to provide a reasonable basis for our findings and conclusions based on our audit objectives. We believe that the evidence obtained provides a reasonable basis for our findings and conclusions based on our audit objectives.

# Appendix II: Detailed Purpose and Status for 30 Acquisitions GAO Reviewed

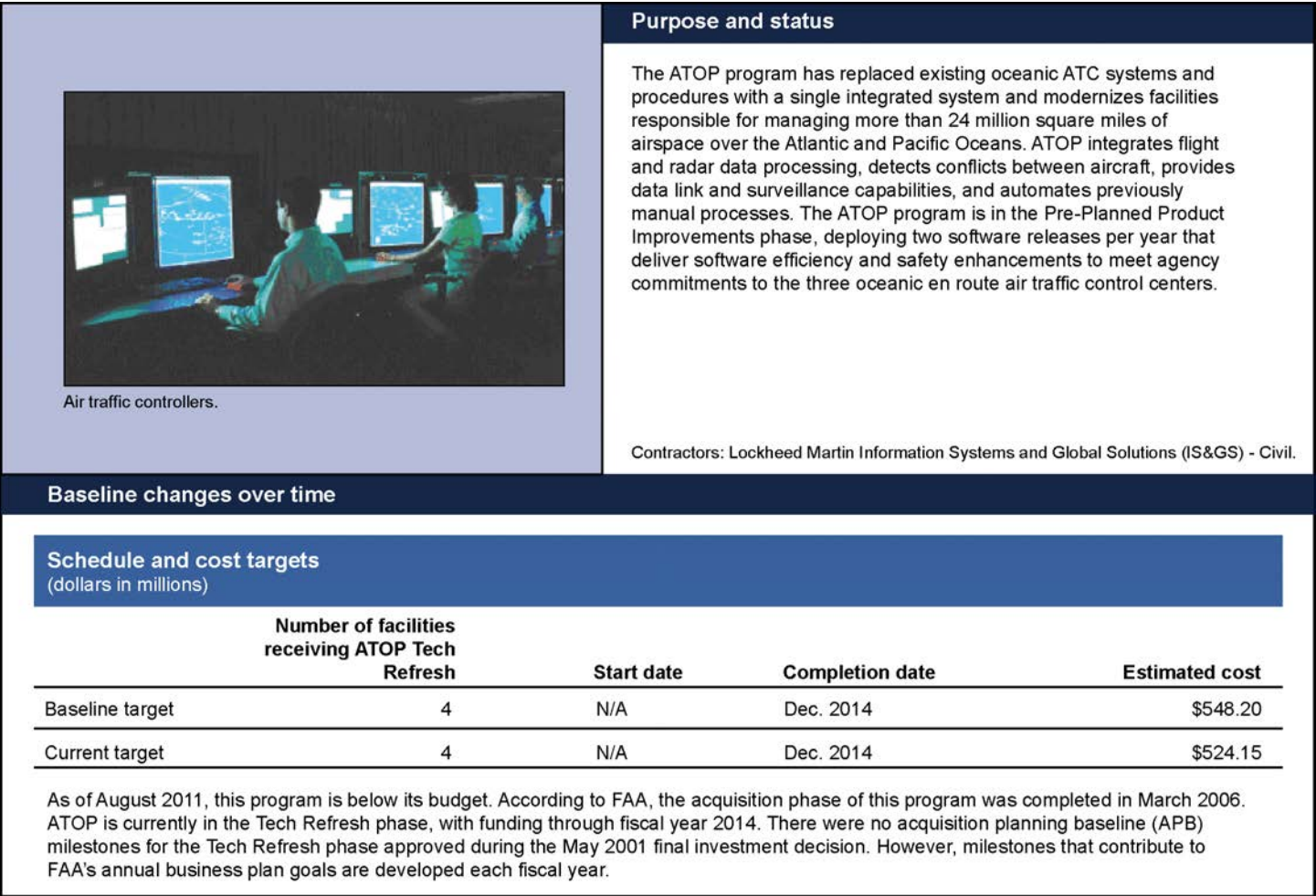
This appendix contains detailed information for 30 individual air traffic control programs. Each overview presents information and data that was provided by FAA. The overviews provide a description of the program and the cost and schedule status. The overviews are based on program office reported information as of August 2011. In most cases, we did not validate the data provided, but reviewed the data and performed various checks to determine they were reliable enough for our purposes.

**Figure 3: Automatic Dependent Surveillance-Broadcast (ADS-B)**



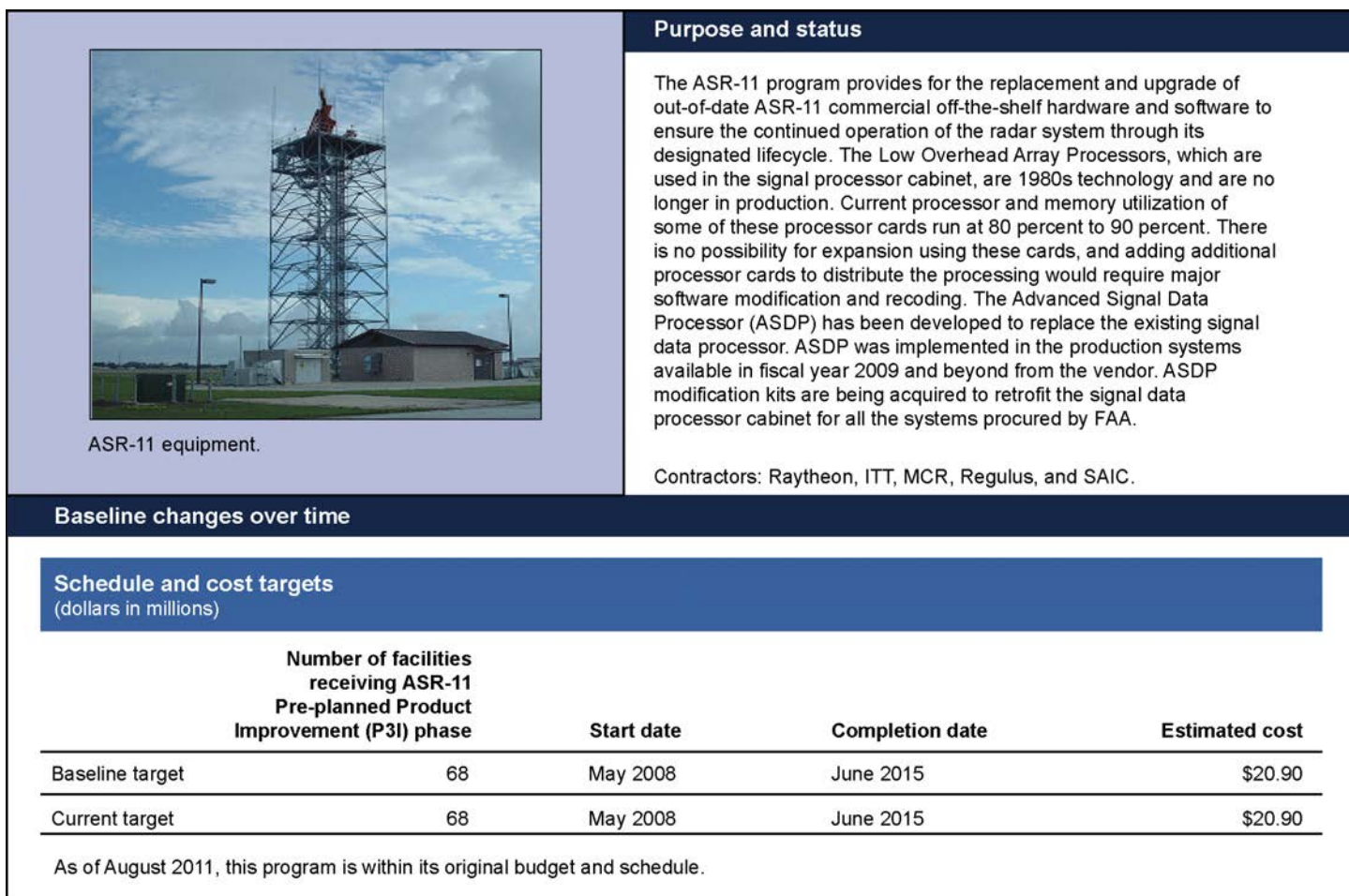
Sources: GAO (analysis); FAA (data and artwork).

Figure 4: Advanced Technologies and Oceanic Procedures (ATOP)



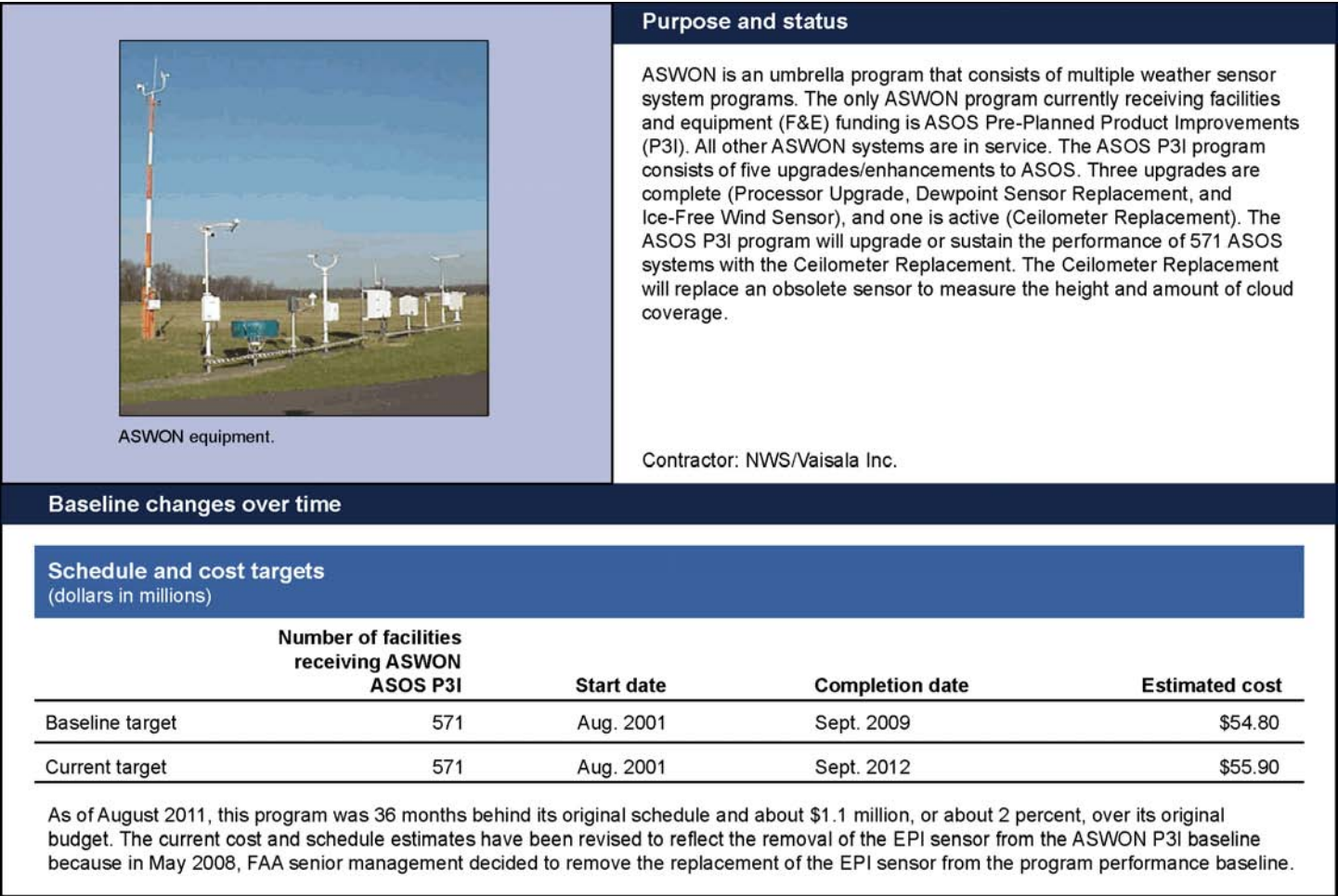
Sources: GAO (analysis); FAA (data and artwork).

Figure 5: Airport Surveillance Radar (ASR) Model 11 *Tech Refresh* Segment 1



Sources: GAO (analysis); FAA (data and artwork).

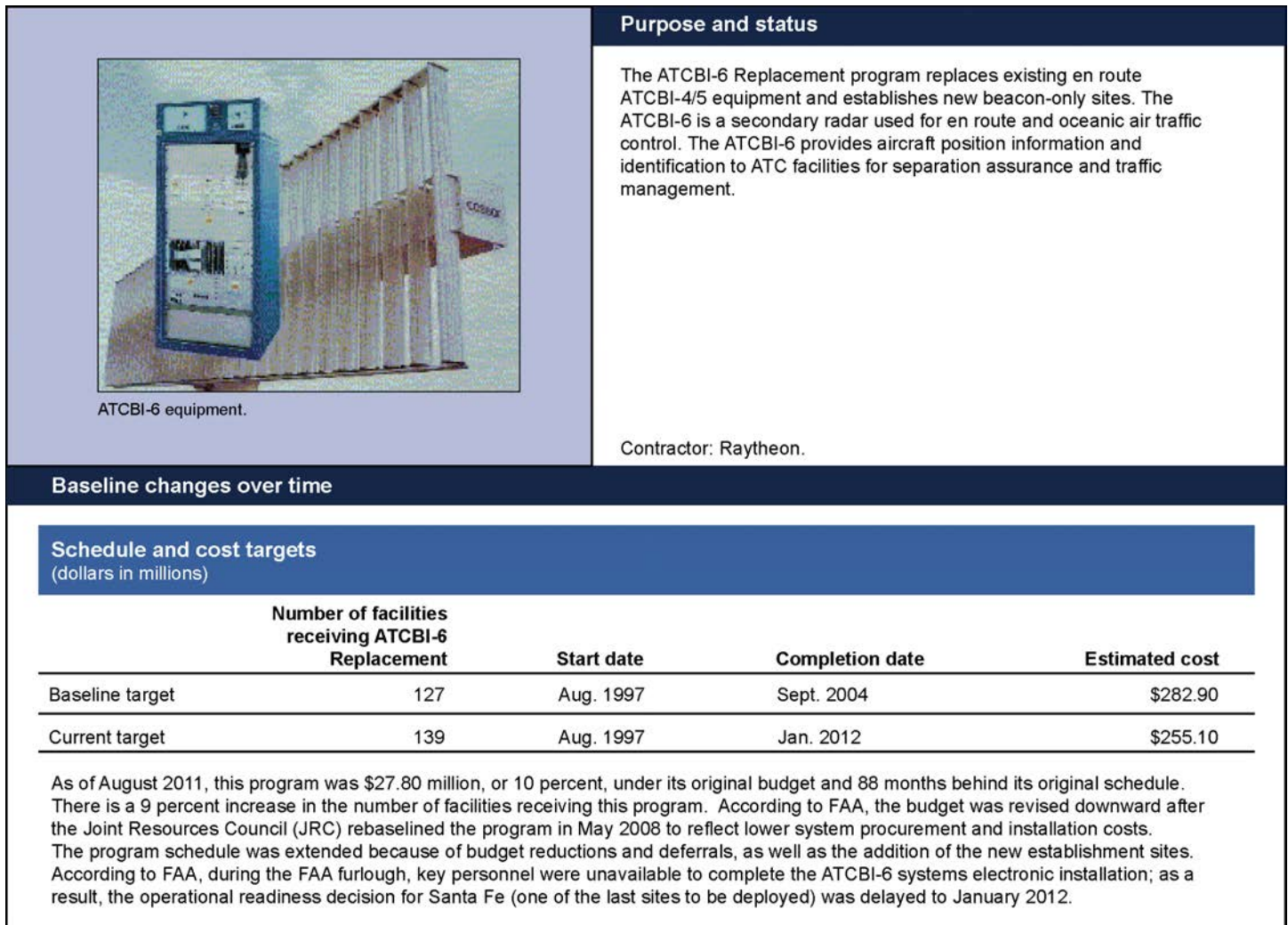
Figure 6: Aviation Surface Weather Observation Network (ASWON) and Automated Surface Observing System (ASOS) P31



Sources: GAO (analysis); FAA (data and artwork).



Figure 7: Air Traffic Control Radar Beacon Interrogator (ATCBI-6)



Sources: GAO (analysis); FAA (data and artwork).

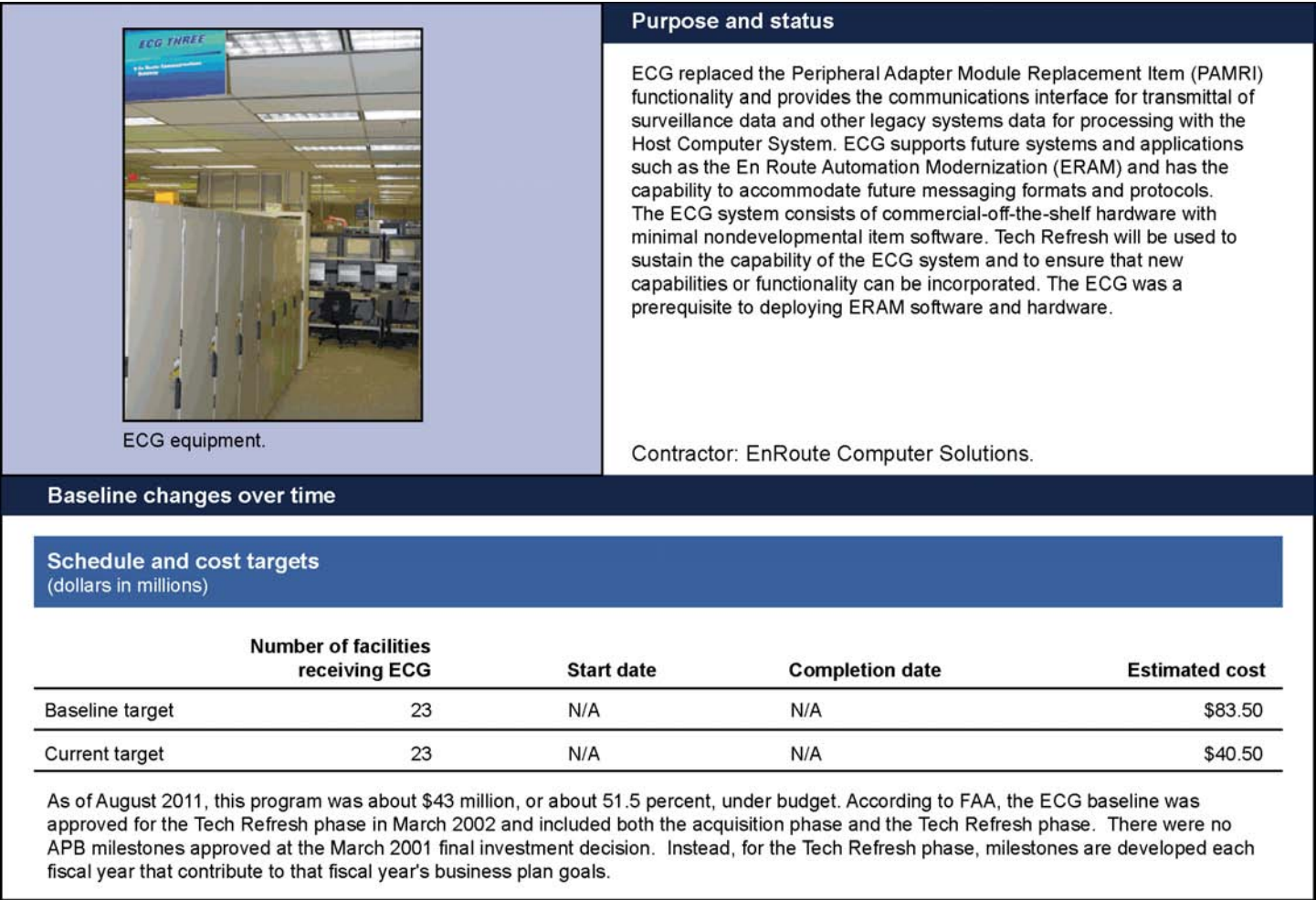
**Figure 8: Collaborative Air Traffic Management Technologies (CATMT), Work Packages 2 and 3 (WP2 and WP3)**

Purpose and status				
<p>The CATMT program implements enhancements that will improve the Traffic Flow Management (TFM) decision support tool suite. CATMT TWP2 includes Arrival Uncertainty Management (AUM), Collaborative Airspace Constraint Resolution (CACR), and Airborne Reroute Execution (ABRR). CATMT WP3 includes enhancements that continue to provide decision support capabilities that leverage the latest technology and research, and enable more efficient communication and collaboration with aircraft operators. WP3 modernizes the TFM remote sites. The Traffic Flow Management System (TFMS) is the automation backbone for the Air Traffic Control System Command Center (ATCSCC) and the nationwide Traffic Management Units that assist the ATCSCC in strategic planning and management of air traffic. CATMT WP2 development started at the beginning of fiscal year 2010 and will continue into fiscal year 2014. CATMT WP3 development began in fiscal year 2011 and will continue through fiscal year 2015.</p> <p>Contractor: Computer Science Corporation (CSC).</p>				
Baseline changes over time				
Schedule and cost targets (dollars in millions)				
	Number of facilities receiving ATCBI-6 CATMT	Start date	Completion date	Estimated cost
<b>CATMT WP2</b>				
Baseline target	81	Sept. 2008	Sept. 2014	\$109.50
Current target	81	Sept. 2008	Sept. 2014	\$109.50
<b>CATMT WP3</b>				
Baseline target	81	Jan. 2010	Dec. 2015	\$53.01
Current target	81	Jan. 2010	Dec. 2015	\$53.01
As of August 2011, this program was within its original schedule, but about \$600,000, or about 1 percent, over its original budget.				

Sources: GAO (analysis); FAA (data).

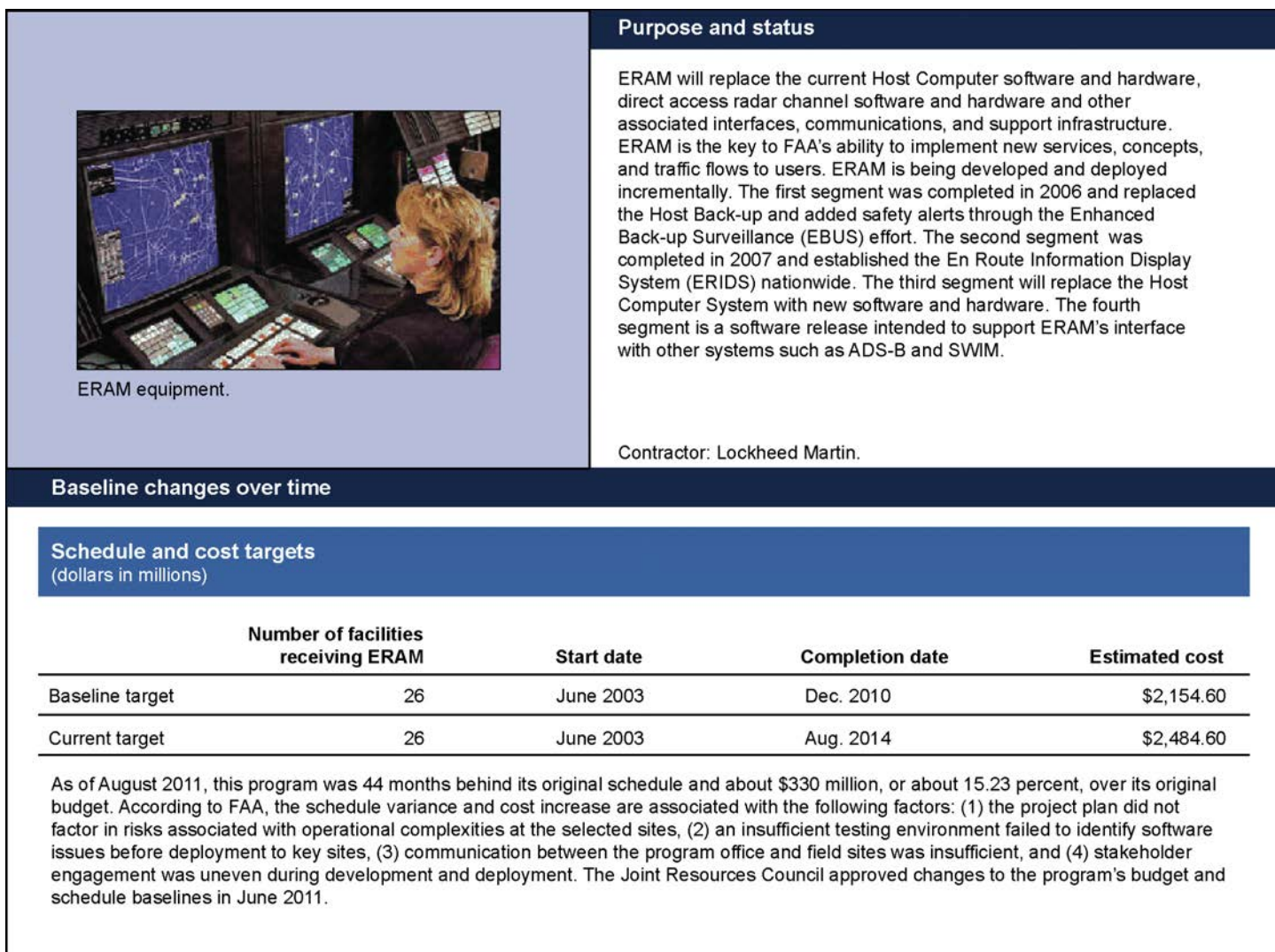


Figure 9: En Route Communication Gateway (ECG) Tech Refresh



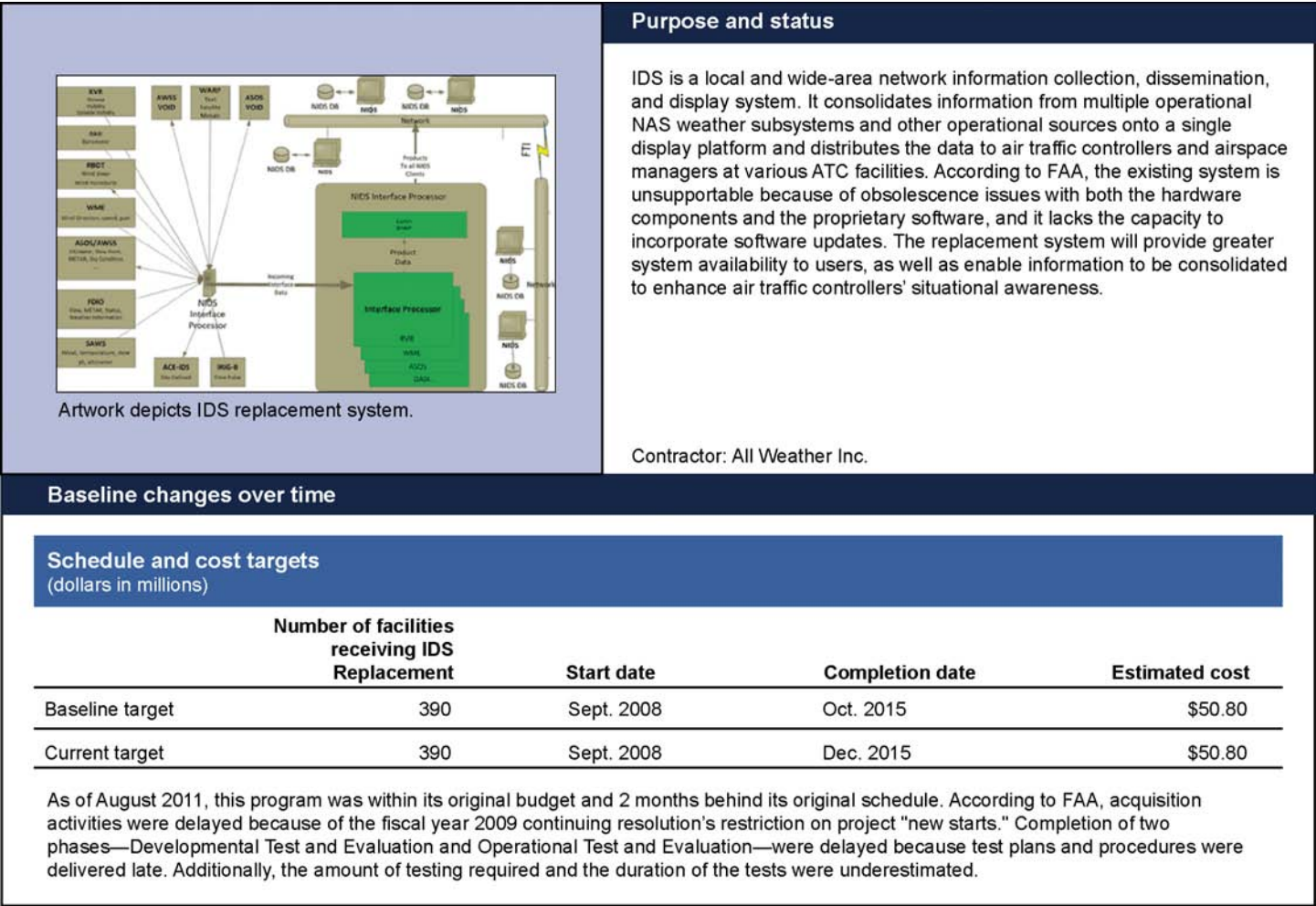
Sources: GAO (analysis); FAA (data and artwork).

Figure 10: En Route Automation Modernization (ERAM)



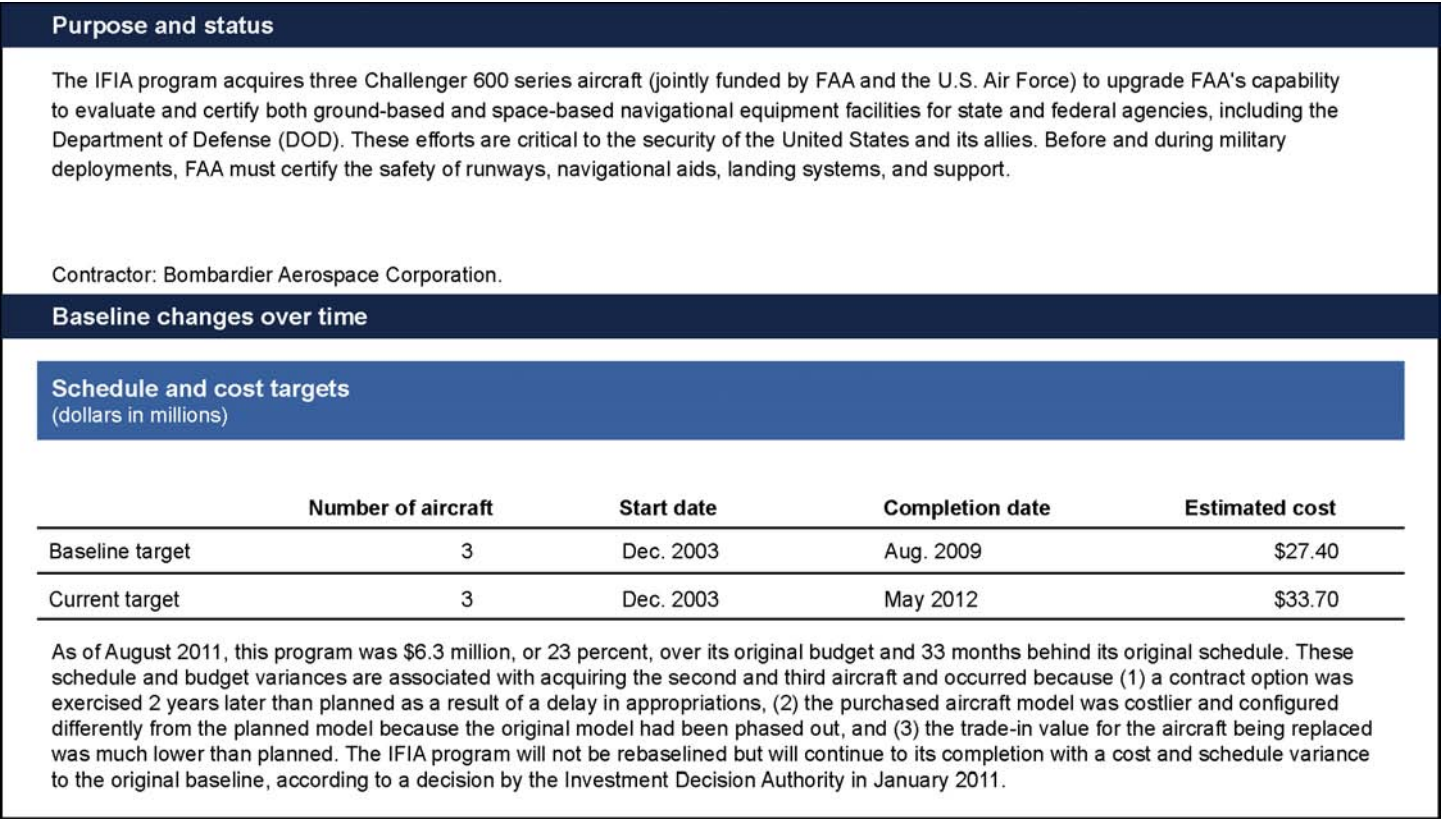
Sources: GAO (analysis); FAA (data and artwork).

Figure 11: Integrated Display Systems (IDS) Replacement



Sources: GAO (analysis); FAA (data and artwork).

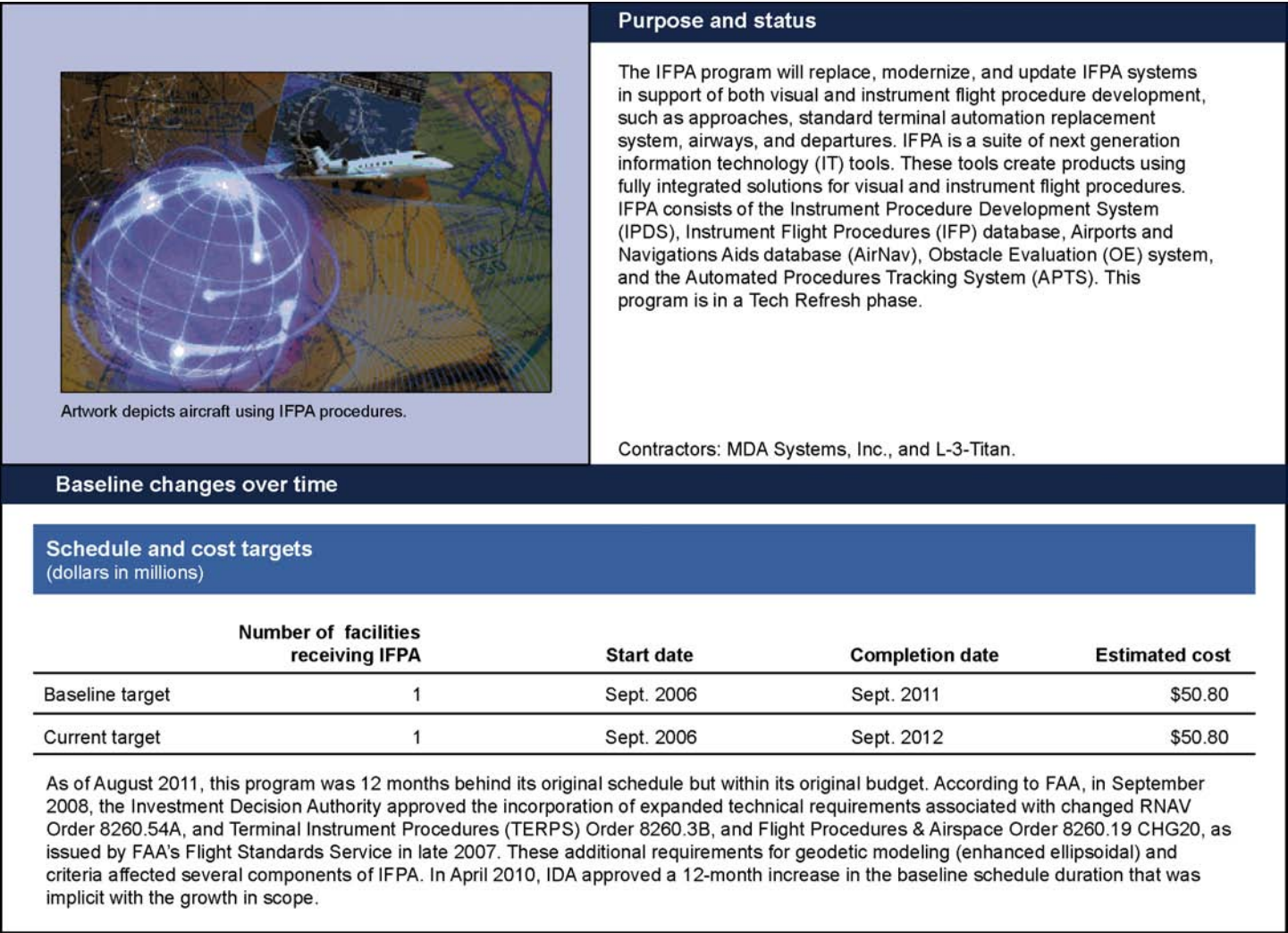
Figure 12: International Flight Inspection Aircraft (IFIA)



Sources: GAO (analysis); FAA (data).

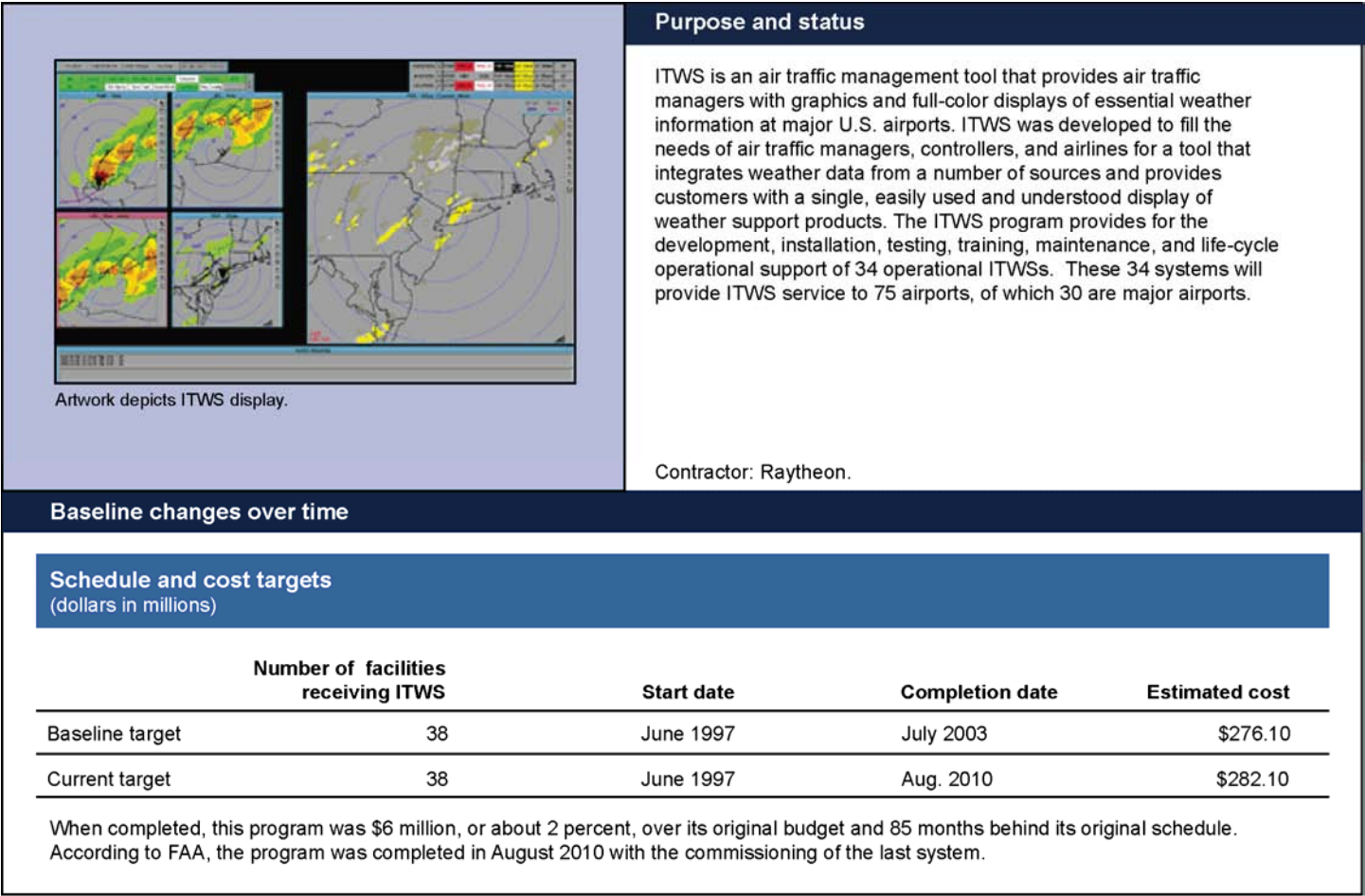


Figure 13: Instrument Flight Procedure Automation (IFPA)



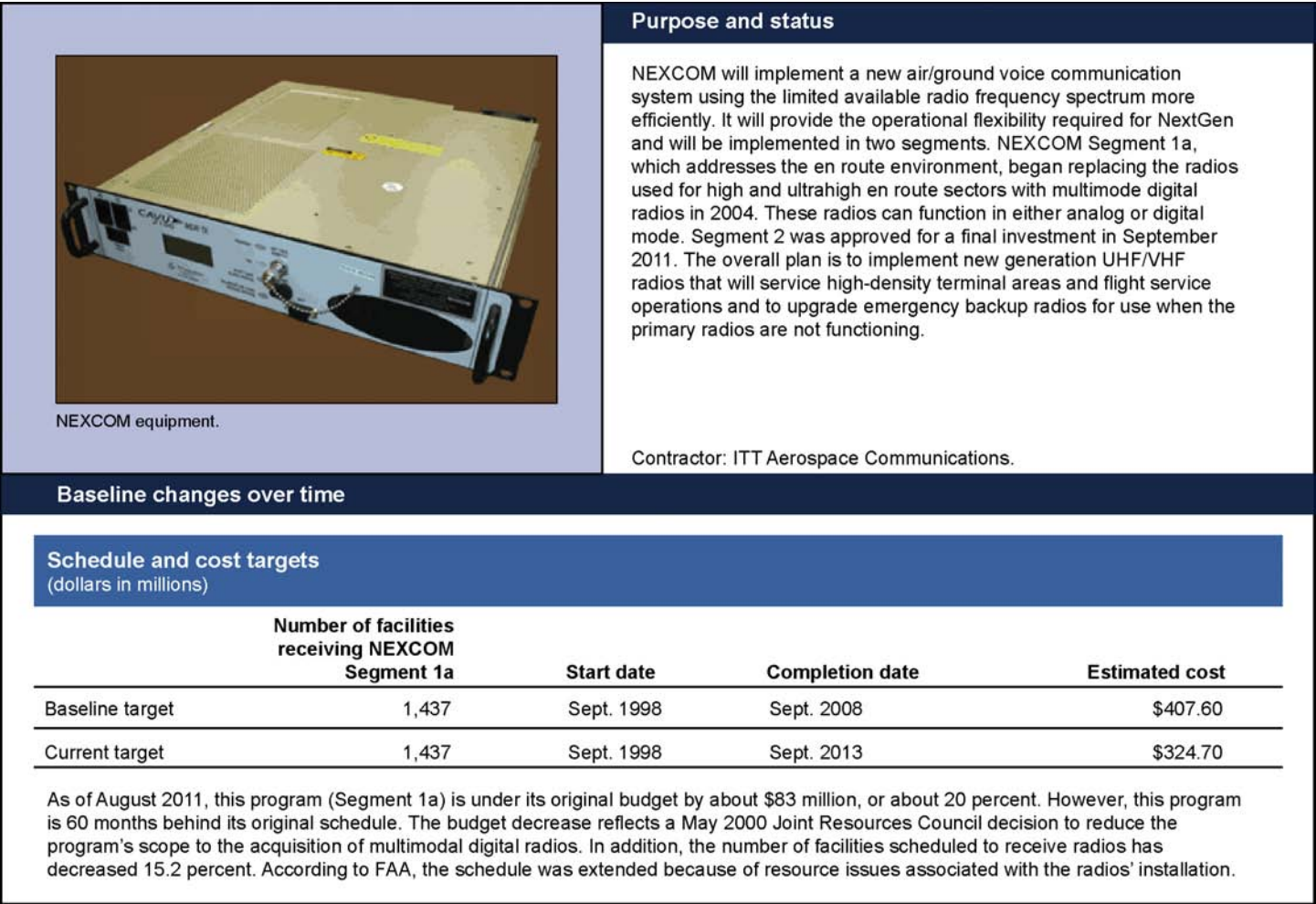
Sources: GAO (analysis); FAA (data and artwork).

Figure 14: Integrated Terminal Weather System (ITWS)



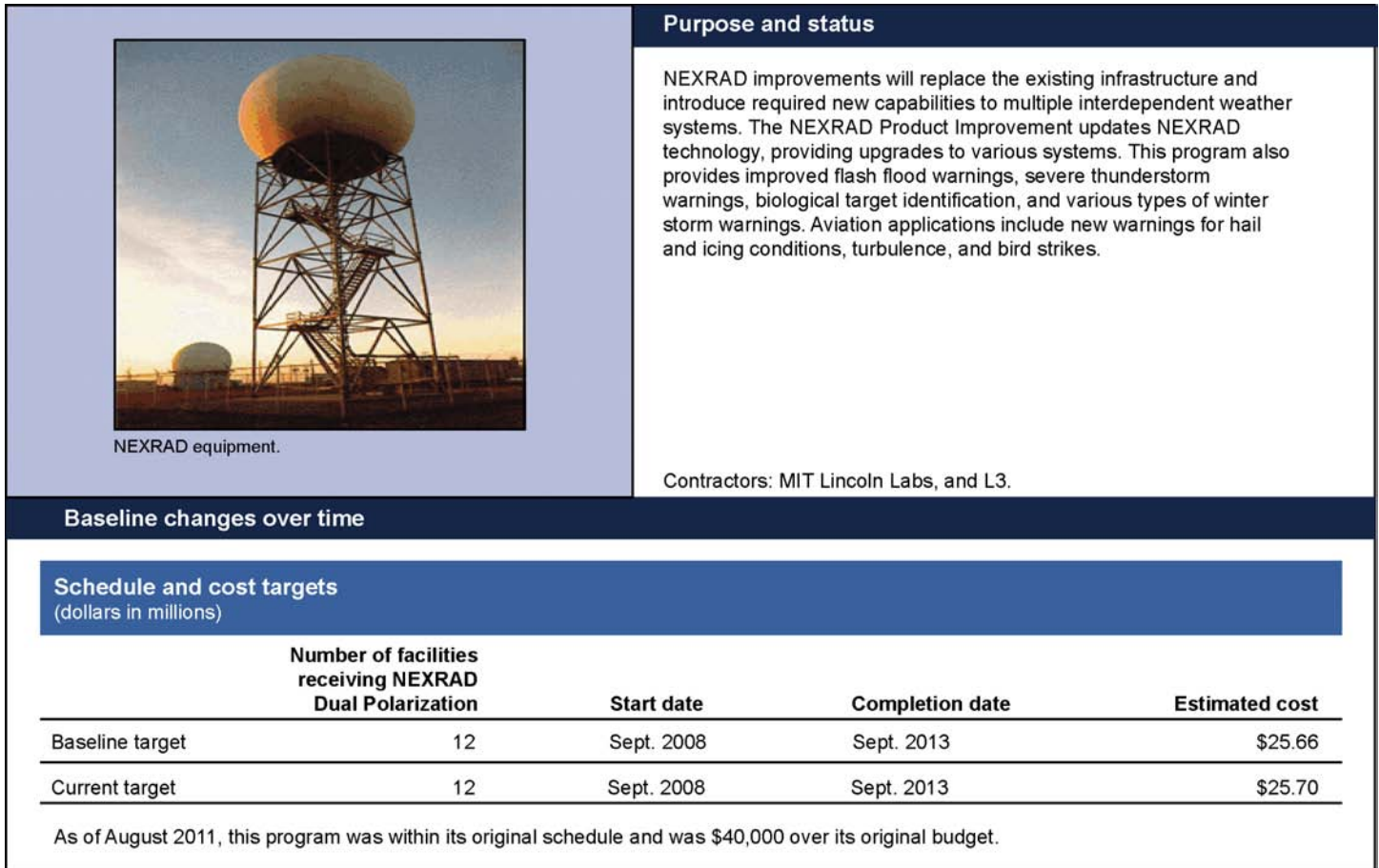
Sources: GAO (analysis); FAA (data and artwork).

Figure 15: Next Generation Air/Ground Communication System (NEXCOM) Segment 1a



Sources: GAO (analysis); FAA (data and artwork).

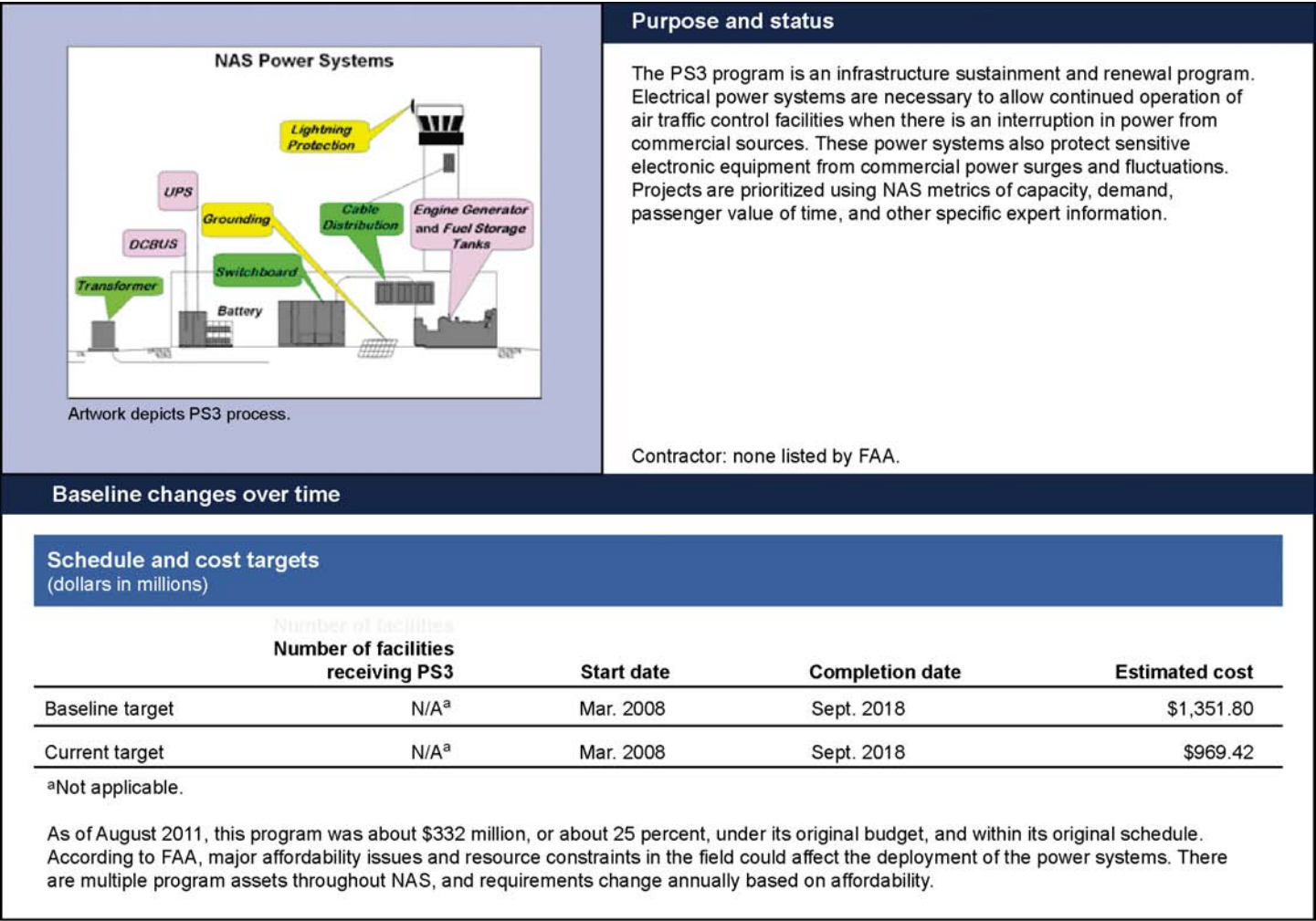
Figure16: Next Generation Weather Radar (NEXRAD) Dual Polarization



Sources: GAO (analysis); FAA (data and artwork).



Figure 17: Power Systems Sustained Support (PS3)



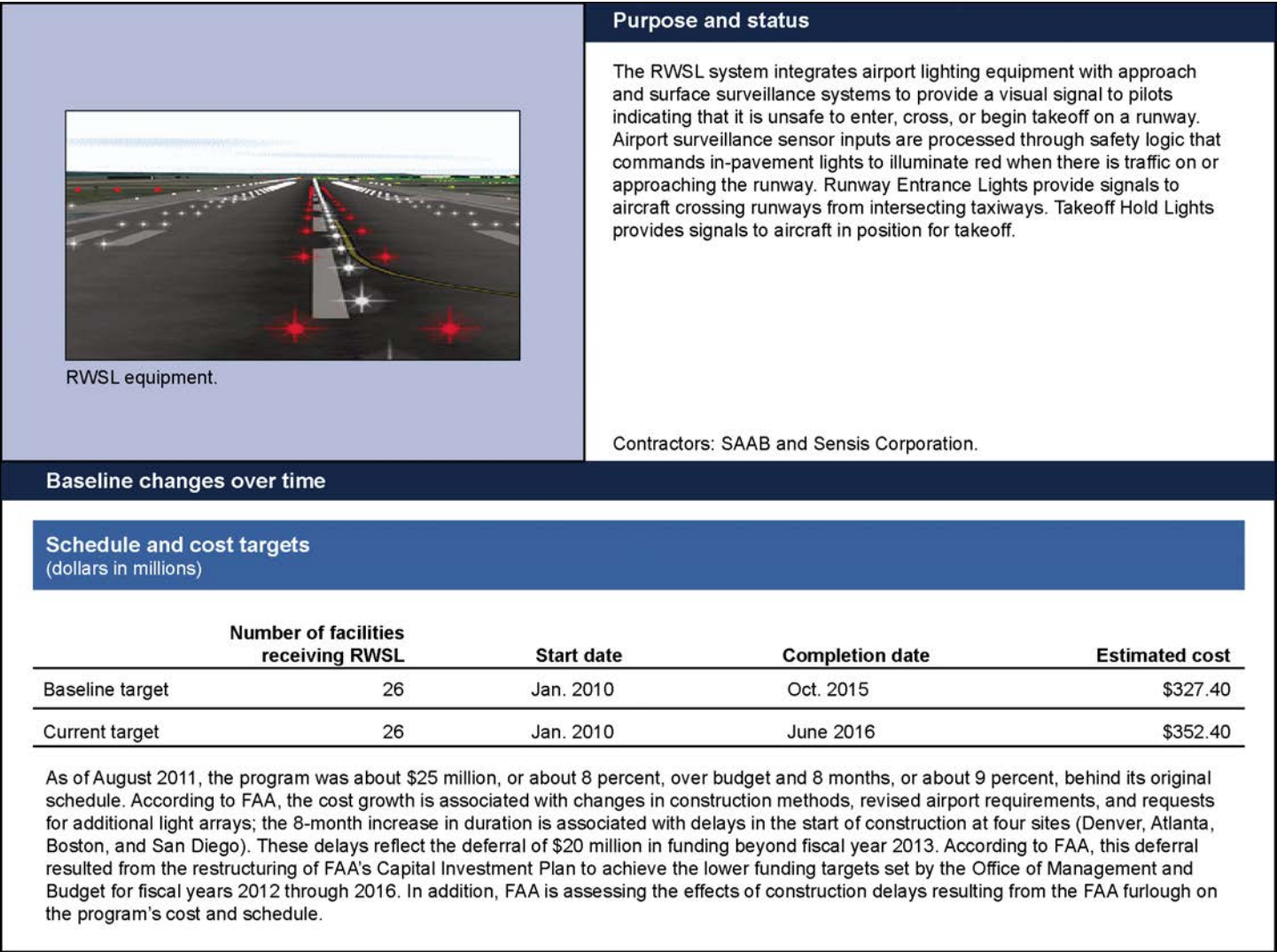
Sources: GAO (analysis); FAA (data and artwork).

**Figure 18: Regulation and Certification Infrastructure for System Safety (RCISS) Segment 2**

Purpose and status				
<p>The RCISS program provides the automation hardware, software, and communication infrastructure to support Aviation Safety information databases and access to them by the increasingly mobile FAA safety work force. RCISS is the next generation infrastructure, which will build upon the legacy infrastructure to improve fact-based decision making. RCISS's enterprise infrastructure plans provide the access methods to all Aviation Safety (AVS) national safety applications developed by Safety Approach for Safety Oversight, Aviation Safety Knowledge Management Environment, and all other national safety programs developed or currently deployed within AVS. The start date for RCISS's Segment 1 was July 2007.</p> <p>Contractors: Dell, eFAST, Harris, and SAVES.</p>				
Baseline changes over time				
Schedule and cost targets (dollars in millions)				
	Number of facilities receiving RCISS Segment 2	Start date	Completion date	Estimated cost
Baseline target	N/A <sup>a</sup>	Oct. 2010	Sept. 2016	\$90.70
Current target	N/A <sup>a</sup>	Oct. 2010	Sept. 2016	\$90.70
<sup>a</sup> Not applicable.				
As of August 2011, this program was within its original budget and schedule.				

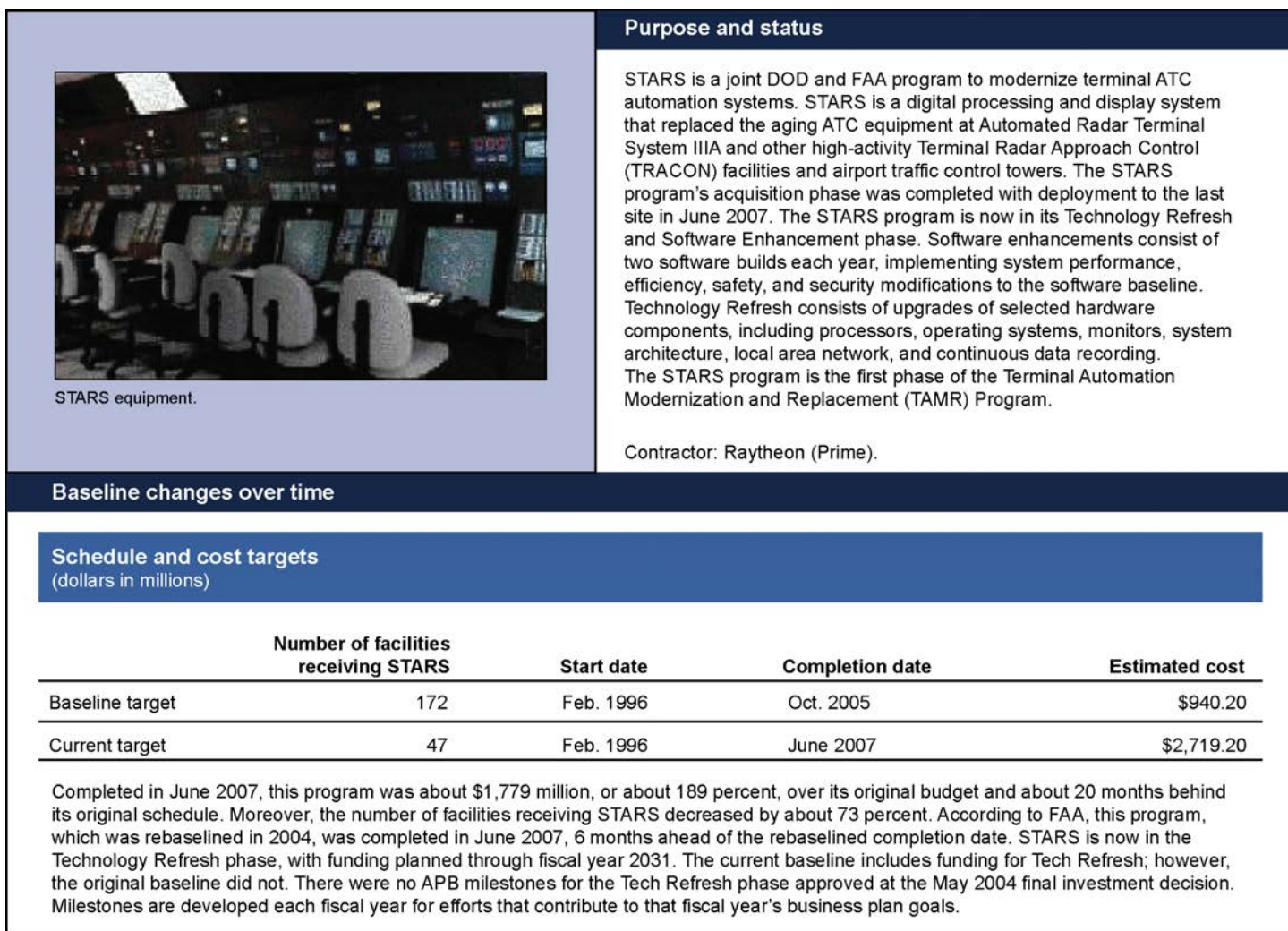
Sources: GAO (analysis); FAA (data).

Figure 19: Runway Status Lights (RWSL)



Sources: GAO (analysis); FAA (data and artwork).

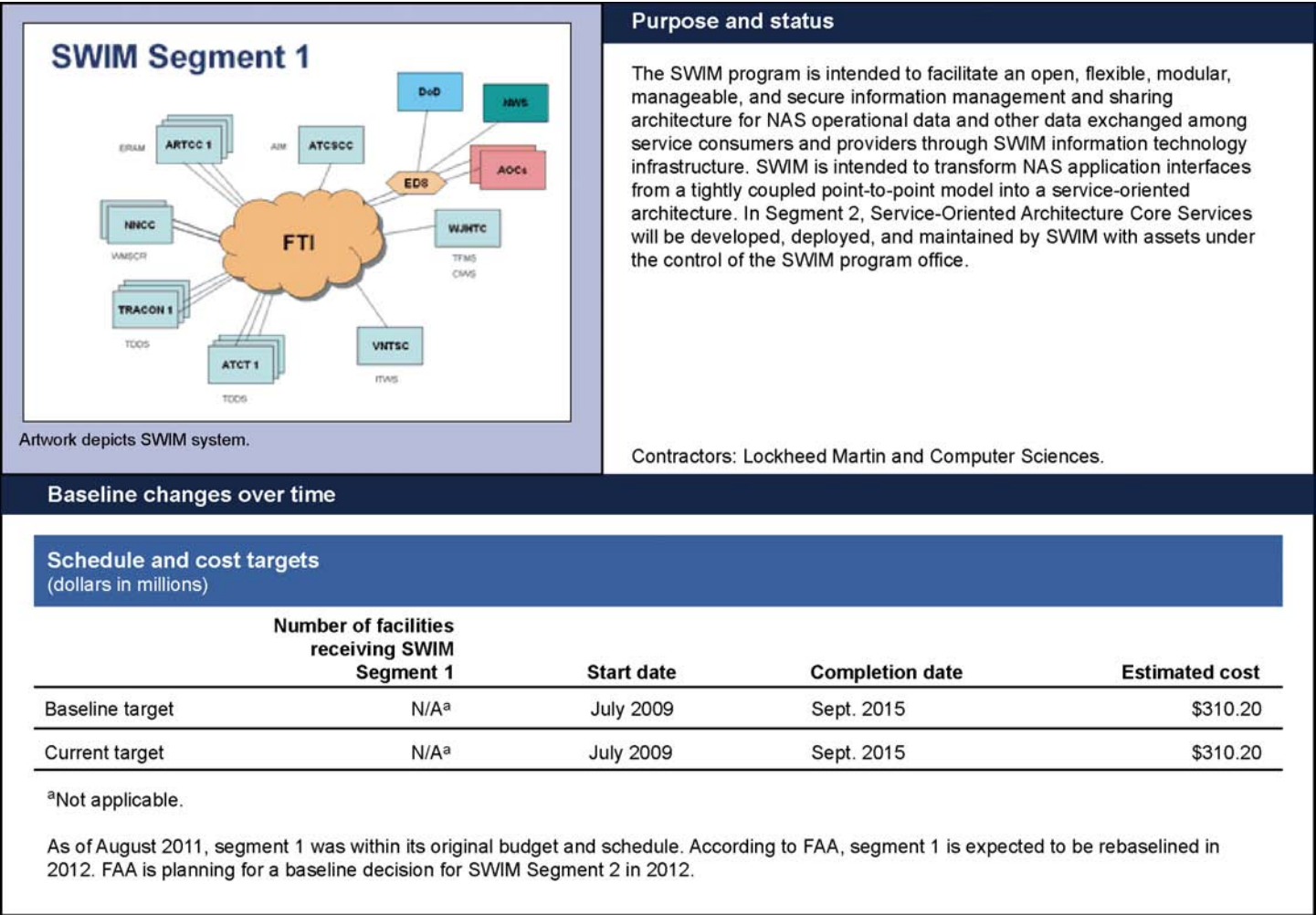
Figure 20: Standard Terminal Automation Replacement System (STARS) (TAMR Phase 1)



Sources: GAO (analysis); FAA (data and artwork).

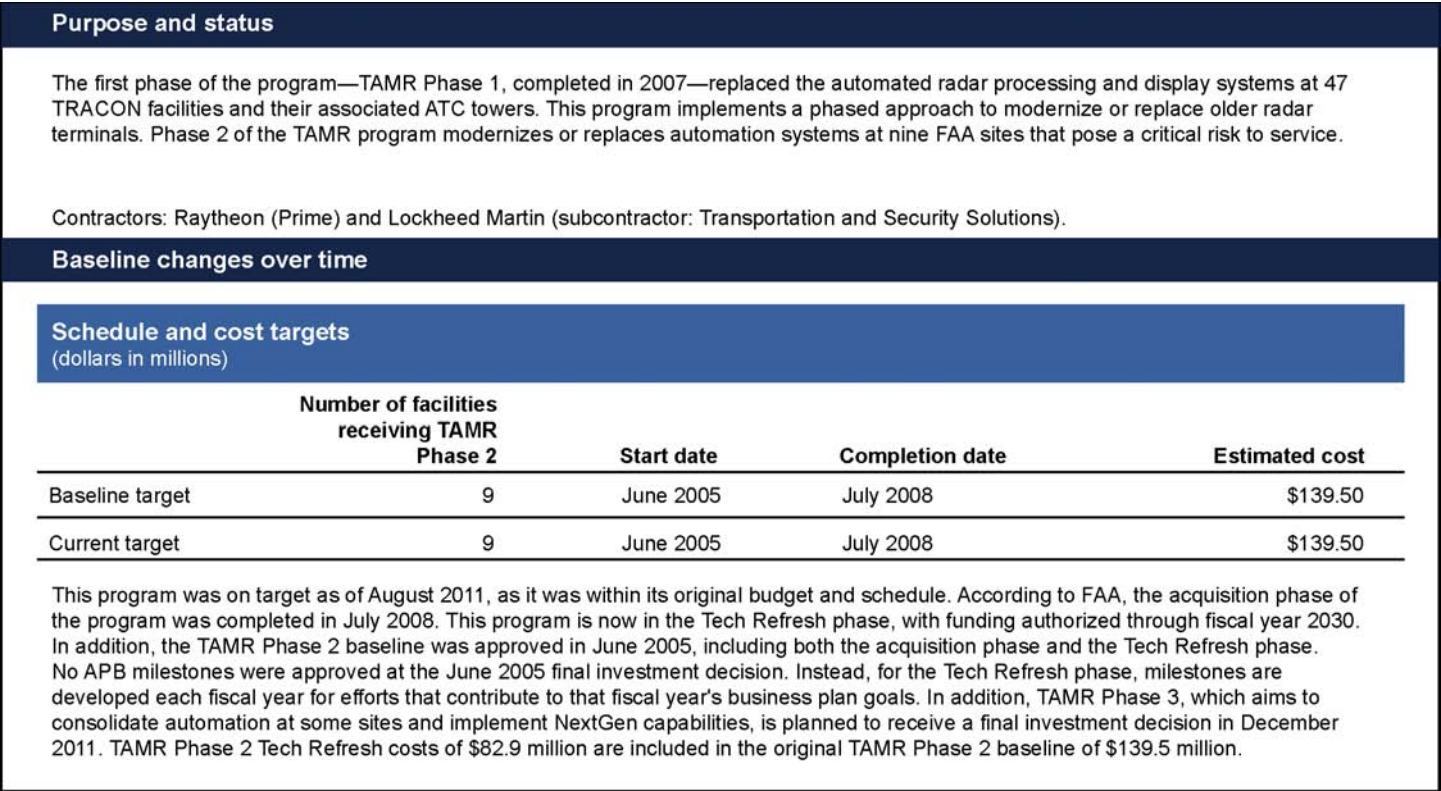


Figure 21: System Wide Information Management (SWIM) Segment 1



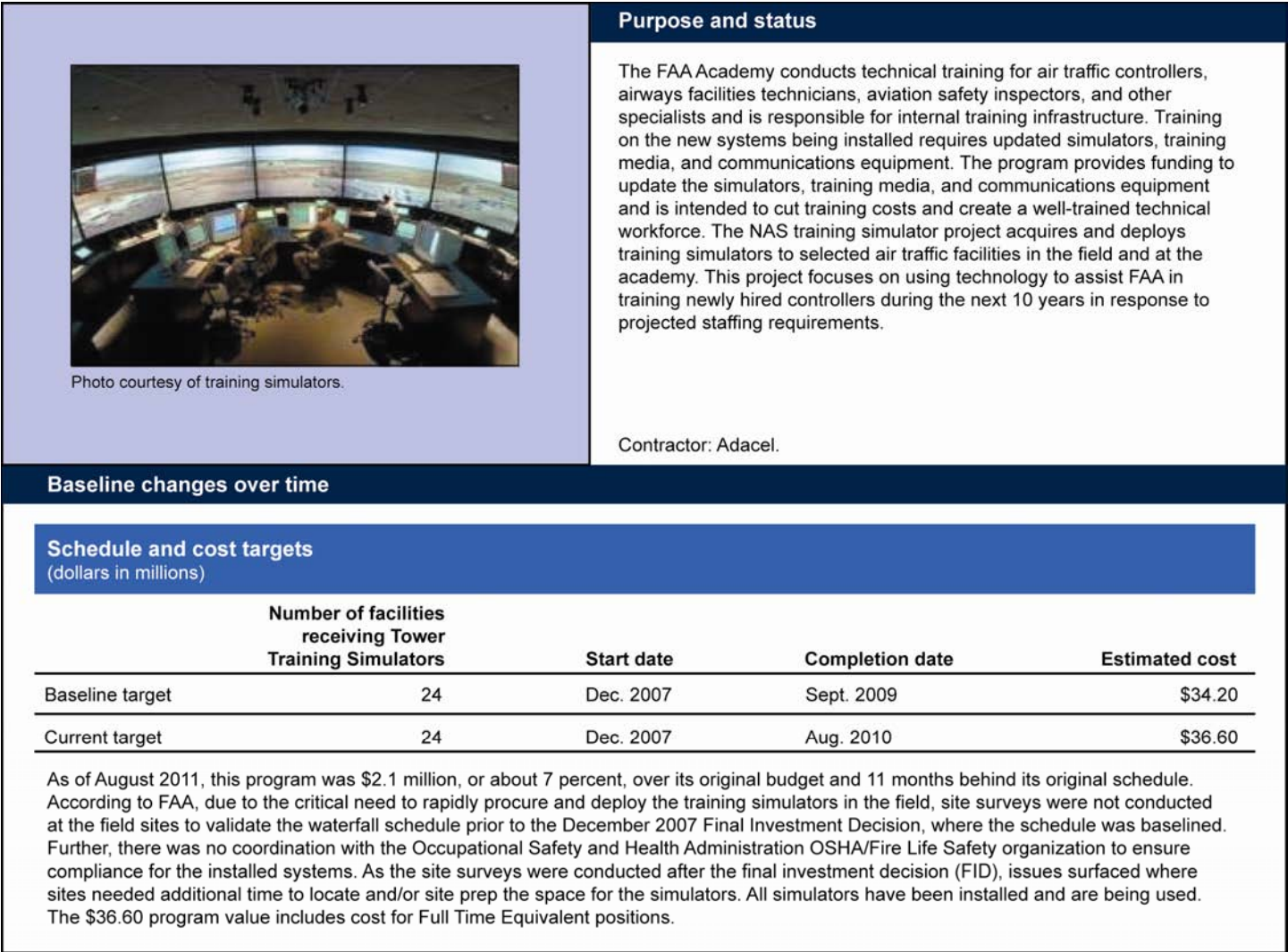
Sources: GAO (analysis); FAA (data and artwork).

Figure 22: Terminal Automation Modernization and Replacement (TAMR)—Phase 2



Sources: GAO (analysis); FAA (data).

Figure 23: Tower Training Simulator Systems



Sources: GAO (analysis); FAA (data and artwork).

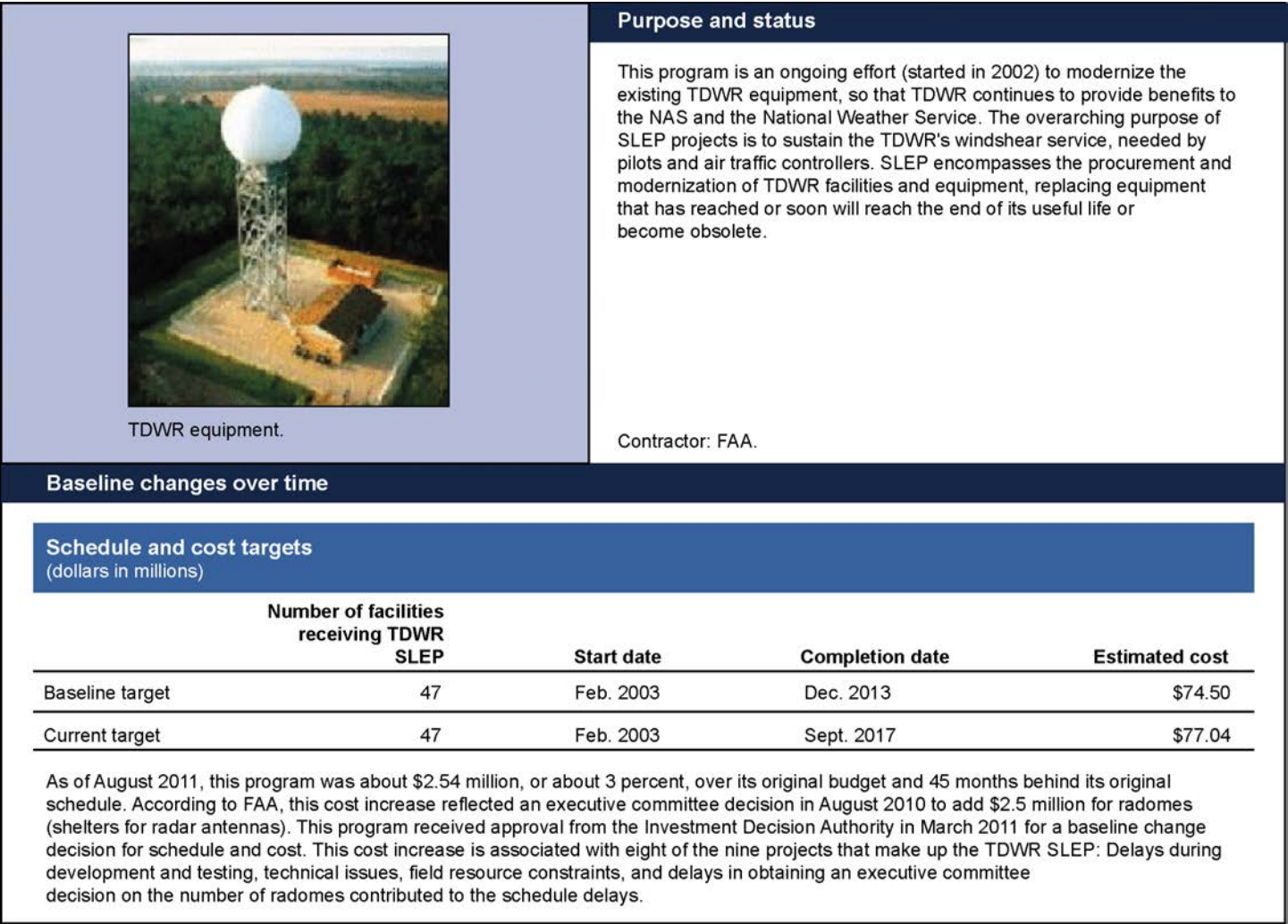
Figure 24: Trajectory Management—Arrival Tactical Flow Time Based Flow Management

Purpose and status				
<p>Time Based Flow Management (TBFM) will modernize and enhance the current Traffic Management Advisor (TMA) System. Traffic Management Advisor (TMA) is a vital part of the NAS and enhances air traffic operations by reducing delays and increasing efficiency of airline operations. TMA is an automation system currently available that enables the use of time-based metering to optimize the flow of aircraft as they approach and depart congested airspace and airports. TBFM is an evolution of the TMA Program and uses time-based metering software to optimize capacity in the NAS.</p> <p>Contractors: Lockheed Martin.</p>				
Baseline changes over time				
Schedule and cost targets (dollars in millions)				
	Number of facilities receiving Trajectory Management	Start date	Completion date	Estimated cost
Baseline target	80	Apr. 2010	Nov. 2014	\$115.00
Current target	80	Apr. 2010	Nov. 2014	\$115.00
As of August 2011, this program was within its original budget and schedule.				

Sources: GAO (analysis); FAA (data).

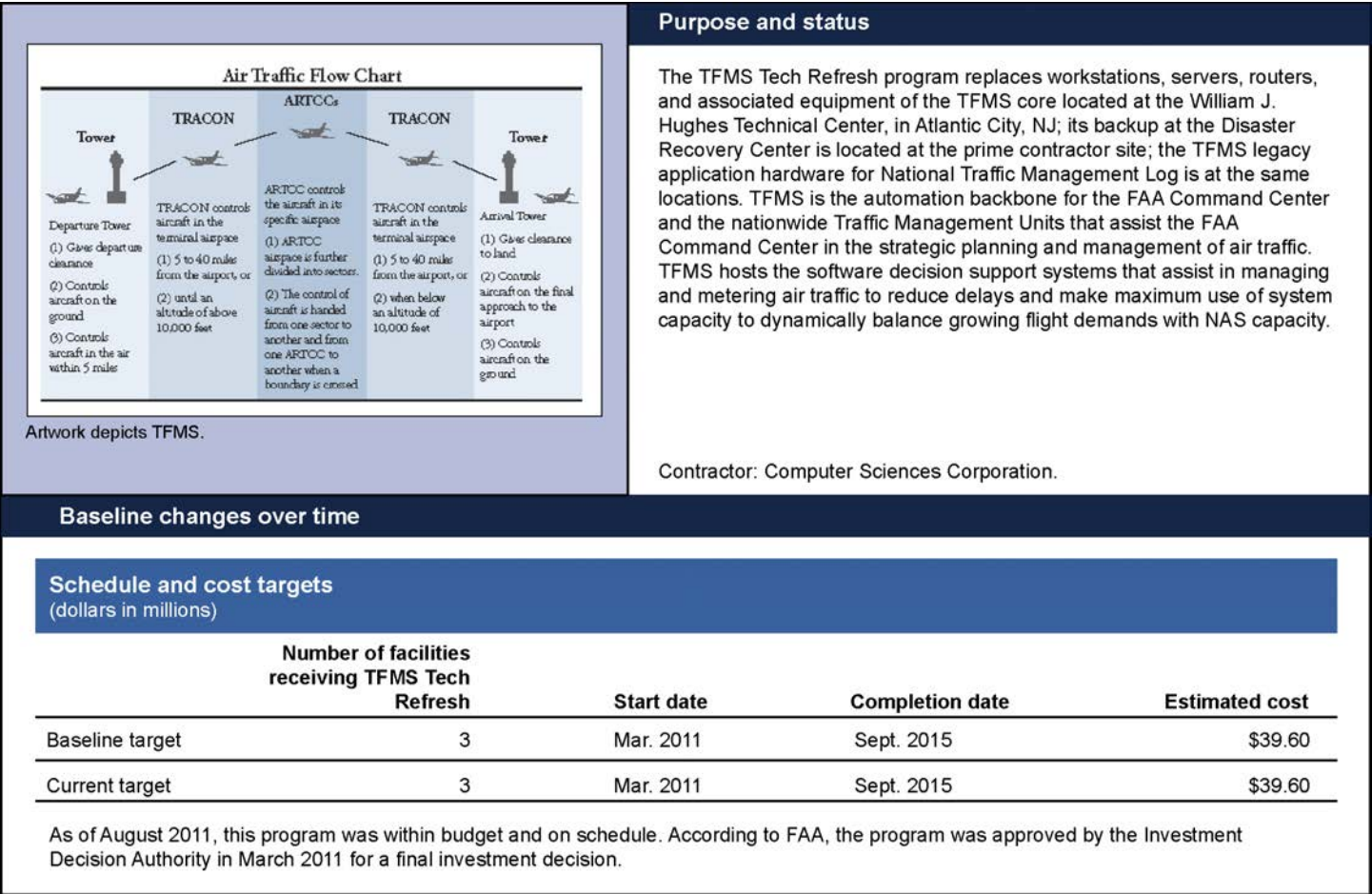


Figure 25: Terminal Doppler Weather Radar (TDWR) Service Life Extension Program (SLEP)



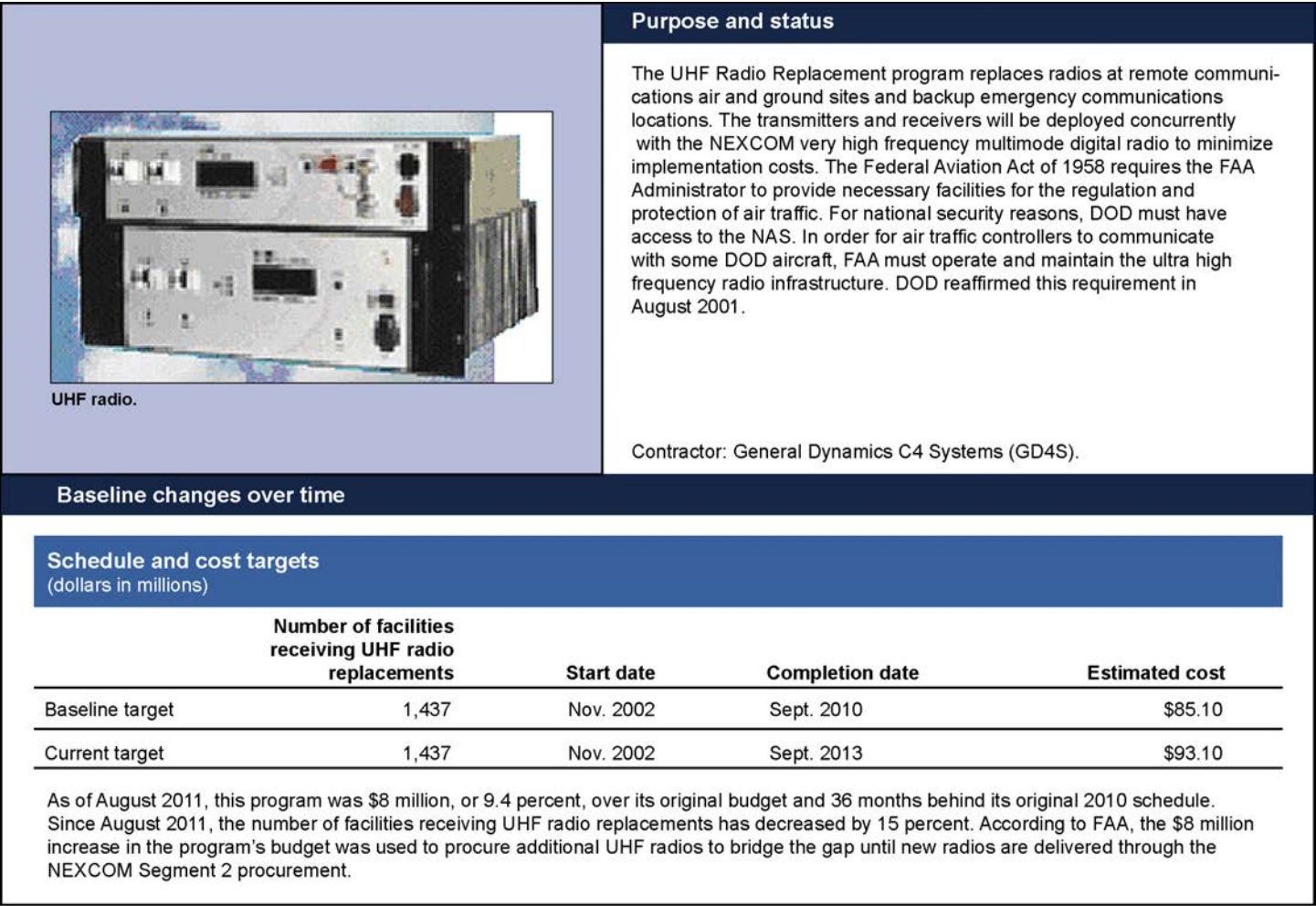
Sources: GAO (analysis); FAA (data and artwork).

Figure 26: Traffic Flow Management System (TFMS) Tech Refresh



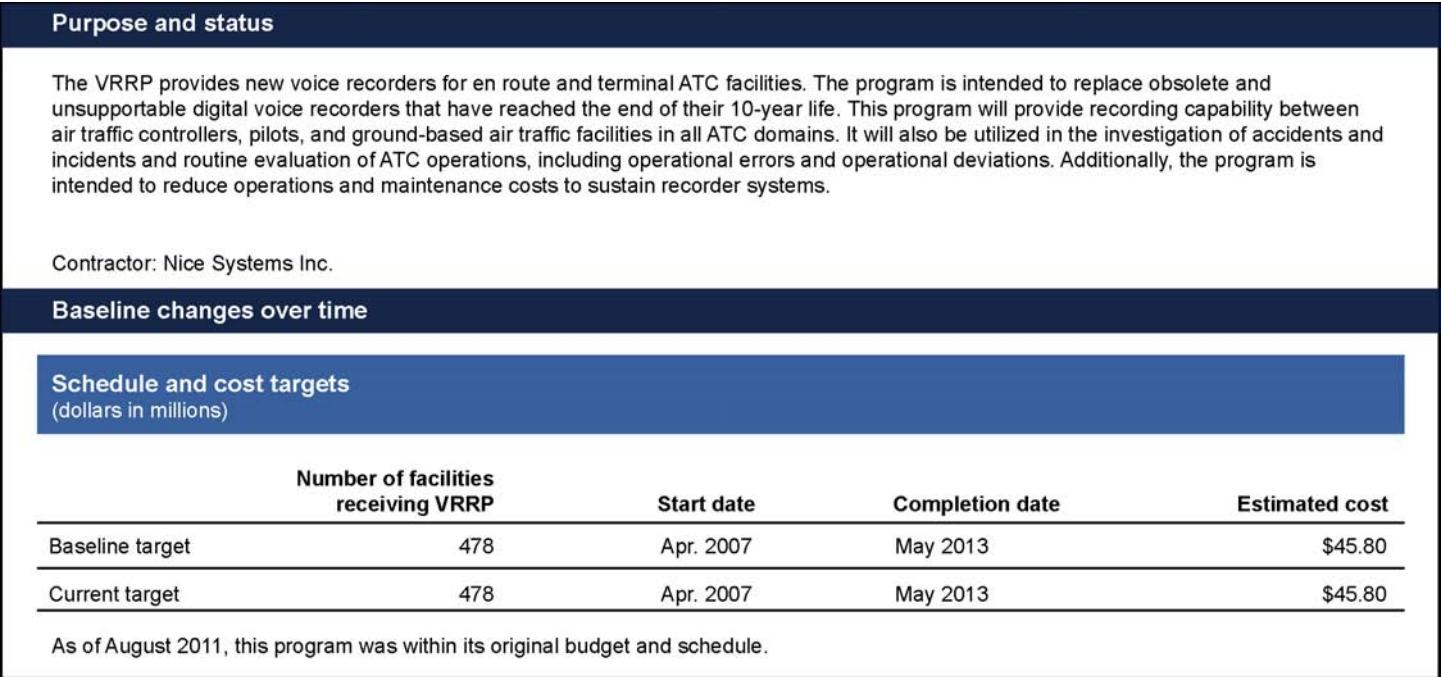
Sources: GAO (analysis); FAA (data and artwork).

Figure 27: Ultra High Frequency (UHF) Radio Replacement



Sources: GAO (analysis); FAA (data and artwork).

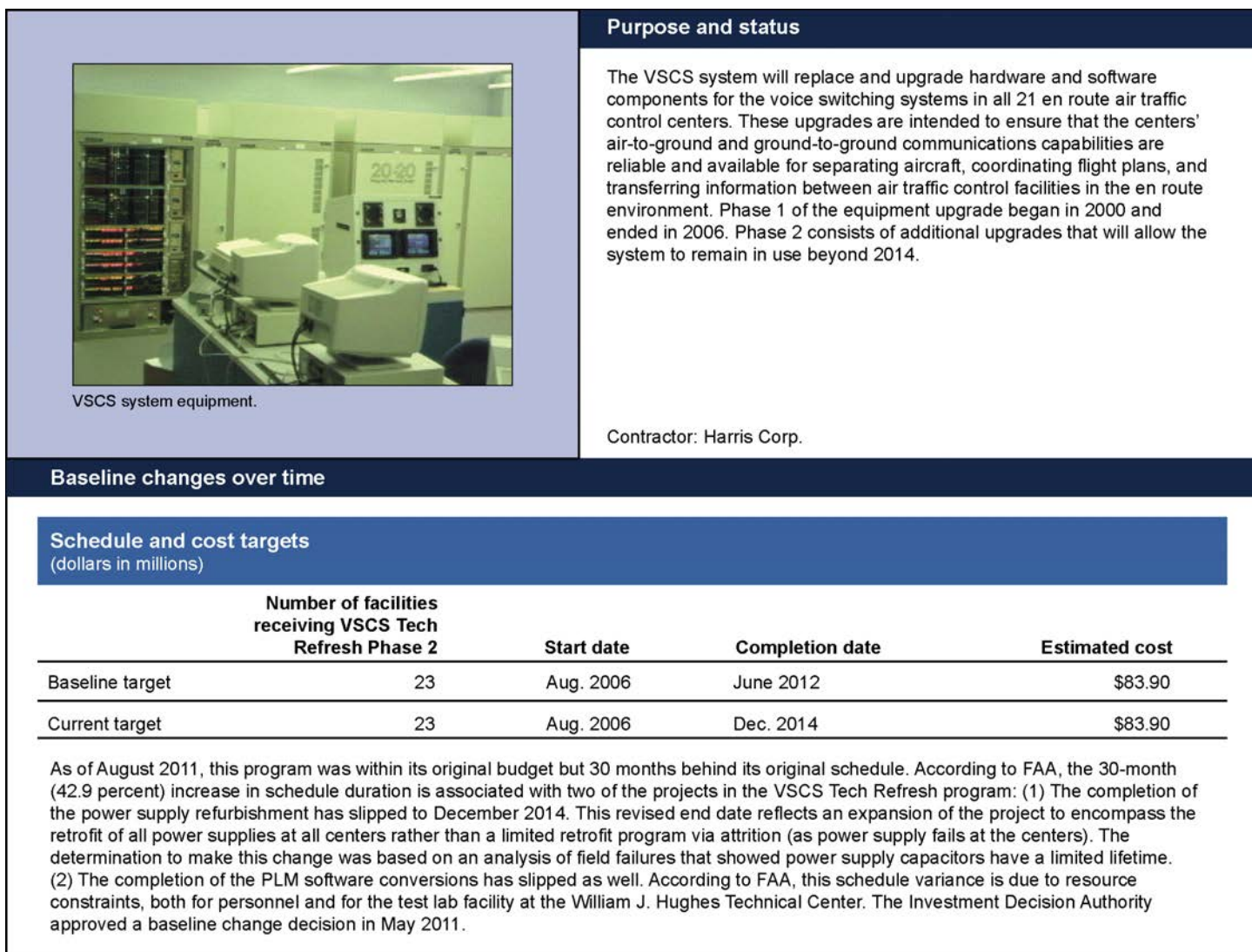
Figure 28: Next Generation Voice Recorder Replacement Program (VRRP)



Sources: GAO (analysis); FAA (data).

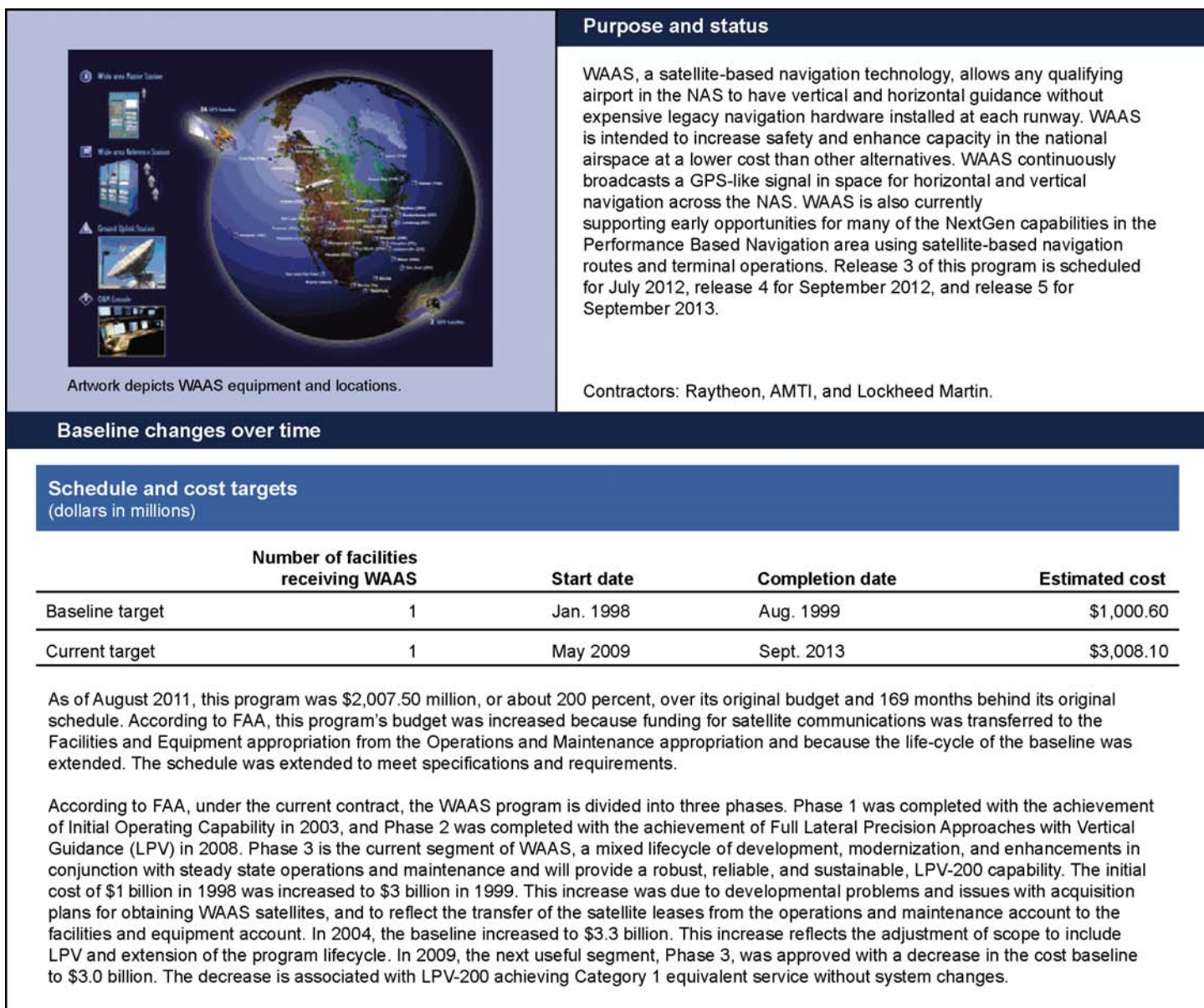


Figure 29: Voice Switching and Control Switching System (VSCS) Tech Refresh Phase 2



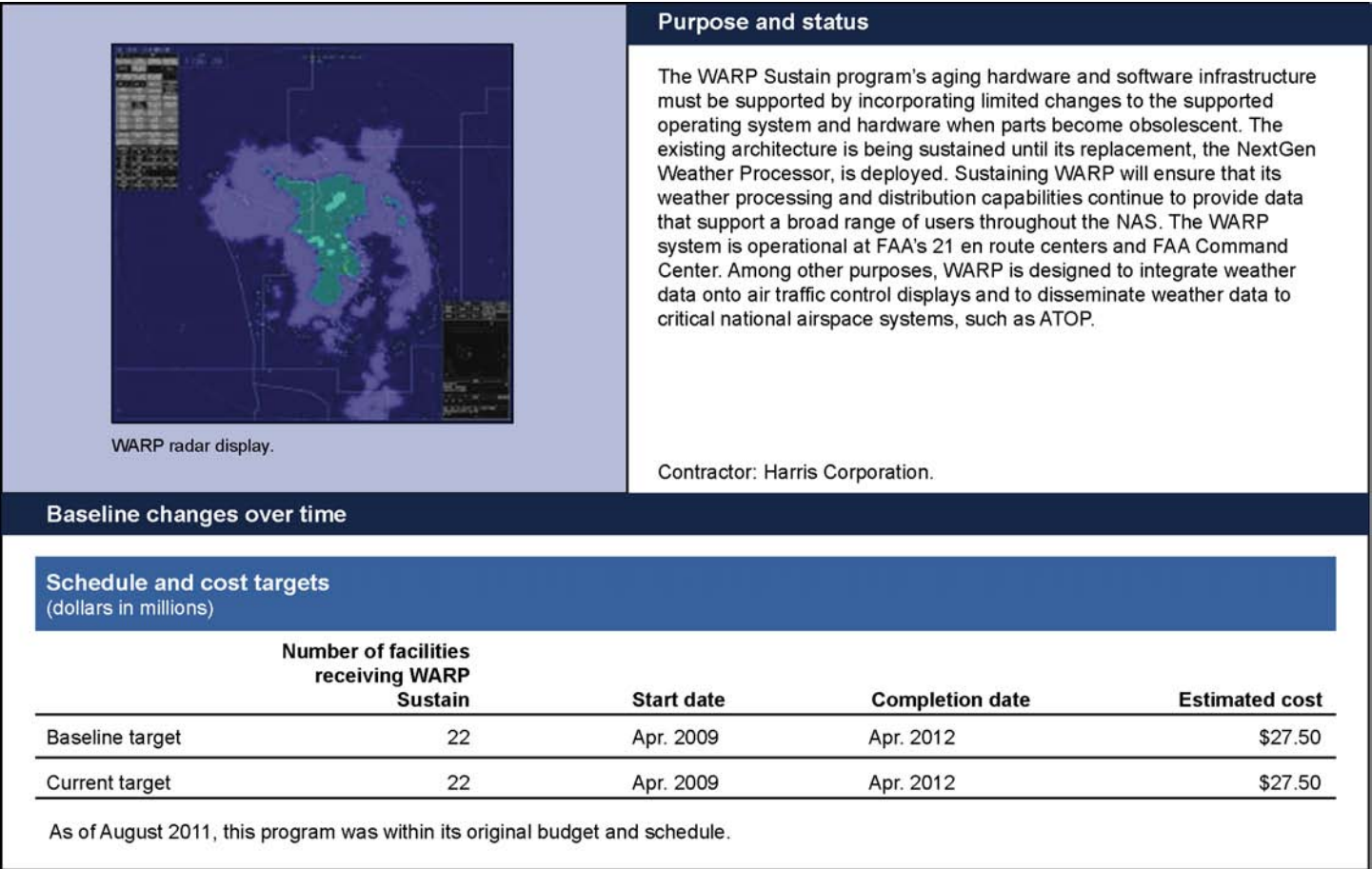
Sources: GAO (analysis); FAA (data and artwork).

Figure 30: Wide Area Augmentation System (WAAS)



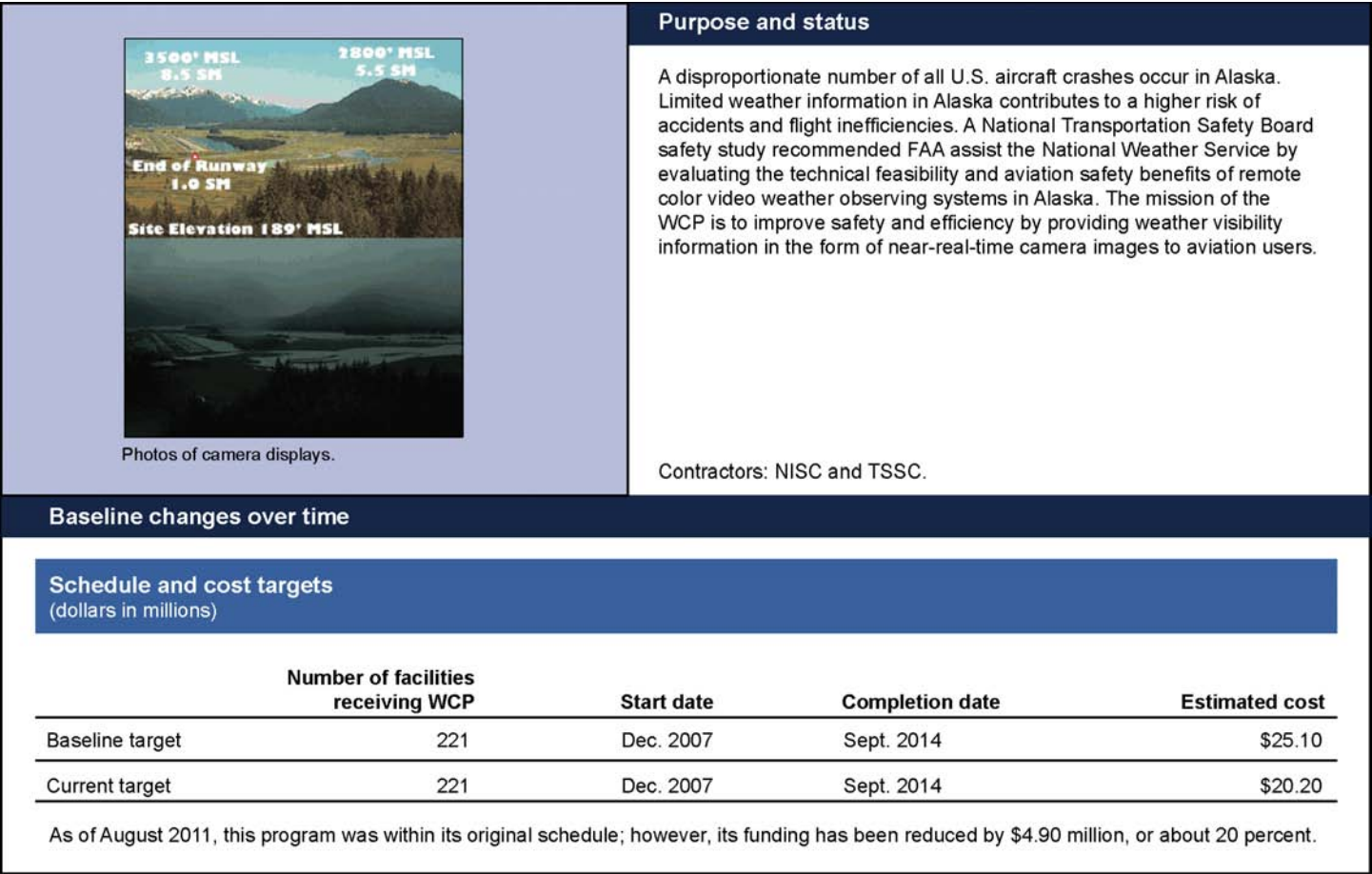
Sources: GAO (analysis); FAA (data and artwork).

Figure 31: Weather and Radar Processor (WARP) Sustain



Sources: GAO (analysis); FAA (data and artwork).

Figure 32: Weather Camera Program (WCP)



Sources: GAO (analysis); FAA (data and artwork).



# Appendix III: Assessments of Four FAA Program Cost Estimates

This appendix provides the results of our analysis of the extent to which the processes and methodologies used to develop and maintain the four FAA cost estimates meet the characteristics of high-quality cost estimates. These characteristics incorporate the 12 steps consistently applied by cost-estimating organizations throughout the federal government and industry and considered best practices for developing cost estimates and that are listed in table 2 of the report. The following tables provide the detailed results of our analysis of the program cost estimates for Automatic Dependent Surveillance-Broadcast (ADS-B), Collaborative Air Traffic Management Technologies (CATMT), System Wide Information Management (SWIM), and Wide Area Augmentation System (WAAS). “Not met” means the program provided no evidence that satisfies any of the criteria. “Minimally met” means the program provided evidence that satisfies a small portion of the criterion. “Partially met” means the program provided evidence that satisfies about half of the criterion. “Substantially met” means the program provided evidence that satisfies a large portion of the criterion. “Fully met” means the program provided evidence that completely satisfies the criterion.

Table 8: GAO’s Analysis of the FAA’s ADS-B Cost Estimates		
Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p><b>Well-documented</b></p> <ul style="list-style-type: none"> <li>Captures the source data used, the reliability of the data, and how the data were made compatible with other data in the estimate.</li> </ul> <p>Data should be collected from primary sources. The source, content, time, and units should be adequately documented. Data should also be analyzed to determine accuracy and reliability, and to identify cost drivers.</p> <ul style="list-style-type: none"> <li>Describes the calculations and the methodology used to derive each element’s cost.</li> </ul> <p>Documentation should describe what calculation methods are used, as well as how they were applied, and explain any anomalies.</p>	Partially met	<ul style="list-style-type: none"> <li>Lists data sources, but does not provide documentation of the source data, bringing into question the reliability of the data. (<i>Minimally meets.</i>) Data are the foundation of every cost estimate. Depending on data quality, an estimate can range anywhere from a mere guess to a highly defensible cost position. Data are often in many different forms and need to be adjusted before being used. The cost estimator needs information about the source and reliability of the data in order to know whether the data collected can be used directly or need to be modified.</li> <li>Documentation does not fully explain how FAA derived estimated costs. For example, FAA relied on expert opinion to estimate several costs but provided no historical data to back up the opinions. There was also no supporting information for the software cost estimates. (<i>Minimally meets.</i>) Poorly documented cost estimates can cause a program’s credibility to suffer because the documentation cannot explain the rationale for the methodology or the calculations. Estimates that lack sufficient documentation are not useful for updates or</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>Describes how the estimate was developed. The data supporting the estimate should be available and adequately documented so that the estimate can be easily documented to reflect actual costs or program changes.</li> <li>Discusses the technical baseline description. A technical baseline description provides a common definition of the program, including detailed technical, program, and schedule descriptions of the system, for a cost estimate to be built on. The data in the technical baseline should be consistent with the data used to develop the cost estimate.</li> <li>Provides evidence of management review and acceptance. There should be a briefing to management, including a clear explanation of how the cost estimate was derived. Management's acceptance of the cost estimate should be documented.</li> </ul>	Substantially met	<p>information sharing and can hinder understanding and proper use.</p> <ul style="list-style-type: none"> <li>Cost calculations are described at a high level, but the documentation does not provide enough detail so that a cost analyst unfamiliar with the program could understand what was done and replicate it. Furthermore, we found an inconsistency between dollar values stored in the cost estimating tool and the Excel spreadsheets used to report life-cycle costs. <i>(Partially met.)</i> Without good documentation, management and oversight officials will not be convinced that the estimate is credible; supporting data, lessons learned, and reasons why costs changed will not be available for future use; questions about the approach or data used to create the estimate cannot be answered; and the scope of the analysis cannot be thoroughly defined.</li> <li>Technical details contained within the basis-of-estimate documentation are consistent with corresponding details in the technical baseline. <i>(Substantially meets.)</i></li> <li>The estimate was briefed to the Joint Resources Council. The briefing included a discussion of the scope, justification, and cost of the program. It also contained an overview of the program's technical requirements, life-cycle costs, assumptions, and results of risk and sensitivity analysis. <i>(Met.)</i></li> </ul>
<p><b>Comprehensive</b></p> <ul style="list-style-type: none"> <li>Includes all life-cycle costs. A life-cycle cost estimate provides a complete and structured accounting of all resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. It should cover the program from its inception through its retirement.</li> <li>Completely defines the program, reflects the current schedule, and is technically reasonable. The cost estimate should be based on a documented technical baseline description, which provides a common definition of the program—including detailed technical, program, and schedule descriptions of the system.</li> </ul>	Substantially met	<ul style="list-style-type: none"> <li>Includes costs from fiscal year 2007 through fiscal year 2035 for both government and contractor efforts across all phases of the program. <i>(Met.)</i></li> <li>Reflects the current project schedule, but no single technical baseline was provided and there was no evidence that the technical documents had been updated to reflect changes. <i>(Substantially met.)</i></li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>Has a product-oriented work breakdown structure, and is traceable to the program's technical scope, at an appropriate level of detail.</li> </ul> <p>A work breakdown structure provides a basic framework for a variety of related activities like estimating costs, developing schedules, identifying resources and potential risks, and providing the means for measuring program status using earned value management. It is product-oriented if it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component.</p> <ul style="list-style-type: none"> <li>Documents all cost-influencing ground rules and assumptions.</li> </ul> <p>Cost estimates are typically based on limited information and therefore need to be bound by ground rules and assumptions. Ground rules are a set of estimating standards that provide guidance and common definitions, while assumptions are judgments about past, present, or future conditions that may affect the estimate.</p>		<ul style="list-style-type: none"> <li>Reflects the FAA standard work breakdown structure, which is not product-oriented; instead, it breaks work down into functional categories. While the cost estimate work breakdown structure matches the work breakdown structure for earned value management, it does not match the work breakdown structure for the schedule. Furthermore, there was no evidence that the work breakdown structure had been updated as the program became better defined. <i>(Partially met.)</i> Without a work breakdown structure, the program lacks a framework to develop a schedule and cost plan that can be used to easily track technical accomplishments. A standard product-oriented work breakdown structure facilitates the tracking of resource allocations and expenditures, which can give an agency insight to reliably estimate the cost of future similar programs.</li> <li>While ground rules and assumptions were discussed, many of the assumptions did not include supporting data. In addition, details supporting risk assumptions were incomplete because the sources for the risk ranges were not provided. <i>(Partially met.)</i> Unless ground rules and assumptions are clearly documented, the cost estimate will not have a basis for assessing potential risks. Furthermore, the estimate cannot be reconstructed when the original estimators are no longer available.</li> </ul>
<p><b>Accurate</b></p> <ul style="list-style-type: none"> <li>Produces unbiased results.</li> </ul> <p>Cost estimates should have an uncertainty analysis, which determines where the estimate falls against the range of all possible costs.</p> <ul style="list-style-type: none"> <li>Is properly adjusted for inflation.</li> </ul> <p>Cost data should be adjusted for inflation to ensure that comparisons and projections are valid. Data should also be normalized to constant-year dollars to remove the effects of inflation.</p> <ul style="list-style-type: none"> <li>Contains few mistakes.</li> </ul> <p>Results should be checked for accuracy, double counting, and omissions.</p>	<p>Partially met</p>	<ul style="list-style-type: none"> <li>The cost basis of estimate contains minimum, most likely, and maximum values to model uncertainties for each cost element and to provide a range of costs; however, no analysis has been performed to determine the confidence level of the estimate. <i>(Partially met.)</i> A cost estimate is biased if the estimated work is overly conservative or too optimistic. Unless the estimate is based on an assessment of the most likely costs and reflects the degree of uncertainty given all of the risks considered, management will not be able to make good decisions.</li> <li>The cost estimate was adjusted for inflation correctly, but the source data for the government salaries inflation index were not provided. <i>(Substantially met.)</i></li> <li>We found no instances of incorrect formulas, double-counted costs, or omitted costs. Moreover, costs reported by fiscal year correctly summed to their life-cycle totals. <i>(Met.)</i></li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>Is regularly updated to reflect significant program changes.</li> </ul> <p>The cost estimate should be updated to reflect significant program changes, such as changes to schedules or other assumptions. Updates should also reflect actual costs so that the estimate always reflects the current program status.</p> <ul style="list-style-type: none"> <li>Documents and explains variances between planned and actual costs.</li> </ul> <p>Variances between planned and actual costs should be documented, explained, and reviewed. For any elements whose actual costs or schedules differ from the estimate, the estimate should discuss variances and lessons learned.</p> <ul style="list-style-type: none"> <li>Reflects cost-estimating experiences from comparable programs.</li> </ul> <p>The estimate should be based on historical cost estimation data and actual experiences from other comparable programs. These data should be reliable and relevant to the new program.</p>		<ul style="list-style-type: none"> <li>There was no evidence that the cost estimate was updated to reflect changes or actual costs to reflect the current program status. (<i>Not met.</i>) A lack of cost estimate updates interferes with analysis of changes in program costs and hinders collection of cost and technical data to support future estimates. The cost estimate should be updated when the technical baseline changes; otherwise, it will lack credibility. A properly updated cost estimate can provide decision makers with accurate information for assessing alternative decisions.</li> <li>Variances between planned and actual costs, and explanations for the variance, were documented in earned value management data, but no variance for total cost at completion was included in the cost estimate documentation. (<i>Substantially met.</i>) Without a documented comparison between the current estimate (updated with actual costs) and the old estimate, cost estimators cannot determine the level of variance between the two estimates. That is, the estimators cannot see how well they are estimating and how the program is changing over time.</li> <li>There is some evidence that the estimate was based on a historical record of cost-estimating and actual experiences from other analogous programs. However, the reliability, risks, and applicability of the analogous data were not addressed. Also, comparisons were not made between ADS-B and analogous programs. (<i>Minimally met.</i>) Historical data provide the cost estimator with insight into actual costs on similar programs, including any cost growth that occurred after the original estimate. As a result, historical data can be used to challenge optimistic assumptions and bring more realism to a cost estimate.</li> </ul>
<p><b>Credible:</b></p> <ul style="list-style-type: none"> <li>Includes a sensitivity analysis that identifies a range of possible costs based on varying inputs.</li> </ul> <p>A sensitivity analysis examines how changes to key assumptions and inputs affect the estimate. The estimate should identify key cost drivers, examine their parameters and assumptions, and re-estimate the total cost by varying each parameter between its minimum and maximum range.</p>	Partially met	<ul style="list-style-type: none"> <li>While a high-level sensitivity analysis was provided to the Joint Resources Council for the equipage cost driver, other key cost drivers, assumptions, and data inputs were not varied. (<i>Minimally met.</i>) Because uncertainty cannot be avoided, it is necessary to identify the cost elements that represent the most risk. A sensitivity analysis reveals how the cost estimate is affected by a change in a single assumption, which helps the cost estimator understand the extent to which each variable affects the cost estimate. Any sources of variation should be well-documented and traceable.</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>Contains a risk and uncertainty analysis.</li> </ul> <p>A risk and uncertainty analysis recognizes the potential for error and attempts to quantify it by identifying the effects of changing key cost drivers.</p> <ul style="list-style-type: none"> <li>Includes cross-checking of major cost elements.</li> </ul> <p>A cross-check is done by using a different method to see if it produces similar results.</p> <p>Includes a comparison to an independent cost estimate conducted by another organization.</p> <p>A second, independent cost estimate should be performed by an organization outside of the program office's influence. It should be based on the same technical baseline, ground rules, and assumptions as the original estimate.</p>		<ul style="list-style-type: none"> <li>A risk analysis for each cost element was performed but the risk data were essentially the same for each element and there was no documentation of correlations of risks between the cost elements. (<i>Substantially met.</i>)</li> <li>Contains no evidence that cross-checks were performed. (<i>Not met.</i>) The main purpose of cross-checking is to determine whether alternative methods produce similar results. If so, then confidence in the estimate increases, leading to greater credibility.</li> <li>A rough order-of-magnitude estimate was performed by another organization but addressed only a part of the total program. (<i>Partially met.</i>) An independent cost estimate is considered one of the best and most reliable estimate validation methods. It provides an independent view of expected program costs that tests the program office's estimate for reasonableness. Without an independent cost estimate, decisions makers will lack insight into a program's potential costs because independent cost estimates frequently use different methods and are less burdened with organizational bias.</li> </ul>

Source: GAO analysis of FAA's ADS-B cost estimate.

Table 9: GAO's Analysis of FAA's CATMT Cost Estimates

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p><b>Well-documented:</b></p> <ul style="list-style-type: none"> <li>Captures the source data used, the reliability of the data, and how the data were made compatible with other data in the estimate; Data should be collected from primary sources. The source, content, time, and units should be adequately documented. The data should also be analyzed to determine accuracy and reliability, and to identify cost drivers.</li> <li>Describes the calculations and the methodology used to derive each element's cost. Documentation should describe what calculation methods are used, as well as how they were applied, and explain any anomalies.</li> <li>Describes how the estimate was developed. The data supporting the estimate should be available and adequately documented so that the estimate can be easily documented to reflect actual costs or program changes.</li> <li>Discusses the technical baseline description. A technical baseline description provides a common definition of the program, including</li> </ul>	<p>Partially met</p>	<ul style="list-style-type: none"> <li>Lists data sources, the majority of which were subject matter experts. No details on the qualifications or background of these experts were provided, and there was no documentation about the reliability of the data. (<i>Partially met.</i>) Data are the foundation of every cost estimate. Depending on data quality, an estimate can range anywhere from a mere guess to a highly defensible cost position. Data are often in many different forms and need to be adjusted before being used. The cost estimator needs information about the source and reliability of the data in order to know whether the data collected can be used directly or need to be modified.</li> <li>Documentation does not fully explain how FAA derived estimated costs. For example, FAA relied on expert opinion to estimate several costs based on a percentage of other cost elements but provided no historical data to back up the opinions. There was also no supporting information for the software cost estimates. (<i>Partially met.</i>) Poorly documented cost estimates can cause a program's credibility to suffer because the documentation cannot explain the rationale for the methodology or the calculations. Estimates that lack sufficient documentation are not useful for updates or information sharing and can hinder understanding and proper use.</li> <li>Cost calculations are described in detail for fiscal year 2014, but documentation was missing for fiscal years 2015 through 2022. As a result, the documentation does not provide enough detail so that a cost analyst unfamiliar with the program could understand what was done and replicate it. (<i>Partially met.</i>) Without good documentation, management and oversight officials will not be convinced that the estimate is credible; supporting data, lessons learned, and reasons why costs changed will not be available for future use; questions about the approach or data used to create the estimate cannot be answered; and the scope of the analysis cannot be thoroughly defined.</li> <li>Many inconsistencies were found between the cost basis of the estimate document and the cost model. (<i>Partially met.</i>) Because the technical baseline is intended to serve as the basis for developing a cost estimate, it should be</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p>detailed technical, program, and schedule descriptions of the system, for a cost estimate to be built on. The data in the technical baseline should be consistent with the cost estimate.</p> <ul style="list-style-type: none"> <li>Provides evidence of management review and acceptance.</li> </ul> <p>There should be a briefing to management, including a clear explanation of how the cost estimate was derived. Management's acceptance of the cost estimate should be documented.</p>		<p>discussed in the cost estimate documentation. Without a technical baseline, the cost estimate will not be based on a comprehensive program description and will lack specific information about technical and program risks.</p> <ul style="list-style-type: none"> <li>The estimate was presented to the Joint Resources Council management during an investment decision briefing. The briefing included a program overview, life-cycle costs over time, risk analysis, budget justification, and recommendation. The briefing did not include detail on the estimating methodology for each cost element; sensitivity, risk, and uncertainty analysis; or an affordability analysis. <i>(Substantially met.)</i></li> </ul>
<p><b>Comprehensive:</b></p> <ul style="list-style-type: none"> <li>Includes all life-cycle costs.</li> </ul> <p>A life-cycle cost estimate provides a complete and structured accounting of all resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. It should cover the program from its inception through its retirement.</p> <ul style="list-style-type: none"> <li>Completely defines the program, reflects the current schedule, and is technically reasonable.</li> </ul> <p>The cost estimate should be based on a documented technical baseline description, which provides a common definition of the program—including detailed technical, program, and schedule descriptions of the system.</p> <ul style="list-style-type: none"> <li>Has a product-oriented work breakdown structure, and is traceable to the program's technical scope, at an appropriate level of detail.</li> </ul> <p>A work breakdown structure provides a basic framework for a variety of related activities like estimating costs, developing schedules, identifying resources and potential risks, and providing the means for measuring program status using earned value management. It is product-oriented if it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component.</p> <ul style="list-style-type: none"> <li>Documents all cost-influencing ground rules and assumptions.</li> </ul> <p>Cost estimates are typically based on limited information and therefore need to be bound by ground rules and assumptions. Ground rules are a set of estimating standards that provide</p>	<p>Substantially met</p>	<ul style="list-style-type: none"> <li>Includes costs from fiscal year 2009 through fiscal year 2022 for both government and contractor efforts across all phases of the program. However, some government labor costs for in-service management were not included. <i>(Substantially met.)</i></li> <li>Reflects many detailed technical requirements, but no single technical baseline was provided. <i>(Substantially met.)</i></li> <li>Reflects FAA's standard work breakdown structure, which does not follow a product-oriented work breakdown structure. Instead, it breaks work down into functional categories. The cost estimate work breakdown structure matches the schedule work breakdown structure. However, we found no evidence that the work breakdown structure had been updated as the program became better defined. <i>(Substantially met.)</i></li> <li>The estimate provides a limited set of cost-influencing ground rules and assumptions; however, many of the assumptions did not include supporting data. In addition, there was little evidence risks were identified if the assumption did not hold. <i>(Partially met.)</i> Unless</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
guidance and common definitions, while assumptions are judgments about past, present, or future conditions that may affect the estimate.		ground rules and assumptions are clearly documented, the cost estimate will not have a basis for assessing potential risks. Furthermore, the estimate cannot be reconstructed when the original estimators are no longer available.
<b>Accurate:</b> <ul style="list-style-type: none"> <li>• Produces unbiased results.</li> </ul> Cost estimates should have an uncertainty analysis, which determines where the estimate falls against the range of all possible costs.	Partially met	<ul style="list-style-type: none"> <li>• The cost basis of estimate contains low, likely, and high estimates for software lines of code, but the estimate did not have a similar analysis for every assumption in the cost model. In addition, we found no confidence level associated with the estimate. (<i>Partially met.</i>) A cost estimate is biased if the estimated work is overly conservative or too optimistic. Unless the estimate is based on an assessment of the most likely costs and reflects the degree of uncertainty given all of the risks considered, management will not be able to make good decisions.</li> </ul>
<ul style="list-style-type: none"> <li>• Is properly adjusted for inflation.</li> </ul> Cost data should be adjusted for inflation to ensure that comparisons and projections are valid. Data should also be normalized to constant-year dollars to remove the effects of inflation. <ul style="list-style-type: none"> <li>• Contains few mistakes.</li> </ul> Results should be checked for accuracy, double counting, and omissions.		<ul style="list-style-type: none"> <li>• The cost estimate was adjusted for inflation correctly and the source data for the inflation indexes were provided. (<i>Met.</i>)</li> </ul>
<ul style="list-style-type: none"> <li>• Is regularly updated to reflect significant program changes.</li> </ul> The cost estimate should be updated to reflect significant program changes, such as changes to schedules or other assumptions. Updates should also reflect actual costs so that the estimate always reflects the current program status.		<ul style="list-style-type: none"> <li>• While we found no apparent mistakes in the calculations, as stated earlier, there were inconsistencies in costs between the cost model and the cost basis of estimate documentation. (<i>Partially met.</i>) Validating that a cost estimate is accurate requires thoroughly understanding and investigating how the cost model was constructed. Without access to a detailed cost model and estimate details, calculations may not be accurate or expressed consistently,</li> <li>• We found no evidence that the cost estimate was updated to reflect changes or actual costs. (<i>Not met.</i>) A lack of cost estimate updates interferes with analysis of changes in program costs and hinders collection of cost and technical data to support future estimates. The cost estimate should be updated when the technical baseline changes; otherwise, it will lack credibility. A properly updated cost estimate can provide decision makers with accurate information for assessing alternative decisions.</li> </ul>
<ul style="list-style-type: none"> <li>• Documents and explains variances between planned and actual costs.</li> </ul> Variances between planned and actual costs should be documented, explained, and reviewed. For any elements whose actual costs or		<ul style="list-style-type: none"> <li>• There was no documentation of variances between planned and actual costs. (<i>Not met.</i>) Without a documented comparison between the current estimate (updated with actual costs) and the old estimate, the cost estimators cannot</li> </ul>



**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p>schedules differ from the estimate, the estimate should discuss variances and lessons learned.</p> <ul style="list-style-type: none"> <li>Reflects cost-estimating experiences from comparable programs.</li> </ul> <p>The estimate should be based on historical cost estimation data and actual experiences from other comparable programs. These data should be reliable and relevant to the new program.</p>		<p>determine the level of variance between the two estimates. That is, the estimators cannot see how well they are estimating and how the program is changing over time.</p> <ul style="list-style-type: none"> <li>There is some evidence that the estimate was based on a historical record of cost-estimating and actual experiences from other analogous programs. For example, software costs were estimated using function points and the the Constructive Cost Model (COCOMO). However, no comparison was made between CATMT and other comparable FAA programs for the purpose of the validating the CATMT estimate. (<i>Minimally met.</i>) Historical data provide the cost estimator with insight into actual costs on similar programs, including any cost growth that occurred after the original estimate. As a result, historical data can be used to challenge optimistic assumptions and bring more realism to a cost estimate.</li> </ul>
<p><b>Credible:</b></p> <ul style="list-style-type: none"> <li>Includes a sensitivity analysis that identifies a range of possible costs based on varying inputs;</li> </ul> <p>A sensitivity analysis examines how changes to key assumptions and inputs affect the estimate. The estimate should identify key cost drivers, examine their parameters and assumptions, and re-estimate the total cost by varying each parameter between its minimum and maximum range.</p> <ul style="list-style-type: none"> <li>Contains a risk and uncertainty analysis.</li> </ul> <p>A risk and uncertainty analysis recognizes the potential for error and attempts to quantify it by identifying the effects of changing key cost drivers.</p> <ul style="list-style-type: none"> <li>Cross-checking of major cost elements.</li> </ul> <p>A cross-check is done by using a different method to see if it produces similar results.</p>	Minimally met	<ul style="list-style-type: none"> <li>A sensitivity analysis was provided on the discount rate used in the economic analysis, but other key cost drivers like software design and development, as well as assumptions and data inputs, were not varied. (<i>Minimally met.</i>) Because uncertainty cannot be avoided, it is necessary to identify the cost elements that represent the most risk. A sensitivity analysis reveals how the cost estimate is affected by a change in a single assumption, which helps the cost estimator understand the extent to which each variable affects the cost estimate. Any sources of variation should be well-documented and traceable.</li> <li>The documentation discusses some aspects of a risk and uncertainty analysis, such as risk percents, but lacks some results, such as the confidence level for the cost estimate. (<i>Partially met.</i>) The program estimate should reflect the degree of uncertainty, so that a level of confidence can be provided to management about the estimate. An estimate without risk and uncertainty analysis is unrealistic because it does not assess the variability in the cost estimate from such effects as schedules slipping, missions changing, and proposed solutions not meeting users' needs.</li> <li>The documentation states that a function point analysis and a historical cost estimation method were used to cross-check the software cost estimate. However, a comparison of the model results was not provided, and we could not</li> </ul>

Appendix III: Assessments of Four FAA  
Program Cost Estimates

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>A comparison to an independent cost estimate conducted by another organization.</li> </ul> <p>A second, independent cost estimate should be performed by an organization outside of the program office's influence. It should be based on the same technical baseline, ground rules, and assumptions as the original estimate.</p>		<p>identify other examples of cross-checks. <i>(Minimally met.)</i> The main purpose of cross-checking is to determine whether alternative methods produce similar results. If so, then confidence in the estimate increases, leading to greater credibility.</p> <ul style="list-style-type: none"> <li>There was no evidence that an independent cost estimate was conducted. <i>(Not met.)</i> An independent cost estimate is considered one of the best and most reliable estimate validation methods. It provides an independent view of expected program costs that tests the program office's estimate for reasonableness. Without an independent cost estimate, decision makers will lack insight into a program's potential costs because independent cost estimates frequently use different methods and are less burdened with organizational bias.</li> </ul>

Source: GAO analysis of FAA's CATMT cost estimate.

Table 10: GAO's Analysis of FAA's SWIM Cost Estimates

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p><b>Well-documented:</b></p> <ul style="list-style-type: none"> <li>Captures the source data used, the reliability of the data, and how the data were made compatible with other data in the estimate. Data should be collected from primary sources. The source, content, time, and units should be adequately documented. Data should also be analyzed to determine accuracy and reliability, and to identify cost drivers.</li> <li>Describes the calculations and the methodology used to derive each element's cost. Documentation should describe what calculation methods are used, as well as how they were applied, and explain any anomalies.</li> <li>Describes how the estimate was developed. The data supporting the estimate should be available and adequately documented so that the estimate can be easily documented to reflect actual costs or program changes.</li> <li>Discusses the technical baseline description. A technical baseline description provides a common definition of the program, including detailed technical, program, and schedule descriptions of the system, for a cost estimate to be built on. The data in the technical baseline should be consistent with the cost estimate.</li> <li>Provides evidence of management review and acceptance. There should be a briefing to management, including a clear explanation of how the cost estimate was derived. Management's acceptance of the cost estimate should be documented.</li> </ul>	Substantially met	<ul style="list-style-type: none"> <li>The documentation captures the majority of the data sources used. However, it does not provide specific backup of the data sources and does not capture the reliability or the accuracy of the data. <i>(Partially met.)</i> Data are the foundation of every cost estimate. Depending on data quality, an estimate can range anywhere from a mere guess to a highly defensible cost position. Data are often in many different forms and need to be adjusted before being used. The cost estimator needs information about the source and reliability of the data in order to know whether the data collected can be used directly or need to be modified.</li> <li>The documentation describes in detail the methodology, calculations, basis of data, and quantities used to determine most of the cost estimate. However, there is little detail provided about the cost elements that used the analogy and parametric estimating methodologies. <i>(Substantially met.)</i></li> <li>The documentation provides enough detail so that a cost analyst unfamiliar with the program could understand what was done and replicate it; however, there was no sensitivity analysis performed. <i>(Substantially met.)</i></li> <li>The technical details contained within the basis of estimate are consistent with the corresponding details in the technical baseline, but there is no mapping between the basis of estimate, the technical baseline, and the life-cycle cost estimate. <i>(Substantially met.)</i></li> <li>The estimate was presented to management during a briefing and was accepted by the issuance of a Joint Resources Council record of decision. The briefing included a program overview, a comparison between the 2007 and 2009 estimates, a breakout of cost drivers, and a business case analysis. In addition, a software estimate briefing discussed the estimating methodology used. However, more specific items, such as data sources, risk information, and a comparison to an independent cost estimate were not provided. <i>(Partially met.)</i> A cost estimate is not considered valid until management has approved it. It is imperative that</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p><b>Comprehensive:</b></p> <ul style="list-style-type: none"> <li>Includes all life-cycle costs.</li> </ul> <p>A life-cycle cost estimate provides a complete and structured accounting of all resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. It should cover the program from its inception through its retirement.</p> <ul style="list-style-type: none"> <li>Completely defines the program, reflects the current schedule, and is technically reasonable.</li> </ul> <p>The cost estimate should be based on a documented technical baseline description, which provides a common definition of the program—including detailed technical, program, and schedule descriptions of the system.</p> <ul style="list-style-type: none"> <li>Has a product-oriented work breakdown structure, and is traceable to the program's technical scope, at an appropriate level of detail.</li> </ul> <p>A work breakdown structure provides a basic framework for a variety of related activities like estimating costs, developing schedules, identifying resources and potential risks, and providing the means for measuring program status using earned value management. It is product-oriented if it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component.</p> <ul style="list-style-type: none"> <li>Documents all cost-influencing ground rules and assumptions.</li> </ul> <p>Cost estimates are typically based on limited information and therefore need to be bound by ground rules and assumptions. Ground rules are a set of estimating standards that provide guidance and common definitions, while assumptions are judgments about past, present, or future conditions that may affect the estimate.</p>	Substantially met	<p>management understand how the estimate was developed, including the risks associated with the underlying data and methods.</p> <ul style="list-style-type: none"> <li>Includes all life-cycle costs for each of the seven SWIM Implementing Programs (SIP) from fiscal year 2011 through fiscal year 2033. However, costs for fiscal year 2009 and fiscal year 2010 were not included because these costs were already baselined. The cost estimate also includes both government and contractor efforts across all phases of the program. (<i>Substantially met.</i>)</li> <li>Reflects many detailed technical requirements, including scope and schedule requirements, but no single technical baseline was provided. Also, there was no evidence that the technical baseline requirements had been updated. (<i>Substantially met.</i>)</li> <li>Reflects FAA's standard work breakdown structure, which does not follow a product-oriented work breakdown structure. Instead, it breaks work down into functional categories. The cost estimate work breakdown structure also does not match either the schedule or the earned value management work breakdown structure. In addition, we found no evidence that the work breakdown structure had been updated as the program became better defined. (<i>Partially met.</i>) Without a work breakdown structure, the program lacks a framework to develop a schedule and cost plan that can be used to easily track technical accomplishments. A standard, product-oriented work breakdown structure facilitates the tracking of resource allocations and expenditures, which can give FAA <i>insight</i> into reliable estimates of the cost of similar programs in the future.</li> <li>The estimate documents all cost-influencing ground rules and assumptions; however, in several instances, not all of the data sources supporting each were provided. In addition, while there was a risk adjustment section in the documentation, the majority of the risk adjustments were based on the judgment of the SWIM program office team. (<i>Partially met.</i>) Unless ground rules and assumptions are clearly documented, the cost estimate will not have a basis for assessing potential risks. Furthermore, the estimate cannot be reconstructed when the original estimators are no longer available.</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p><b>Accurate:</b></p> <ul style="list-style-type: none"> <li>Produces unbiased results.</li> </ul> <p>Cost estimates should have an uncertainty analysis, which determines where the estimate falls against the range of all possible costs.</p> <ul style="list-style-type: none"> <li>Is properly adjusted for inflation.</li> </ul> <p>Cost data should be adjusted for inflation to ensure that comparisons and projections are valid. Data should also be normalized to constant-year dollars to remove the effects of inflation.</p> <ul style="list-style-type: none"> <li>Contains few mistakes.</li> </ul> <p>Results should be checked for accuracy, double counting, and omissions.</p> <ul style="list-style-type: none"> <li>Is regularly updated to reflect significant program changes.</li> </ul> <p>The cost estimate should be updated to reflect significant program changes, such as changes to schedules or other assumptions. Updates should also reflect actual costs so that the estimate always reflects the current program status.</p> <ul style="list-style-type: none"> <li>Documents and explains variances between planned and actual costs.</li> </ul> <p>Variances between planned and actual costs should be documented, explained, and reviewed. For any elements whose actual costs or schedules differ from the estimate, the estimate should discuss variances and lessons learned.</p>	<p>Partially met</p>	<ul style="list-style-type: none"> <li>The cost basis of estimate contains minimum, most likely and maximum values to model uncertainties for each cost element. No historical data were provided to support any of the risk adjustments, and no level of confidence was associated with the estimate. <i>(Minimally met.)</i> A cost estimate is biased if the estimated work is overly conservative or too optimistic. Unless the estimate is based on an assessment of the most likely costs and reflects the degree of uncertainty given all of the risks considered, its usefulness to management for making decisions is limited.</li> <li>The cost estimate was adjusted for inflation correctly and the source data for the inflation indexes were provided for all elements except for government salaries. <i>(Substantially met.)</i></li> <li>The estimate contains no mistakes, and we found no evidence of double counting or omissions. Additionally, the documentation, equations, and results were consistent between the documentation and the cost model. <i>(Met.)</i></li> <li>There was no evidence that the cost estimate was recently updated to reflect changes or actual costs to reflect current program status. The cost estimate was updated in 2009 from the original 2007 estimate, which requested funding only for fiscal year 2009 through fiscal year 2010. <i>(Minimally met.)</i> A lack of cost estimate updates interferes with analysis of changes in program costs and hinders collection of cost and technical data to support future estimates. The cost estimate should be updated when the technical baseline changes; otherwise, it will lack credibility. A properly updated cost estimate can provide decision makers with accurate information for assessing alternative decisions.</li> <li>Earned value management system reports for July 2010 through December 2010 contained actual costs and variances. However, no recent earned value management reports captured actual costs and variances. In addition, because the cost estimate work breakdown structure did not match the earned value management work breakdown structure, it would be difficult to track variances from the earned value management system back to the cost estimate. <i>(Minimally met.)</i> Without a documented comparison between the current estimate (updated with actual costs) and the old</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>Reflects cost estimating experiences from comparable programs.</li> </ul> <p>The estimate should be based on a historical cost estimation data and actual experiences from other comparable programs. These data should be reliable and relevant to the new program.</p>		<p>estimate, cost estimators cannot determine the level of variance between the two estimates. That is, the estimators cannot see how well they are estimating and how the program is changing over time.</p> <ul style="list-style-type: none"> <li>There is some evidence that the estimate was based on a historical record of cost estimating. For example, per diem and hotel rates were obtained from a government website; however, no such comparable data were provided for other cost elements. (<i>Minimally met.</i>) Historical data provide the cost estimator with insight into actual costs on similar programs, including any cost growth that occurred after the original estimate. As a result, historical data can be used to challenge optimistic assumptions and bring more realism to a cost estimate.</li> </ul>
<p><b>Credible:</b></p> <ul style="list-style-type: none"> <li>Includes a sensitivity analysis that identifies a range of possible costs based on varying inputs.</li> </ul> <p>A sensitivity analysis examines how changes to key assumptions and inputs affect the estimate. The estimate should identify key cost drivers, examine their parameters and assumptions, and re-estimate the total cost by varying each parameter between its minimum and maximum range.</p> <ul style="list-style-type: none"> <li>Contains a risk and uncertainty analysis.</li> </ul> <p>A risk and uncertainty analysis recognizes the potential for error and attempts to quantify it by identifying the effects of changing key cost drivers.</p> <ul style="list-style-type: none"> <li>Includes cross-checking of major cost elements.</li> </ul> <p>A cross-check is done by using a different method to see if it produces similar results.</p>	Minimally met	<ul style="list-style-type: none"> <li>While an independent evaluation includes a breakout of cost drivers as a percentage of total cost, the cost estimate documentation does not show evidence that a sensitivity analysis was performed. (<i>Minimally met.</i>) Because uncertainty cannot be avoided, it is necessary to identify the cost elements that represent the most risk. A sensitivity analysis reveals how the cost estimate is affected by a change in a single assumption, which helps the cost estimator to understand the extent to which each variable affects the cost estimate. Any sources of variation should be well-documented and traceable.</li> <li>The documentation discusses some aspects of a risk and uncertainty analysis, and each element receives a risk adjustment. A risk briefing that showed cost risk ranges for all of the SIPs were also provided. However, the documentation did not discuss what level of confidence was associated with the cost estimate. (<i>Partially met.</i>) The program estimate must reflect the degree of uncertainty, so that a level of confidence can be provided to management about the estimate. An estimate without risk and uncertainty analysis is unrealistic because it does not assess the variability in the cost estimate from such effects as schedules slipping, missions changing, and proposed solutions not meeting users' needs.</li> <li>There was no evidence that cross-checks were performed. (<i>Not met.</i>) The main purpose of cross-checking is to determine whether alternative methods produce similar results. If so, then confidence in the estimate increases, leading to greater credibility.</li> </ul>

Appendix III: Assessments of Four FAA  
Program Cost Estimates

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"><li>Contains a comparison to an independent cost estimate conducted by another organization.</li></ul> <p>A second, independent cost estimate should be performed by an organization outside of the program office's influence. It should be based on the same technical baseline, ground rules, and assumptions, as the original estimate.</p>		<ul style="list-style-type: none"><li>There was no evidence that an independent cost estimate was conducted; however, there was an independent assessment briefing that showed a review of all SIP cost estimates. (<i>Minimally met.</i>) An independent cost estimate is considered one of the best and most reliable estimate validation methods. It provides an independent view of expected program costs that tests the program office's estimate for reasonableness. Without an independent cost estimate, decisions makers will lack insight into a program's potential costs because independent cost estimates frequently use different methods and are less burdened with organizational bias.</li></ul>

Source: GAO analysis of FAA's SWIM cost estimate.

Table 11: GAO's Analysis of FAA's WAAS Cost Estimates

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p><b>Well-documented:</b></p> <ul style="list-style-type: none"> <li>Captures the source data used, the reliability of the data, and how the data were made compatible with other data in the estimate.</li> </ul> <p>Data should be collected from primary sources. The source, content, time, and units should be adequately documented. Data should also be analyzed to determine accuracy and reliability, and to identify cost drivers.</p> <ul style="list-style-type: none"> <li>Describes the calculations and the methodology used to derive each element's cost.</li> </ul> <p>Documentation should describe what calculation methods were used, as well as how they were applied, and explain any anomalies.</p> <ul style="list-style-type: none"> <li>Describes how the estimate was developed.</li> </ul> <p>The data supporting the estimate should be available and adequately documented so that the estimate can be easily documented to reflect actual costs or program changes.</p> <ul style="list-style-type: none"> <li>Discusses the technical baseline description.</li> </ul> <p>A technical baseline description provides a common definition of the program, including detailed technical, program, and schedule descriptions of the system, for a cost estimate to be built on. The data in the technical baseline should be consistent with the cost estimate.</p> <ul style="list-style-type: none"> <li>Provides evidence of management review and acceptance.</li> </ul> <p>There should be a briefing to management, including a clear explanation of how the cost estimate was derived. Management's acceptance of the cost estimate should be</p>	<p>Substantially met</p>	<ul style="list-style-type: none"> <li>The documentation captures the majority of the data sources used; however, it does not capture the reliability or the accuracy of the data. (<i>Partially met.</i>) Data are the foundation of every cost estimate. Depending on data quality, an estimate can range anywhere from a mere guess to a highly defensible cost position. Data are often in many different forms and need to be adjusted before being used. The cost estimator needs information about the source and reliability of the data in order to know whether the data collected can be used directly or need to be modified.</li> <li>The documentation describes in great detail the methodology, calculations, basis of data, and quantities used in the cost estimate. However, estimates for some elements were based on the judgment of subject matter experts. (<i>Substantially met.</i>)</li> <li>The documentation provides enough detail so that a cost analyst unfamiliar with the program could understand what was done and replicate it. There was no sensitivity analysis performed, and some cost elements did not have a risk adjustment because they were considered ongoing efforts. (<i>Substantially met.</i>)</li> <li>The technical details contained within the basis of the estimate are consistent with the corresponding details in the technical baseline. However, the cost estimate does not reference the technical baseline documents, and there is no mapping between the basis of estimate, the technical baseline, and the cost estimate. (<i>Substantially met.</i>)</li> <li>The estimate was presented to management during a briefing and was accepted by the issuance of a Joint Resources Council record of decision. The briefing included a program overview and specific details about the service area, previous baselines, and a cost benefit analysis. In addition, information about equipment procurement, the schedule, and the spending plan were also presented along with a risk analysis, an affordability analysis, and an independent evaluation. However, more specific items such as data sources for each cost element, a sensitivity analysis, an uncertainty analysis, and a comparison against an independent cost estimate were not provided. (<i>Substantially met.</i>)</li> </ul>



**Appendix III: Assessments of Four FAA  
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Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<p>documented.</p> <p><b>Comprehensive:</b></p> <ul style="list-style-type: none"> <li>Includes all life-cycle costs.</li> </ul> <p>A life-cycle cost estimate provides a complete and structured accounting of all resources and associated cost elements required to develop, produce, deploy, and sustain a particular program. It should cover the program from its inception through its retirement.</p> <ul style="list-style-type: none"> <li>Completely defines the program, reflects the current schedule, and is technically reasonable.</li> </ul> <p>The cost estimate should be based on a documented technical baseline description, which provides a common definition of the program, including detailed technical, program, and schedule descriptions of the system.</p> <ul style="list-style-type: none"> <li>Has a product-oriented work breakdown structure, and is traceable to the program's technical scope, at an appropriate level of detail.</li> </ul> <p>A work breakdown structure provides a basic framework for a variety of related activities like estimating costs, developing schedules, identifying resources and potential risks, and providing the means for measuring program status using earned value management. It is product-oriented if it allows a program to track cost and schedule by defined deliverables, such as a hardware or software component.</p> <ul style="list-style-type: none"> <li>Documents all cost-influencing ground rules and assumptions.</li> </ul> <p>Cost estimates are typically based on limited information and therefore need to be bound</p>	<p>Substantially met</p>	<ul style="list-style-type: none"> <li>Includes all life-cycle costs from fiscal year 2009 through fiscal year 2028 except sunk costs and disposition costs. The cost estimate covers both government and contractor efforts for the solution development, implementation, and in-service management phases of the program. (<i>Partially met.</i>) A life-cycle cost estimate should encompass all past, present, and future costs for every aspect of the program, regardless of funding source—including all government and contractor costs. Life-cycle cost estimates can enhance decision making by allowing for design trade-off studies to be evaluated on a total cost basis as well as on a technical and performance basis.</li> <li>Reflects many detailed technical requirements, including scope and schedule requirements, but no single technical baseline was provided. Consistent with best practices, we found evidence that the technical baseline requirements had been updated to reflect technical, program, and schedule changes to the program. (<i>Substantially met.</i>)</li> <li>Reflects FAA's standard work breakdown structure, which does not follow a product-oriented work breakdown structure. Instead, it breaks work down into functional categories. The cost estimate work breakdown structure also does not match either the schedule or the earned value management work breakdown structure; however, there was a mapping from the schedule work breakdown structure to the cost work breakdown structure. In addition, we found evidence that the work breakdown structure had been updated as the program became better defined. (<i>Partially met.</i>) Without a work breakdown structure, the program lacks a framework to develop a schedule and cost plan that can be used to easily track technical accomplishments. A standard, product-oriented work breakdown structure facilitates the tracking of resource allocations and expenditures, which can give the agency a basis to reliably estimate the cost of future similar programs.</li> <li>The estimate documents all cost-influencing ground rules and assumptions. In addition, there were additional ground rules and assumptions found in the technical baseline's authoritative</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
by ground rules and assumptions. Ground rules are a set of estimating standards that provide guidance and common definitions, while assumptions are judgments about past, present, or future conditions that may affect the estimate.		references. However, in several instances, not all of the data sources supporting the assumptions were provided. In addition, while there was a risk adjustment section in the documentation, the majority of the risk adjustments were blank, based on the assumption that the costs were well defined by this point. <i>(Substantially met.)</i>
<p><b>Accurate:</b></p> <ul style="list-style-type: none"> <li>• Produces unbiased results.</li> </ul> <p>Cost estimates should have an uncertainty analysis, which determines where the estimate falls against the range of all possible costs.</p> <p>Is properly adjusted for inflation.</p> <p>Cost data should be adjusted for inflation to ensure that comparisons and projections are valid. Data should also be normalized to constant-year dollars to remove the effects of inflation.</p> <p>Contains few mistakes.</p> <p>Results should be checked for accuracy, double counting, and omissions.</p> <ul style="list-style-type: none"> <li>• Is regularly updated to reflect significant program changes.</li> <li>• The cost estimate should be updated to reflect significant program changes, such as changes to schedules or other assumptions. Updates should also reflect actual costs so that the estimate always reflects the current program status.</li> <li>• Documents and explains variances between planned and actual costs.</li> <li>• Variances between planned and actual costs should be documented, explained, and reviewed. For any elements whose actual costs or schedules differ from the estimate, the estimate should discuss variances and lessons learned.</li> <li>• Reflects cost estimating experiences from comparable programs.</li> </ul> <p>The estimate should be based on a historical cost estimation data and actual experiences from other comparable programs. These data should be reliable and relevant to the new program.</p>	Partially met	<ul style="list-style-type: none"> <li>• A minimal uncertainty analysis was performed for select cost elements with an 80 percent confidence level reported. No analysis was done to show the accuracy of the data sources used for this analysis. <i>(Minimally met.)</i> A cost estimate is biased if the work estimate is overly conservative or too optimistic. Unless the estimate is based on an assessment of the most likely costs and reflects the degree of uncertainty given all of the risks considered, management will not be able to make good decisions.</li> <li>• The cost estimate was adjusted for inflation correctly, and the source data for the inflation indexes were provided. <i>(Met.)</i></li> <li>• The estimate contains no mistakes, and we found no evidence of double counting or omissions. Additionally, the documentation, equations, and results were consistent between the documentation and the cost model. <i>(Met.)</i></li> <li>• There was evidence that the cost estimate was updated to reflect changes in technical and program requirements. For example, the WAAS program has undergone four rebaselines from fiscal year 1994 through fiscal year 2009. During each rebaseline, the cost estimate was updated. However, the cost model is not updated on a frequent basis. It is only updated to reflect major changes in technical and program requirements. There was no evidence that the cost estimate was updated with actual costs. <i>(Partially met.)</i> A lack of cost estimate updates interferes with analysis of changes in program costs and hinders collection of cost and technical data to support future estimates. The cost estimate should be updated when the technical baseline changes; otherwise, it will lack credibility. A properly updated cost estimate can provide decision makers with accurate information for assessing alternative decisions.</li> <li>• Earned value management system reports for November 2008 through February 2009 contained actual costs and variances. However,</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
		<p>no recent earned value management reports captured actual costs and variances. In addition, because the cost estimate work breakdown structure did not match the earned value management work breakdown structure, updating the cost estimate would not be a straightforward effort. (<i>Partially met.</i>) Without a documented comparison between the current estimate (updated with actual costs) and the old estimate, cost estimators cannot determine the level of variance between the two estimates. That is, the estimators cannot see how well they are estimating and how the program is changing over time.</p> <ul style="list-style-type: none"> <li>There is some evidence that the estimate was based on a historical record of cost estimating. For example, software source lines of code were estimated based on analogous historical data, but there was no documentation to support these costs. For the other cost elements, we did not find sufficient documentation of historical costs from comparable programs. (<i>Minimally met.</i>) Historical data provide the cost estimator with insight into actual costs on similar programs, including any cost growth that occurred after the original estimate. As a result, historical data can be used to challenge optimistic assumptions and bring more realism to a cost estimate.</li> </ul>
<p>Credible:</p> <ul style="list-style-type: none"> <li>Includes a sensitivity analysis that identifies a range of possible costs based on varying inputs;</li> </ul> <p>A sensitivity analysis examines how changes to key assumptions and inputs affect the estimate. The estimate should identify key cost drivers, examine their parameters and assumptions, and re-estimate the total cost by varying each parameter between its minimum and maximum range.</p> <ul style="list-style-type: none"> <li>A risk and uncertainty analysis.</li> </ul> <p>A risk and uncertainty analysis recognizes the potential for error and attempts to quantify it by identifying the effects of changing key cost drivers.</p>	Partially met	<ul style="list-style-type: none"> <li>Minimal evidence was provided to show that a sensitivity analysis was provided for some cost elements, such as labor. However, we could not determine if key cost drivers were identified across the entire program or if input ranges were varied. (<i>Minimally met.</i>) Because uncertainty cannot be avoided, it is necessary to identify the cost elements that represent the most risk. A sensitivity analysis reveals how the cost estimate is affected by a change in a single assumption, which helps the cost estimator to understand the extent to which each variable affects the cost estimate. Any sources of variation should be well-documented and traceable.</li> <li>The documentation discusses some aspects of a risk and uncertainty analysis, such as a risk adjustment; however, only a few (4 out of 40) of the cost elements contained detailed documentation to support the risk adjustments. The majority of the cost elements (36 out of 40) did not have any risk adjustments applied. In addition, the documentation did not discuss what</li> </ul>

**Appendix III: Assessments of Four FAA  
Program Cost Estimates**

Characteristic of high-quality cost estimates/assessment criterion/explanation	Extent to which criterion was met	Key examples of rationale for assessment
<ul style="list-style-type: none"> <li>• Cross-checking of major cost elements. A cross-check is done by using a different method to see if it produces similar results.</li> <li>• A comparison to an independent cost estimate conducted by another organization. A second, independent cost estimate should be performed by an organization outside of the program office's influence. It should be based on the same technical baseline, ground rules, and assumptions, as the original estimate.</li> </ul>		<p>level of confidence was associated with the cost estimate. (<i>Partially met.</i>) The program estimate must reflect the degree of uncertainty, so that a level of confidence can be provided to management about the estimate. An estimate without risk and uncertainty analysis is unrealistic because it does not assess the variability in the cost estimate from such effects as schedules slipping, missions changing, and proposed solutions not meeting users' needs.</p> <ul style="list-style-type: none"> <li>• There was minimal evidence that cross-checks were identified. During the fiscal year 2004 rebaseline, the basis of estimate was reviewed by several independent staff, but there was no evidence to supporting specific elements being cross-checked. (<i>Minimally met.</i>) The main purpose of cross-checking is to determine whether alternative methods produce similar results. If so, then confidence in the estimate increases, leading to greater credibility.</li> <li>• There was no evidence that an independent cost estimate was conducted. However, as stated earlier, there was an independent review during the fiscal year 2004 rebaseline; since that time, the cost model has been reviewed several times. For example, in 2007 an independent evaluation analyzed eight cost issues. (<i>Partially met.</i>) An independent cost estimate is considered one of the best and most reliable estimate validation methods. It provides an independent view of expected program costs that tests the program office's estimate for reasonableness. Without an independent cost estimate, decisions makers will lack insight into a program's potential costs because independent cost estimates frequently use different methods and are less burdened with organizational bias.</li> </ul>

Source: GAO analysis of FAA's WAAS cost estimate.

# Appendix IV: Assessments of Four FAA Program Schedules

This appendix provides the results of our analysis of the extent to which the processes and methodologies used to develop and maintain four FAA integrated master schedules meet nine best practices associated with effective schedule estimating. The following tables provide the detailed results of our analyses of the schedules for the Automatic Dependent Surveillance-Broadcast (ADS-B), Collaborative Air Traffic Management Technologies (CATMT), System Wide Information Management (SWIM), and Wide Area Augmentation System (WAAS) programs compared to the nine best practices.

“Not met” means the program provided no evidence that satisfies any portion of the criterion. “Minimally met” means the program provided evidence that satisfies a small portion of the criterion. “Partially met” means the program provided evidence that satisfies about half of the criterion. “Substantially met” means the program provided evidence that satisfies a large portion of the criterion. “Fully met” means the program provided evidence that satisfies the entire criterion.

**Table 12: Extent to Which the ADS-B Schedule Met Best Practices**

Best practice	Explanation	Extent to which criterion was met	GAO analysis
1. Capturing all activities	The schedule should reflect all activities as defined in the project’s work breakdown structure, which defines in detail the work necessary to accomplish a project’s objectives—including activities to be performed by both the owner and the contractors.	Partially met	<p>Our analysis found that detailed activities within the schedule are mapped to a four-level work breakdown structure, an organization breakdown structure, and unique control account numbers. Activities are further mapped to service areas, control account managers, and project leaders. Level-of-effort activities are included in the schedule and are clearly marked as such. In addition, several risk mitigation activities are included in the schedule. For example, activities associated with a contingency plan for the 2011 Mississippi River flood are included.</p> <p>The government owns and maintains the program schedule for the ADS-B program, which covers all government and nonprime contract work through fiscal year 2013. The schedule is planned in 6-month rolling wave periods. Officials stated that they have not requested a detailed schedule deliverable from the prime contractor because the contractor portion represents work performed in the fixed-price subscription phase. The contractor owns a separate schedule that is not a required deliverable</p>

**Appendix IV: Assessments of Four FAA  
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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>to the government. The government integrated master schedule includes prime contractor touch points that are updated monthly according to the contractor's progress. However, without fully integrating all contractor and government activities, we cannot guarantee that the schedule has adequately captured all key activities necessary for the program's completion.</p> <p>Officials stated that work needs to be accomplished in and beyond fiscal year 2014, but the program schedule does not contain long-term planning activities beyond the current FAA-approved baseline. Effort from fiscal year 2015 to fiscal year 2020 is not included in the schedule because the program has no budget until Joint Resources Council approval of the next baseline. However, officials noted that the prime contract extends to 2025. Relevant guidance states that a comprehensive schedule should reflect all activities for a project and recognizes that there can be uncertainties and unknown factors in schedule estimates due to, among other things, limited data.</p>
2. Sequencing all activities	The schedule should be planned so that critical project dates can be met. To meet this objective, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. This helps ensure that interdependencies among activities that collectively lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress.	Minimally met	<p>Our analysis found 207 remaining activities, or work that remains to be accomplished (19 percent), are missing predecessor logic and 289 remaining activities (27 percent) are missing successor logic. These counts include 50 remaining activities (5 percent) that are missing both predecessor and successor logic.</p> <p>In addition, our analysis found a number of activities with dangling logic. Each activity—other than the start and finish milestones—must have its start date driven by a previous activity, and each activity must drive the start date of another activity. Tasks with dangling logic can either carry on indefinitely without affecting downstream activities (finish date has no successor) or must start earlier in order to finish on time (start date has no predecessor). The schedule includes 372 remaining activities, or 34 percent, with dangling successors.</p> <p>The reliability of the schedule is also hindered by the presence of lags and leads (negative lags).</p>

Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>Lags represent the passing of time between activities but are often misused to put activities on a specific date or to insert a buffer for risk. In particular, 22 percent of the remaining activities are affected by at least one lag or lead. Lags should be justified because they cannot have risk or uncertainty. Furthermore, lags often represent work or a delay whose duration is unknown, yet are hard-coded into the schedule. Using lags rather than activities to account for work or to insert a buffer for risks causes problems because lags persist even when activities are delayed. As a result, when activities take longer than planned, the lags may actually distort the true logic of the schedule. Negative lags are generally not valid because negative time is not demonstrable; additionally, a lead implies the ability to predict the finish date of a predecessor activity with certainty. In general, leads can be replaced with straightforward finish-to-start logic once tasks are broken down further.</p> <p>FAA officials said that there is broken and incomplete logic for the detail planning period (Wave "G") that we assessed. They stated that the schedule we evaluated was in transition because of ongoing negotiations with the prime contractor over ADS-B service volume.</p> <p>Having all interdependencies between tasks identified is necessary for the schedule to properly calculate dates and predict changes in the future. Without the correct linkages, tasks that slip early in the schedule do not transmit delays to tasks that should depend on them. When this happens, the schedule will not provide a sufficient basis for understanding the program as a whole, and users of the schedule will lack confidence in the dates and the critical path. Unless complete network logic is established, the schedule cannot predict impacts on the project's planned finish date of, among other things, misallocated resources, delayed tasks, external events, and unrealistic deadlines.</p>

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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
3. Assigning resources to all activities	The schedule should reflect what resources (e.g., labor, materials, and overhead) are needed to do the work, whether all required resources will be available when needed, and whether any funding or time constraints exist.	Substantially met	<p>The ADS-B integrated master schedule is resource-loaded at the work package level by resource name, and contains approximately 250 resources, including both government and nongovernment full-time-equivalents. Each has responsibility for managing the resources at that level. The program office leadership teams define what work will be done in each control account at a high level and which resources are available. The control account manager is then responsible for assigning resources at the work package level. Once the rolling wave planning is approved, resources are assigned accordingly with resource leveling occurring outside of the schedule. Officials use the integrated master schedule to track all resources that are not related to the prime contract (approximately 70 percent of the baseline work).</p> <p>Allocation reports are run during the initial rolling wave planning process to ensure resources are neither underallocated nor overallocated, but are not assessed monthly to track resource allocations along with schedule progress updates. However, allocations are assessed whenever a change request is initiated to ensure resources are available for these additional activities.</p>
4. Establishing the duration of all activities	The schedule should realistically reflect how long each activity will take to execute. In determining the duration of each activity, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be as short as possible and have specific start and end dates. The schedule should be continually monitored to determine when forecasted completion dates differ from planned dates; this information can be used to determine whether schedule variances will affect subsequent work.	Substantially met	<p>Our analysis found that approximately 75 percent of the activities within the detail planning period of the schedule had original durations of 44 days or less, which generally meets best practices. Our analysis also found that all durations are consistently estimated in days and adhere to a standard 5-day workweek that accounts for holidays. Our analysis found no activities scheduled to begin on a weekend. Program officials stated that long-duration planning packages exist in the schedule for the period fiscal year 2012 through fiscal year 2014 and that they hold high-level resources and budget meetings until officials are able to plan future rolling wave periods.</p> <p>Officials stated that duration estimates are based on estimates from responsible control account managers who follow earned value management guidance.</p>



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Best practice	Explanation	Extent to which criterion was met	GAO analysis
5. Integrating the schedule horizontally and vertically	The schedule should be horizontally integrated, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as “hand-offs” and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. The schedule should also be vertically integrated, meaning that the dates for starting and completing activities in the integrated master schedule should be aligned with the dates for supporting tasks and subtasks. Such mapping or alignment among levels enables different groups to work to the same master schedule.	Partially met	<p>However, these estimates are not formally justified or documented in a basis of estimate. The schedule aligns to an earned value management system, and the earned value technique used for each activity is stored in the schedule.</p> <p>The schedule is vertically integrated, with low-level activities being traceable to higher-level summary activities in the work breakdown structure hierarchy. However, our analysis determined that the schedule is not horizontally integrated because of the issues described in Best Practice 2. Officials stated that all logic is not in place for the current detail planning period. Instead, the scheduler has used a combination of soft constraints, lags, and out-of-sequence updates in an attempt to match as closely as possible actual execution of activities while the deployment phase is under negotiation. Horizontal integration demonstrates that the overall schedule is rational, planned in a logical sequence, accounts for the interdependencies of activities, and provides a way to evaluate current status. Therefore, if the schedule lacks horizontal integration, the effects of slipped tasks on downstream work cannot be determined and there will be little confidence in the calculated dates or critical path.</p>
6. Establishing the critical path for all activities	Scheduling software should be used to identify the critical path, which represents the chain of dependent activities with the longest total duration. Establishing a project's critical path is necessary to examine the effects of any activity slipping along this path. Potential problems along or near the critical path should also be identified and reflected in scheduling the duration of high-risk activities.	Not met	<p>Officials stated that there is no critical path in the current schedule because of the incomplete logic noted in Best Practice 2. Officials stated that once the program began deploying service volumes, a critical path was difficult to derive because the contractor has the authority to implement service volumes in any order it chooses. However, now that negotiations for service volumes are complete, program officials plan to begin identifying a critical path to all Office of Management and Budget (OMB) Exhibit 300 (annual performance report) milestones.</p> <p>Without a valid program critical path, management cannot determine which slipped tasks will have detrimental effects on the project finish date and it cannot determine if float within the schedule can be used to mitigate critical tasks by</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
7. Identifying reasonable float	The schedule should identify the float—the amount of time by which a predecessor activity can slip before the delay affects successor activities—so that a schedule’s flexibility can be determined. As a general rule, activities along the critical path have the least float. Total float is the total amount of time by which an activity can be delayed without delaying the project’s completion, if everything else goes according to plan.	Not met	<p>reallocating resources from tasks that can safely slip to tasks that must be completed on time. Until the schedule can produce a true critical path, the program office will not be positioned to provide reliable timeline estimates and it will not be able to identify when problems or changes may occur and what effect they may have on downstream work.</p> <p>Officials stated that because of the missing logic in the current detail planning period, the float represented in the schedule is not realistic. Our analysis confirmed this, as we found many activities within the schedule with extremely high float; that is, unrealistically high float that is greater than 199 days. Specifically, there are 12 (1 percent) in-progress activities and 745 planned activities (69 percent) that are able to slip more than 199 days without affecting the end date of the program.</p> <p>Program officials stated they do not yet monitor float in the schedule because this particular version of the ADS-B schedule is in transition during deployment negotiations with the prime contractor.</p>
8. Conducting a schedule risk analysis	A schedule risk analysis (SRA) should be performed using statistical techniques to predict the level of confidence in meeting a project’s completion date. This analysis focuses not only on critical path activities but also on activities near the critical path, since they can affect the project’s status.	Minimally met	<p>Officials stated that a schedule risk analysis is not part of the rolling wave planning process. They perform uncertainty analysis on the cost estimate, but do not <i>implement it</i> on the schedule. Our analysis found this practice to be minimally met because, as noted in Best Practice 1, risk mitigation activities are entered into the schedule as baseline change requests. The program scheduler does not mark these as risk mitigation activities per se, but the documentation associated with a baseline change request will list the additional activities. An example of a risk mitigation activity is “Boxer Contingency Plan,” which was added for the 2011 flooding of the Mississippi River.</p>

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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
9. Updating the schedule using logic and durations to determine dates	The schedule should be continuously updated using logic and durations to determine realistic start and completion dates for program activities. The schedule should be analyzed continuously for variances to determine when forecasted completion dates differ from planned dates. This analysis is especially important for those variations that affect activities identified as being in a project's critical path and can influence a scheduled completion date.	Substantially met	<p>Our analysis found that the schedule has a valid and current status date. Our analysis also found there are no activities with start or finish dates in the past that are missing actual start and actual finish dates, and there are no activities with actual start and actual finish dates in the future.</p> <p>Contractor updates are received by each control account manager in the form of expected finish dates, so the program scheduler is aware when a task is running late. Because the contractor has the authority to deploy service volumes in any order, officials are not overly concerned about the effect of a late task on the program as a whole. They stated that the control account managers know each service volume negotiated deadline and are aware of the effects of the slipped tasks. However, too many activities slipping into the future may create a bow-wave of effort that the contractor may not have the resources to complete near the expected deployment completion date in fiscal year 2013. In addition, activities should be updated using actual duration or effort and estimates of remaining duration or effort. The scheduling software will calculate the percentage of completed activities and a forecasted finish date based on actual effort and planned effort remaining.</p> <p>Our analysis found 60 activities (6 percent) as occurring out of sequence. That is, activities have started before their predecessor was completed, contrary to the network logic. Out-of-sequence progress should be corrected, either by changing the logical relationships to reflect what has actually happened or stopping work on the successor activity until the predecessor activity is complete (called "retained logic"). FAA officials stated they expect many activities to be done out of sequence as they adjust to the negotiated deployment dates with the contractor. In future rolling waves, as logic is put in place and negotiated dates are firm, they expect less out-of-sequence logic.</p>

Source: GAO analysis of ADS-B schedule.

**Table 13: Extent to Which the CATMT Schedule Met Best Practices**

Best practice	Explanation	Extent to which criterion was met	GAO analysis
1. Capturing all activities	The schedule should reflect all activities as defined in the project's work breakdown structure, which defines in detail the work necessary to accomplish a project's objectives—including activities to be performed by both the owner and the contractors.	Substantially met	<p>The scope of work for the CATMT project, which has no defined end state, is defined in 6-month increments. The schedule is owned and maintained by the prime contractor, who is responsible for capturing all activities authorized in the schedule. The schedule tracks government-furnished information and equipment deliverables and it covers all work in the statement of work. The work breakdown structure maps to a standardized FAA work breakdown structure but is functionally oriented rather than product-oriented in accordance with FAA standards.</p> <p>Our analysis was able to successfully track detail work activities in the schedule to statement of work requirements, contract line item numbers, and task orders.</p>
2. Sequencing all activities	The schedule should be planned so that critical project dates can be met. To meet this objective, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. This helps ensure that interdependencies among activities that collectively lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress.	Partially met	<p>For the 481 remaining activities, or work that remains to be completed, we found few issues affecting the sequencing logic of the schedule. For example, all activities in the schedule had at least one predecessor and one successor activity.</p> <p>However, our analysis found several issues that would affect the ability of the schedule to dynamically forecast future dates. For example, we found three Must Finish On constraints (1 percent of the remaining activities). A Must Finish On constraint means that the task, whether linked or not, must finish on a certain date. That is, it prevents the activity from finishing any earlier or later than a certain date, thereby overwriting network logic. The use of hard constraints is essentially the same as marking a date on a calendar and, therefore, defeats the purpose of using a dynamic scheduling tool. Officials stated that one Must Finish On constraint, the "Ready for Operations" milestone for Release 5, is used to create the critical path through Release 5, a viable reason that was not justified in documentation. Officials provided no justification for the remaining two Must Finish On constraints. We also found 24 Start No Earlier Than constraints (5 percent of the remaining activities). Start No Earlier Than constraints are considered "soft" in that they allow the activity to slip into the future if their predecessor activity is delayed. However, the activity cannot begin earlier than its constraint date. Officials stated that the constraints were justified but only provided justification for 3 of the 24 Start No Earlier Than constraints. For example,</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>officials stated “Tech Refresh Development Tech Ops” is an obsolete task that will be deleted from the schedule and removed from the contract. In addition, officials said a Start No Earlier Than constraint was in place to prevent multiple level-of-effort tasks (management and other oversight related activities that continue until the detail activities they support have been completed) from being identified as critical activities. Activities with constraints typically are substitutes for logic and can mean that the schedule is not well planned and may not be feasible.</p> <p>Our analysis also found 33 tasks with lags (7 percent of the remaining activities), including 28 activities with positive lags and 5 activities with leads (negative lags). According to officials, the lags are justified, but it is not their policy to document justifications. Lags should be justified because they cannot have risk or uncertainty. Lags often represent work or a delay whose duration is unknown, yet are hard-coded into the schedule. Activities represented by lags are not, in fact, risk free. Lags are often used to put activities on a specific date or to insert a buffer for risk. These lags persist even when activities are delayed and use up the buffer. When that happens, the lag may no longer be necessary. Leads are discouraged, as negative time is not demonstrable. Leads can often be replaced by additional tasks and linked using the appropriate scheduling logic. If used improperly, lags can distort float calculations in the schedule and corrupt the calculation of the critical path.</p>
3. Assigning resources to all activities	The schedule should reflect what resources (e.g., labor, materials, and overhead) are needed to do the work, whether all required resources will be available when needed, and whether any funding or time constraints exist.	Substantially met	<p>Our analysis found 48 resources in the schedule; however, resources are actually tracked outside of the schedule in detailed labor hour spreadsheets. Officials said this way of managing resources meets agency criteria. Moreover, they stated that because of the time frame represented by the schedule, the program may have three software releases in progress at any one time, which results in an overlapping of resources. Staffing levels are reviewed during the monthly management review meetings to ensure resources identified by the contractor map to the associated activities in the schedule.</p> <p>Because resources are tracked outside the schedule rather than loaded within the schedule itself, management’s ability to fully determine whether all required resources will be available when needed, and whether any funding or time</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			constraints exist, is hampered. A resource-loaded schedule implies that all required labor and significant materials, equipment, and other costs are assigned to the appropriate activities within the schedule. Assigning resources to activities ensures that resources are used to determine activity durations because resource requirements directly relate to the duration of an activity.
4. Establishing the duration of all activities	The schedule should realistically reflect how long each activity will take to execute. In determining the duration of each activity, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be as short as possible and have specific start and end dates. The schedule should be continually monitored to determine when forecasted completion dates differ from planned dates; this information can be used to determine whether schedule variances will affect subsequent work.	Met	<p>Excluding level-of-effort activities, more than 90 percent of the remaining detailed activities meet best practices for having durations of 44 days or less. In addition, all activities are assigned to standard calendars that account for holidays.</p> <p>In estimating durations, program officials stated that initially they used production rates for software lines of code to help determine durations. Now that the program is in the execution phase, officials have several years of history pertaining to production, industry standards, and defect rates on which to base duration estimates. Officials also said they try to keep the durations as short as possible, but activities such as coding are naturally 3-month-long tasks whose duration cannot artificially be shortened to 44 days.</p>
5. Integrating schedule activities horizontally and vertically	The schedule should be horizontally integrated, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as “hand-offs” and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. The schedule should also be vertically integrated, meaning that the dates for starting and completing activities in the integrated master schedule should be aligned with the dates for supporting tasks and subtasks. Such mapping or alignment among levels enables different groups to work to the same master schedule.	Partially met	<p>Vertical integration—that is, the ability to consistently trace work breakdown structure elements between detailed and summary master schedules—is demonstrated in the schedule because lower-level activities and milestones roll up into higher-level summary activities. In addition, the schedule shows the dependencies between CATMT and other NextGen programs, such as EnRoute Automation Modernization (ERAM) and SWIM. Officials said in order to help manage these dependencies on ERAM and SWIM, CATMT development leads attend ERAM and SWIM weekly meetings and discuss risk dependencies. In addition, officials stated they also track the ERAM and SWIM schedules and any related schedule slips.</p> <p>However, horizontal traceability is hampered by the reliance on date constraints and lags as discussed in Best Practice 2. For example, extending the durations of selected activities in the schedule more than 400 working days had no effect on the project finish date. If the schedule lacks horizontal integration, then the effects of slipped tasks on downstream work cannot be determined and there will be little confidence in the calculated dates or critical path. Any logic errors between detail, intermediate, and summary</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
6. Establishing the critical path for all activities	Scheduling software should be used to identify the critical path, which represents the chain of dependent activities with the longest total duration. Establishing a project's critical path is necessary to examine the effects of any activity slipping along this path. Potential problems along or near the critical path should also be identified and reflected in scheduling the duration of high-risk activities.	Partially met	<p>schedules will cause inconsistent dates between schedules and will cause different expectations between senior management and activity owners.</p> <p>Officials said because of the 6-month spiral development approach, the schedule cannot deliver a single critical path for the entire program. Instead, the critical paths are calculated and based on by software releases. To calculate a critical path by each software release, the prime contractor uses an end constraint on the key deliverable milestone for each software release.</p> <p>At the time of our analysis, officials stated that only work related to Release 5 was subject to a critical path analysis because that was the focus of management. We were able to trace a contiguous critical path for Release 5, beginning with the project status date and ending with the Release 5 finish milestone. However, the validity of the Release 5 critical path is hampered by the existence of seven in-progress and remaining detail activities within Release 5 that have over 1,300 working days of total float. We also determined that a small number of activities outside of Release 5 were currently under way (for example, in other task orders). Because these activities fall outside of Release 5, and therefore outside the purview of a Release 5 critical path analysis, management may not be fully aware of the effect of any delay on these activities.</p> <p>The critical path is directly related to the logical sequencing of events and float calculations. If the schedule is missing dependencies or if activities are not linked correctly, float estimates will be miscalculated. Incorrect float estimates will result in an invalid critical path and will hinder the ability of management to allocate resources from noncritical activities to those that must be completed on time. Without a valid critical path, there is no true program control because management cannot determine which slipped tasks will have detrimental effects on the project finish date. Until the schedule can produce a true critical path, the program office will not be positioned to provide reliable timeline estimates and it will not be able to identify when problems or changes may occur and what effect they may have on downstream work.</p>

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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
7. Identifying reasonable float	The schedule should identify the float—the amount of time by which a predecessor activity can slip before the delay affects successor activities—so that a schedule's flexibility can be determined. As a general rule, activities along the critical path have the least float. Total float is the total amount of time by which an activity can be delayed without delaying the project's completion, if everything else goes according to plan.	Minimally Met	<p>While officials said the schedule does not contain excessive float values and float values are monitored as part of the schedule's health assessment, our analysis found unreasonable amounts of total float throughout the schedule. For example, 325 (68 percent) of the 481 remaining activities have float values greater than 1,000 days. These unreasonable float values are due mostly to activities being tied to the project finish milestone, which is constrained to start no earlier than July 1, 2016. Interim milestones that are scheduled to finish earlier, such as those marking the end of task orders, are tied to the project finish milestone as predecessors and are, therefore, showing large amounts of float that do not reflect actual flexibility in the schedule. The majority of high-float activities are level-of-effort activities, many of which are extended to the end of these interim milestones and are thus associated with unreasonable amounts of float as well. As noted in our analysis of the schedule's adherence to Best Practice 6, a hard constraint is in place to calculate a critical path through Release 5 activities; however, our analysis also found unreasonable amounts of total float in some of these activities. For example, several activities have more than 1,000 days of float, including "Test and Deploy"—which shows a total float value of 1,280 days. Because of this excessive float, delays in the activities above will have no effect on the finish date of Release 5.</p> <p>Float estimates are directly related to the logical sequencing of activities and, therefore, if the schedule is not properly sequenced, float calculations will be miscalculated. Without reliable float estimates, management may be unable to allocate resources from noncritical activities to activities that cannot slip without affecting the project finish date.</p>



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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
8. Conducting a schedule risk analysis	A schedule risk analysis should be performed using statistical techniques to predict the level of confidence in meeting a project's completion date. This analysis focuses not only on critical path activities but also on activities near the critical path, since they can affect the project's status.	Not met	<p>A risk analysis of the schedule's vulnerability to slippages in the completion of activities has not been performed. Officials stated that a schedule risk analysis was not conducted because it is not a contractual deliverable. However, to address schedule risk with software development, the contractor performed cross-check and risk analyses on estimated lines of code using industry standard software development estimating tools. In addition, the officials stated they perform what-if analyses and discuss risks during their monthly earned value management analysis reviews.</p> <p>However, a comprehensive schedule risk analysis is an essential tool for decision makers. A schedule risk analysis can be used to determine a level of confidence in meeting the completion date or whether proper reserves have been incorporated into the schedule. A schedule risk analysis will calculate schedule reserve, which can be set aside for those activities identified as high risk. Without this reserve, the program faces the risk of delays to the scheduled completion date if any delays occur on critical path activities.</p>
9. Updating the schedule using logic and durations to determine the dates	The schedule should be continuously updated using logic and durations to determine realistic start and completion dates for program activities. The schedule should be analyzed continuously for variances to determine when forecasted completion dates differ from planned dates. This analysis is especially important for those variations that affect activities identified as being in a project's critical path and can influence a scheduled completion date.	Substantially met	<p>The schedule is updated by the contractor weekly, and the contractor also provides a formal update of the schedule to the program office on a monthly or bimonthly basis as necessary. Officials stated that during the monthly schedule reviews, FAA is an active participant in discussions involving network logic and forecasted activity dates.</p> <p>We found 47 activities (10 percent of remaining activities) with start dates in the past or with no actual start dates and 49 activities (10 percent of remaining activities) with finish dates in the past with no actual finish dates. The program office said the majority of these data anomalies are associated with "on-hold" activities. After reviewing the schedule, we did find that majority of these activities were labeled as "on-hold." We found no activities in the schedule with actual start dates in the future or actual finish dates in the future.</p>

Source: GAO analysis of CATMT schedule.

Table 14: Extent to Which the SWIM Schedule Met Best Practices

Best practice	Explanation	Extent to which criterion was met	GAO analysis
1. Capturing all activities	The schedule should reflect all activities as defined in the project's work breakdown structure, which defines in detail the work necessary to accomplish a project's objectives—including activities to be performed by both the owner and the contractors.	Minimally met	<p>Our analysis found that, despite a substantial amount of detail and clearly marked level-of-effort activities, the program schedule does not effectively represent the work required to complete SWIM, primarily because of the way in which the schedule was created and the limited authority of the SWIM program office. The Integrated Schedule is a synopsis of the individual SWIM implementation program (SIP) schedules and includes only activities whose timeliness is assumed to be crucial to meeting Joint Resources Council milestone dates, resulting in a schedule that likely excludes a portion of the program's scope. Because of missing activities, it is unlikely that this schedule will highlight opportunities for process improvement (e.g., identifying redundant activities), what-if analysis, and risk mitigation.</p> <p>The SWIM program office does not have purview over the content that is included in the individual SIP schedules. Instead, this responsibility is held by FAA's Joint Resources Council secretariat. Thus, the SWIM program office cannot enforce the use of a standard work breakdown structure for all SIP schedules or dictate the way in which the SIPs name their activities. Our analysis found repetitive naming of activities across SIP schedules that are not associated with specific products or phases. This makes communication difficult between teams, particularly between team members that are responsible for updating and integrating multiple schedules.</p> <p>If the schedule does not fully and accurately reflect the project's activities, it will not serve as an appropriate basis for analysis and may result in unreliable completion dates, time extension requests, and delays. Since the schedule is used for coordination, missing elements will hinder coordination efforts, increasing the likelihood of disruption and delays. In addition, if activities are missing from the schedule, then other best practices will not be met. Without accounting for all necessary activities, it is uncertain whether: all activities are scheduled in the correct order, resources are properly allocated, missing activities would appear on the critical path, or a schedule risk analysis accounts for all risk.</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
2. Sequencing all activities	The schedule should be planned so that critical project dates can be met. To meet this objective, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. This helps ensure that interdependencies among activities that collectively lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress.	Minimally met	<p>Our analysis found that the activities in the SWIM Integrated Schedule were not properly sequenced because of missing dependencies and the presence of dangling activities, date constraints, and lags. Dangling logic reduces the credibility of the calculated activity start and finish dates and the identity of the critical paths because the slip or elongation of an activity that has no logical successor will not affect the scheduled dates of successor activities.</p> <p>In addition, the schedule contains 23 constraints (6 percent of the remaining activities), or work that remains to be completed, including 13 soft constraints and 10 hard constraints. Program officials stated that hard constraints were added to enable the creation of the critical path for the subprogram. However, officials stated that float is not monitored. If float is not monitored, the critical path may be invalid, and there is thus no credible reason to include these constraints in the schedule.</p> <p>Constraints jeopardize the ability of the schedule to remain dynamic—that is, to compute the correct delivery dates and critical path if durations change. Constraints artificially set dates in the software and may mislead users of the schedule, since they do not force the actual project to do anything. A large number of activities with constraints typically are substitutes for logic and can mean that the schedule is not well planned and may not be feasible.</p> <p>The quality of the schedule is significantly degraded by the presence of lags and leads (negative lags). In particular, 61 percent of the remaining activities are affected by at least one lag or lead. Program officials explained that lags are used to represent collections of activities that were present in the original SIP schedules but deemed noncrucial during the Integrated Schedule creation process. The purpose of these lags is then to preserve the underlying network logic and timeline. However, in this case, a summary activity would be a more appropriate modeling choice, since it would allow for logic preservation, but also maintain the dynamic nature of the schedule.</p> <p>Using lags rather than activities to account for work or to insert a buffer for risks causes problems because lags persist even when activities are delayed. For this reason, lags should be eliminated and replaced with activities so they can be tracked. Furthermore, lags</p>

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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
			lessen the ability of the project schedule to dynamically respond to changes in the status of predecessor activities, and the lags' need to be constantly manually updated defeats the purpose of a dynamic schedule and can cause errors in the schedule when there are too many lags to maintain.
3. Assigning resources to all activities	The schedule should reflect what resources (e.g., labor, materials, and overhead) are needed to do the work, whether all required resources will be available when needed, and whether any funding or time constraints exist.	Not met	<p>The schedule is not resource-loaded. According to program officials, the SWIM program is somewhat atypical with respect to resource loading. In particular, the substantive effort for the program is handled by SIP support contractors and the SWIM program office serves to monitor the SIPs' progress and ensure that deliverables are completed on time. Moreover, in accordance with the program's federated approach, the SWIM program office does not dictate the content that is included in the individual SIP schedules. As a result, the SIPs are not required to resource-load their schedules and, thus, the Integrated Schedule itself is not resource loaded.</p> <p>Because this schedule does not have resource assignments, it cannot be used to monitor productivity or resource-constrained activities, allocate idle resources, or level resources across activities.</p>
4. Establishing the duration of all activities	The schedule should realistically reflect how long each activity will take to execute. In determining the duration of each activity, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be as short as possible and have specific start and end dates. The schedule should be continually monitored to determine when forecasted completion dates differ from planned dates; this information can be used to determine whether schedule variances will affect subsequent work.	Partially met	<p>The requirements for compliance with this best practice have been partially met, primarily because of the nature of the schedule creation and update processes. Durations for many of the activities in the schedule are significantly longer than 2 working months (44 working days). Specifically, 190 (55 percent) of the remaining activities have a duration longer than the threshold of 44 days, and half of the activities are scheduled for longer than 66 days. Furthermore, the average duration of all remaining activities is 158 days, or roughly 7 working months. Such a schedule is likely to be very challenging to manage and is indicative of insufficient detail. Long-duration activities also make it difficult for management to gauge progress and can skew schedule risk analysis results.</p> <p>Officials stated that many of these lengthy durations are the result of the way in which the schedule was created. Those activities that are not level-of-effort were originally summary activities in the SIP schedule from which they were extracted and, thus, are</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>composed of many detailed activities with shorter durations.</p> <p>In addition, because the method by which activity durations are estimated is not within the purview of the SWIM program office, there is little insight into how the durations are derived. However, as noted in the discussion of Best Practice 3, there is no requirement for the SIP contractor schedules to be resource-loaded. Because activity durations are based on many underlying assumptions, including the number of hours per workweek, number of full-time-equivalent personnel, productivity rates, and other factors, they should be estimated under normal conditions, not optimal conditions. If durations are not realistic, program management does not have the information necessary to properly allocate resources to tasks and understand how those tasks affect downstream work.</p>
5. Integrating the schedule horizontally and vertically	<p>The schedule should be horizontally integrated, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as "hand-offs" and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. The schedule should also be vertically integrated, meaning that the dates for starting and completing activities in the integrated master schedule should be aligned with the dates for supporting tasks and subtasks. Such mapping or alignment among levels enables different groups to work to the same master schedule.</p>	Minimally met	<p>This schedule suffers from a lack of horizontal integration for reasons identified in other Best Practice responses. The schedule failed several tests for horizontal integration, primarily because of the hard constraints on the SIP completion milestones. For example, the duration of a critical activity was increased by 50 days, changing its float (and that of its predecessor) from 0 to 50 days and its finish date from February 28, 2011, to May 9, 2011, but without any effect on the project completion date. Further increasing this activity's duration by 1,500 days had the expected effect on the finish dates of the activity and its successor, but left the project's completion date unchanged and several years before the new finish date of the critical activity. Horizontal integration demonstrates that the overall schedule is rational, planned in a logical sequence, accounts for interdependent activities, and provides a way to evaluate current status. Therefore, if the schedule lacks horizontal integration, the effects of slipped tasks on subsequent work cannot be determined and there will be little confidence in the calculated dates or critical path.</p> <p>Schedules that are not horizontally integrated may not depict relationships between different program elements and product hand-offs. When this happens, product hand-offs of project subcomponents cannot be fully traced to the end product, leading to less effective</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
6. Establishing the critical path for all activities	Scheduling software should be used to identify the critical path, which represents the chain of dependent activities with the longest total duration. Establishing a project's critical path is necessary to examine the effects of any activity slipping along this path. Potential problems along or near the critical path should also be identified and reflected in scheduling the duration of high-risk activities.	Minimally met	<p>management of the project. According to officials, all parties involved in the creation and updating of the SWIM program office schedules meet routinely for status reviews and have signed off on all "touch points" and hand-offs. However, because of the structure of the schedule, it is difficult to determine where key hand-offs are made and how they are related to top-level milestone dates.</p> <p>As noted in the discussion of Best Practice 1, there are several inconsistencies between lower- and upper-level milestone dates. In addition, this schedule does not contain all lower-level activities but, rather, only a selection of activities from the lower-level SIP schedules. Any logic errors between detail, intermediate, and summary schedules will cause inconsistent dates between schedules, as well as different expectations between senior management and activity owners.</p> <p>Based on the description of critical path management practices provided by the SWIM program office, we analyzed this best practice from the traditional, top-level perspective, as well as from that of the individual SIPs. In both cases, we found that the requirements for compliance were only minimally met. For each analysis that we performed, we traced the paths of activities with the least amount of total float since they are considered "drivers" of a critical finish milestone.</p> <p>Program officials stated that, although the SIP schedules are integrated in the schedule, the SIPs are unrelated and, thus, each has its own critical path. However, the full individual critical paths are not accessible through the Integrated Schedule, and the SIP schedules are not used by the SWIM program office for management purposes, so their existence offers little advantage from a SWIM management perspective. Furthermore, the SWIM program itself should have its own critical path, which includes, at the very least, acceptance of all major deliverables from the SIPs.</p> <p>We first examined the SWIM-wide critical path identified by the scheduling software. This critical path was found to be invalid for a variety of reasons, including the inclusion of line-of-effort activities, date constraints, activities with excessive durations, and lags and leads. Additionally, issues identified during the</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
7. Identifying reasonable float	The schedule should identify the float—the amount of time by which a predecessor activity can slip before the delay affects successor activities—so that a schedule’s flexibility can be determined. As a general rule, activities along the critical path have the least float. Total float is the total amount of time by which an activity can be delayed without delaying the project’s completion, if everything else goes according to plan.	Minimally met	<p>analysis of other best practices—particularly Best Practices 1 and 2—prevent this critical path from being valid. Without a valid program critical path, management cannot determine which slipped tasks will have detrimental effects on the project finish date.</p> <p>We also analyzed the schedule from the perspective of each SIP to determine the validity of individual critical paths. In each case, the critical path failed to meet the requirements for this best practice because of the presence of one or more of the following: line-of-effort activities, lags, leads, long durations, program management activities, and excessive float.</p> <p>Program officials noted that total float is within acceptable limits for the project but that float is not monitored by the SWIM program office. However, our analysis found unreasonable float calculations in the schedule. In particular, 107 (28 percent) of the 393 remaining detail and milestone activities have float values greater than or equal to 100 working days; that is, 27 percent of all remaining activities can slip more than 4 working months without affecting successor activities. Additionally, two activities with excessive negative float values (95 working days) were discovered.</p> <p>The abnormal float values are primarily caused by the schedule integration process. In particular, these high values arise because of large differences between the finish dates of individual SIP capabilities and the SWIM program completion date. Program officials noted that adding links between the completion dates of the individual SIP capabilities and the project completion milestone (in order to lower the float values) is unnecessary since float management is not used by the SWIM program office. Officials stated that total float is not monitored because the schedule is not resource-loaded and the work is performed at the SIP level. In addition to the integration process, other possible causes of excessive float are the missing dependencies and constraints noted in the discussion of Best Practice 2.</p> <p>Float is directly related to the logical sequencing of events and the critical path. If the schedule is missing activities or dependencies, or links activities incorrectly,</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
8. Conducting a schedule risk analysis	A schedule risk analysis should be performed using statistical techniques to predict the level of confidence in meeting a project's completion date. This analysis focuses not only on critical path activities but also on activities near the critical path, since they can affect the project's status.	Minimally met	<p>float estimates will not be accurate. Incorrect float estimates may result in an invalid critical path and an inaccurate assessment of project completion dates. In addition, inaccurate values of total float result in a false depiction of true project status, which could lead to decisions that may jeopardize the project.</p> <p>No schedule risk analysis was conducted for this schedule. However, our analysis found that this best practice was minimally met because a risk analysis was conducted on a separate higher-level SWIM schedule and risk management has been considered, to some extent, by the SWIM program office.</p> <p>The schedule risk analysis was performed on a high-level schedule, consisting of standard work packages designed to represent a generic software development program, in order to satisfy Joint Resources Council requirements. According to the SWIM program office, the SWIM Joint Resources Council met with each of the SIP program offices to develop high-level schedules that were risk adjusted and priced for the original cost estimate. These individual schedules were combined, resulting in a schedule with 182 activities. This risk analysis does not comply with this best practice because the underlying schedule was created using standard work packages, not specific to SWIM, and does not accurately capture the relationships between the SIP capabilities and the success of the SWIM program.</p> <p>Furthermore, even if a risk analysis had been performed on the Integrated Schedule, several issues have been identified that would call its validity into question. If the schedule risk analysis is to be credible, the program must have a quality schedule that reflects reliable logic and clearly identifies the critical path—conditions that the SWIM program's Integrated Schedule does not meet.</p> <p>Program officials have stated that it has not been practice to perform risk analysis on the Integrated Schedule because it is a derivative of several lower-level schedules and does not capture the work of the original program. However, a schedule risk analysis should be conducted on each schedule used for planning purposes, in order to provide a more realistic view of the expected project timeline.</p>



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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
9. Updating the schedule using logic and durations to determine dates	The schedule should be continuously updated using logic and durations to determine realistic start and completion dates for program activities. The schedule should be analyzed continuously for variances to determine when forecasted completion dates differ from planned dates. This analysis is especially important for those variations that affect activities identified as being in a project's critical path and can influence a scheduled completion date.	Partially met	<p>Our analysis found that the requirements for compliance with this best practice have been partially met. According to program officials, the schedule is updated regularly during monthly status meetings. This has been partially confirmed by the latest schedule status on January 31, 2011, shortly before the program office transmitted it to us. Despite the regularity of these meetings, however, the update process described by program officials is quite labor-intensive and likely prone to error.</p> <p>We discovered evidence of the inherent error in this process through our analysis. Although the schedule was recently updated, there were 32 activities with start dates in the past but without a recorded actual start date, and 46 activities with finish dates in the past but without an actual finish date entered in the schedule. If these activities have started (finished), their actual start (finish) date should be updated to reflect this accomplishment. If not, the start (finish) date should be updated to reflect the current plan.</p> <p>Additionally, our analysis identified 28 activities in the schedule with finish dates that occurred before the status date, 58 activities with remaining durations exceeding their planned finish date, and 21 activities updated out of sequence. The existence of these date anomalies indicates error in the duration-estimating methodology or neglect in the schedule-updating process, and a schedule with remaining out-of-sequence progress may have the wrong logic in place and hence have inaccurate critical paths and completion dates.</p>

Source: GAO analysis of SWIM schedule.

**Table 15: Extent to Which the FAA-Prepared WAAS Schedule Met Best Practices**

Best practice	Explanation	Extent to which criterion was met	GAO analysis
1. Capturing all activities	The schedule should reflect all activities as defined in the project's work breakdown structure, which defines in detail the work necessary to accomplish a project's objectives—including activities to be performed by both the owner and the contractors.	Minimally met	<p>Our analysis found that the program schedule is not fully integrated. Program officials said the government's integrated master schedule, which is maintained by FAA, is made up of 15 subschedules; however, these subschedules are not linked to the government's integrated master schedule. Furthermore, identification of these subschedules in the government's integrated master schedule is difficult because that schedule does not contain any custom text fields, statements of work, or contract line item mappings. Without these mappings, it is impossible to determine which activities in the government's integrated master schedule belong to which subschedules and whether all the work has been captured.</p> <p>In addition, we found that the work breakdown structure for the government's integrated master schedule does not match the work breakdown structure used for the cost estimate or the work breakdown structure used in the program's Earned Value Management System Control Plan. Because the work breakdown structure is not standardized, we cannot be sure that the schedule contains all of the work necessary to accomplish the program's objectives, and it is difficult, if not impossible, to identify activities across cost, schedule, and earned value management reporting.</p> <p>Without an integrated master schedule that accounts for all planned government and contractor effort, management is not able to reliably estimate planned dates beyond the current schedule's end date of September 2016. Moreover, unless all activities are accounted for, it is uncertain whether all activities are properly sequenced, resources are properly assigned, the critical path reflects all activities, or a schedule risk analysis accounts for all risk. Finally, if the schedule does not fully and accurately reflect the project's activities, it will not serve as an appropriate basis for analysis and may result in unreliable completion dates, time extension requests, and delays.</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
2. Sequencing all activities	The schedule should be planned so that critical project dates can be met. To meet this objective, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. This helps ensure that interdependencies among activities that collectively lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress.	Minimally met	<p>Our analysis found 116 remaining activities—or remaining work to be completed. (36 percent) <i>missing predecessor logic</i> and 162 activities (48 percent) <i>missing successor logic</i>. In addition, our analysis found a number of activities with constraints. The schedule includes 198 activities (49 percent) with Start No Earlier Than constraints. These constraints are considered “soft” in that they allow the activity to slip into the future if their predecessor activity is delayed. However, the activity cannot begin earlier than its constraint date. We also found 92 activities (23 percent) with Finish No Earlier Than constraints. These constraints are also considered “soft” date constraints because they prevent activities from finishing earlier than their constraint date.</p> <p>The reliability of the schedule is also hindered by the presence of lags and leads (negative lags). In particular, 38 activities (9 percent) are affected by at least one lag or lead. Lags should be justified because they cannot have risk or uncertainty. Furthermore, lags often represent work or a delay whose duration is unknown, yet are hard-coded into the schedule. Using lags rather than activities to account for work or to inset a buffer for risks causes problems because lags persist even when activities are delayed. As a result, when activities take longer, the lags may actually distort the true logic of the schedule. Negative lags are generally not valid because time is not demonstrable; moreover, a lead implies the ability to predict the finish date of a predecessor activity with certainty. In general, leads can be replaced with straightforward finish-to-start logic once tasks are broken down further.</p> <p>Having all interdependencies between tasks identified is necessary for the schedule to properly calculate dates and predict changes. Without the right linkages, tasks that slip early in the schedule do not transmit delays to tasks that should depend on them. When this happens, the schedule will not provide a sufficient basis for understanding the program as a whole, and users of the schedule will lack confidence in the dates and the critical path. Unless complete network logic is established, the schedule cannot predict effects on the project’s planned finish date of, among other things, misallocated resources, delayed tasks, external events, and unrealistic deadlines.</p>

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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
3. Assigning resources to all activities	The schedule should reflect what resources (e.g., labor, materials, and overhead) are needed to do the work, whether all required resources will be available when needed, and whether any funding or time constraints exist.	Minimally met	<p>Program officials stated that the schedule is not resource-loaded, and our analysis confirmed that resources are not assigned to activities. Program officials said the general resource allocation process begins with the 5-year Strategic Plan that lays out the program's long-term goals.</p> <p>Program officials said given the current political and budget environment, it is very difficult to hire government employees, and, as a result, it is easier to fill resource gaps with contractor personnel than with government personnel.</p> <p>Assigning resources to activities ensures that resources are used to determine activity durations because resource requirements directly relate to the duration of an activity. Labor, material, equipment, and funding requirements are examined to determine the feasibility of the schedule, so that resources provide a benchmark of the total and per-period cost of the project. If the current schedule does not allow for insight into current or projected allocation of resources, then the risk of the program slipping is significantly increased.</p>
4. Establishing the duration of all activities	The schedule should realistically reflect how long each activity will take to execute. In determining the duration of each activity, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be as short as possible and have specific start and end dates. The schedule should be continually monitored to determine when forecasted completion dates differ from planned dates; this information can be used to determine whether schedule variances will affect subsequent work.	Partially met	<p>Our analysis found that more than 70 percent of the remaining activities within the detail planning period of the schedule had original durations of 44 days or less, which generally meets best practices. Forty-one activities had long durations, of between 200 and 630 days that appear to be based on a fiscal year's period of work, without regard to deliverables either at the end or at an intermediate point of shorter duration. Usually activities in the schedule are organized around producing deliverables rather than on the end of the calendar or fiscal year, or of a 12-month period.</p> <p>Program officials said the team uses past experiences to estimate activity durations. Officials also said durations are determined in meetings between program engineers, control account managers, and upper management. We found no deadlines in the schedule, and program officials noted that there is no mandated date for the schedule.</p> <p>Although the activity durations in the program's schedule appear to be reasonable, not assigning resources in the schedule</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>directly affects the estimated work and duration of activities. Assigning resources to activities inside the schedule ensures that resources are used to determine activity durations because resource requirements directly relate to the duration of an activity. Therefore, because the schedule does not include adequate resources, it is questionable that the activity durations realistically reflect how long each activity will take to execute. Furthermore, only one activity had a calendar assigned to it. All of the other activities had no calendar assignment, which means that holidays were not accounted for in this schedule, immediately calling into question the validity of the calculated dates.</p>
5. Integrating schedule activities horizontally and vertically	<p>The schedule should be horizontally integrated, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as “hand-offs” and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. The schedule should also be vertically integrated, meaning that the dates for starting and completing activities in the integrated master schedule should be aligned with the dates for supporting tasks and subtasks. Such mapping or alignment among levels enables different groups to work to the same master schedule.</p>	Partially met	<p>The results for Best Practice 2, Sequencing of All Activities, and Best Practice 7: Identifying Reasonable Float, on activities and paths indicate that the logic is not in place to demonstrate vertical integration in the integrated master schedule.</p> <p>The WAAS program office said vertical integration is demonstrated in the contractor schedules, because the lower-level schedules map to milestones in the integrated master schedule. However, we found that the dates for two key milestones in the detailed contractor schedule did not match the dates in the government's integrated master schedule, indicating a problem with vertical integration among the detailed and higher-level schedules.</p> <p>Program officials said horizontal integration is identified in the schedule when activities are handed off from givers to receivers, but our analysis could not identify these hand-offs in the schedule. In addition, the schedule does not fully demonstrate horizontal traceability because it does not include complete logic from program start to program finish and does not fully integrate the entire scope of work for all parties involved in the program.</p> <p>Program officials said the WAAS program uses both the acquisition program baseline and the Office of Management and Budget (OMB) Exhibit 300 to track the program.<sup>a</sup> However, our analysis found that the WAAS integrated master schedule only reflects work approved through 2016, even though the</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>acquisition program baseline and OMB Exhibit 300 have estimated work planned beyond that date. Without horizontal traceability, there is no assurance that the forecasted dates within the schedule will be determined by network logic and progress to date rather than artificial constraints.</p> <p>We also tested horizontal integrity by extending the durations of key activities for Release 3B, the current release during the GAO audit, to observe the effects on successor activity dates and the project finish date. Extending the durations of selected activities in the schedule by more than 1,000 working days had no effect on the successor activities or the project finish date.</p> <p>Unless a schedule is fully horizontally integrated, the effects of slipped tasks on succeeding work cannot be determined. Horizontal integration demonstrates that an overall schedule is rational, planned in a logical sequence, accounts for interdependencies between work and planning packages, and provides a way to evaluate a program's current status. When schedules are not horizontally integrated, relationships between different program teams cannot be seen and product hand-offs cannot be identified. Vertical integration traces the consistency of data between work breakdown structure elements within the layers of the schedule—master, intermediate, detailed. Without schedules that are vertically integrated, lower-level schedules cannot be clearly traced to upper-tiered milestones, and, as a result, total schedule integrity is compromised. This can hamper the ability of different teams to use the schedule to manage expectations.</p>
6. Establishing the critical path for all activities	Scheduling software should be used to identify the critical path, which represents the chain of dependent activities with the longest total duration. Establishing a project's critical path is necessary to examine the effects of any activity slipping along this path. Potential problems along or near the critical path should also be identified and reflected in scheduling the duration of high-risk activities.	Minimally met	<p>Officials stated that there is no critical path in the current schedule, but they know what the critical activities are in the subschedules that make up the integrated master schedule. As evidence, they pointed out hard-copy versions of five detail schedule critical paths for the subschedules, including those for the safety computer. However, we were unable to find a valid "critical path" in the schedule itself. Both critical paths in the schedule start with a Start No Earlier Than constraint, which is not in line with best practices. Moreover, one of the paths includes several activities with lags that</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>equate to 39 months (approximately 854 working days) of unexplained duration.</p> <p>Without a valid program critical path, management cannot determine which slipped tasks will have detrimental effects on the project finish date and whether float within the schedule can be used to mitigate delays in critical tasks by reallocating resources from tasks that can safely slip to tasks that must be completed on time. Until the schedule can produce a true critical path, the program office will not be positioned to provide reliable timeline estimates and it will not be able to identify when problems or changes may occur and how they may affect downstream work</p>
7. Identifying reasonable float	<p>The schedule should identify the float—the amount of time by which a predecessor activity can slip before the delay affects successor activities—so that a schedule’s flexibility can be determined. As a general rule, activities along the critical path have the least float. Total float is the total amount of time by which an activity can be delayed without delaying the project’s completion if everything else goes according to plan.</p>	Partially met	<p>Our analysis found excessive float values. We found 238 activities (58 percent) with float values greater than 1,000 working days, or 46 months. Our analysis also found 160 activities (39 percent) with float values greater than 148 working days, or 7 months.</p> <p>Float estimates are directly related to the logical sequencing of activities. Therefore, if the schedule is not properly sequenced, float estimates will be miscalculated. Without reliable float estimates, management may be unable to allocate resources from noncritical activities to activities that cannot slip without affecting the project finish date. Furthermore, because the critical path is directly related to the logical sequencing of events and float calculations, if the schedule is missing dependencies or if activities are incorrectly linked, float estimates will be miscalculated, resulting in an invalid critical path.</p>
8. Conducting a schedule risk analysis	<p>A schedule risk analysis should be performed using statistical techniques to predict the level of confidence in meeting a project’s completion date. This analysis focuses not only on critical path activities but also on activities near the critical path, since they can affect the project’s status.</p>	Not met	<p>Officials stated that a schedule risk analysis had not been performed on the integrated master schedule. Program officials said that although they do not have a WAAS contingency schedule, they do manage risk with a risk register with mitigation plans and that the integrated master schedule is also risk-adjusted. Our analysis found no evidence of risk mitigation activities in the schedule.</p> <p>Performing a schedule risk analysis on the integrated master schedule, using statistical analysis, would allow the program office to model the effects of work not yet on contract. One way to estimate the effects of the scope of work not on contract is through the use of a Monte Carlo simulation (used to approximate</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>the probability outcomes of multiple trials by generating random numbers) to estimate the durations and start dates. This would give the program office some visibility into risk impacts (understanding of the effects of risk). However, for a schedule risk analysis to be credible, the program must have a good schedule network that clearly identifies the critical path and represents all work in the schedule, neither of which is demonstrated in the program's schedule</p> <p>A schedule risk analysis will calculate schedule reserve, which can be set aside for those activities identified as high risk. Without this reserve, the program's scheduled completion date faces the risk of delays, if any delays were to occur on critical path activities. However, if the schedule risk analysis is to be credible, the program must have a quality schedule that reflects reliable logic and clearly identifies the critical path—conditions that the schedule does not meet.</p>
9. Updating the schedule using logic and durations to determine the dates	The schedule should be continuously updated using logic and durations to determine realistic start and completion dates for program activities. The schedule should be analyzed continuously for variances to determine when forecasted completion dates differ from planned dates. This analysis is especially important for those variations that affect activities identified as being in a project's critical path and can influence a scheduled completion date.	Partially Met	<p>Program officials said the status of the schedule is updated monthly by incorporating actual effort achieved by the contractors and the support team members. Whether the schedule is properly updated is questionable. During a January 2011 meeting with the program office, officials said they did not believe the schedule status date was correct and, for the purposes of the audit, GAO should use the date in the filename. The status date is an input into the calculations used to update and schedule remaining work. Neither the date on which someone is viewing the schedule nor the latest save date of the file should be used as a substitute for a valid status date. Program officials said they have hired a dedicated scheduler who is responsible for updating the schedule.</p> <p>Our analysis also found several data anomalies. For example, the schedule includes 19 remaining activities (5 percent) with start dates in the past with no recorded actual start dates; 17 remaining activities (4 percent) with finish dates in the past with no recorded actual finish; 15 remaining activities (4 percent) with actual start dates in the future; and 12 remaining activities (3 percent) with actual finish dates in the future.</p> <p>Despite the program office's efforts to keep</p>



Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>the schedule updated, the integrated master schedule does not capture all activities and the schedule does not contain the complete network logic between all activities necessary for the schedule to correctly forecast the start and end dates of activities within the plan. As such, it is questionable that the schedule reflects the program's true status.</p> <p>As a best practice, the schedule should be continually monitored to determine when forecasted completion dates differ from their planned dates. This information can be used to determine whether schedule variances will affect downstream work. Maintaining the integrity of the schedule logic is not only necessary to reflect the program's true status, but is also required before conducting a schedule risk analysis. Without a documented, consistently applied schedule change control process, program managers can continually revise the schedule to match performance. Such adjustments hinder the project manager's understanding of the project's true performance. Good documentation helps with analyzing changes in the program schedule and identifying the reasons for variances between estimates and actual results, thereby contributing to the collection of cost, schedule, and technical data that can be used to support future estimates.</p>

Source: GAO analysis of WAAS schedule.

<sup>a</sup>An Exhibit 300—also called a Capital Asset Plan and Business Case—is used to justify resource requests for major investments and is intended to enable an agency to demonstrate to its own management, as well as to OMB, that a major project is well planned.

**Table 16: Extent to Which the WAAS Contractor-Prepared Schedule Met Best Practices**

Best practice	Explanation	Extent to which criterion was met	GAO analysis
1. Capturing all activities	The schedule should reflect all activities as defined in the project's work breakdown structure, which defines in detail the work necessary to accomplish a project's objectives—including activities to be performed by both the owner and the contractors.	Substantially met	Our analysis found that the contractor's schedule is governed by a statement of work and the contract with FAA. Detailed activities are cross-referenced to elements in the project's work breakdown structure that map to the task order structure in the schedule using custom text fields. Because the contractor did not provide a work breakdown structure, although we found custom text fields in the schedule, we cannot tell without a work breakdown structure whether all the work is included in the schedule.
2. Sequencing all activities	The schedule should be planned so that critical project dates can be met. To meet this objective, activities need to be logically sequenced—that is, listed in the order in which they are to be carried out. In particular, activities that must be completed before other activities can begin (predecessor activities), as well as activities that cannot begin until other activities are completed (successor activities), should be identified. This helps ensure that interdependencies among activities that collectively lead to the accomplishment of events or milestones can be established and used as a basis for guiding work and measuring progress.	Substantially met	<p>Our analysis found 6 remaining activities (1 percent) missing predecessor or successor logic. In addition, our analysis found 6 remaining activities (1 percent) with dangling logic where the start of the activity had no predecessor (only F-F predecessors). Each activity—other than the start and finish milestones—must have its start date driven by a previous activity, and each activity must drive the start date of another activity. Tasks with dangling logic can either carry on indefinitely without affecting downstream activities (finish date has no successor) or must start earlier in order to finish on time (start date has no predecessor). Dangling activities are those activities with logic that do not give the right activity start and finish dates when durations change.</p> <p>Though we found just a few missing dependencies and dangling activities, we identified 46 activities (7 percent) that are affected by at least one lag or lead. Lags should be justified because they cannot have risk or uncertainty. They often represent work or a delay whose duration is unknown, yet are hard-coded into the schedule. Negative lags—also known as leads—are discouraged because negative time is not demonstrable. Leads can often be replaced by additional tasks and linked using the appropriate F-S logic.</p>
3. Assigning resources to all activities	The schedule should reflect what resources (e.g., labor, materials, and overhead) are needed to do the work, whether all required resources will be available when needed, and whether any funding or time constraints exist.	Partially met	<p>Program officials stated that the schedule is not resource-loaded and our analysis confirmed that resources are not assigned to activities. Program officials said resources are managed via their earned value management system in which resources are specified by resource group and skill types and are tied to the schedule by the work breakdown structure.</p> <p>Although the contractor may be conducting this analysis of resources via its earned value</p>

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Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>management system or its critical chain process, it did not provide any supporting documentation to validate this assertion.</p> <p>Assigning resources to activities ensures that resources are used to determine activity durations because resource requirements directly relate to the duration of an activity. Labor, material, equipment, and funding requirements are examined to determine the feasibility of the schedule, so that resources provide a benchmark of the total and per-period cost of the project. If the current schedule does not allow for insight into current or projected overallocation of resources, then the risk of the program slipping is significantly increased.</p>
4. Establishing the duration of all activities	The schedule should realistically reflect how long each activity will take to execute. In determining the duration of each activity, the same rationale, historical data, and assumptions used for cost estimating should be used. Durations should be as short as possible and have specific start and end dates. The schedule should be continually monitored to determine when forecasted completion dates differ from planned dates; this information can be used to determine whether schedule variances will affect subsequent work.	Substantially Met	Our analysis found that more than half of the 154 remaining detailed activities (107 or 69 percent) meet best practices for durations being less than 44 days (or 2 working months). Our analysis found that all durations are consistently estimated in days and adhere to a standard 5-day workweek that accounts for holidays or uses calendars that account for FAA moratoriums. Our analysis found no activities scheduled to begin on a weekend. Program officials said duration estimates for the schedule are based on historical information from past performance, comparable releases, lessons learned, similar work, and other data requirements.
5. Integrating schedule activities horizontally and vertically	The schedule should be horizontally integrated, meaning that it should link products and outcomes associated with other sequenced activities. These links are commonly referred to as “hand-offs” and serve to verify that activities are arranged in the right order to achieve aggregated products or outcomes. The schedule should also be vertically integrated, meaning that the dates for starting and completing activities in the integrated master schedule should be aligned with the dates for supporting tasks and subtasks. Such mapping or alignment among levels enables different groups to work to the same master schedule.	Substantially met	<p>FAA program officials said vertical integration is demonstrated in the contractor’s schedule because the lower-level schedules map to milestones in the FAA integrated master schedule. However, we found that dates for the same milestone activities in the contractor and FAA schedule did not match. Horizontal integration is also hampered in the schedule. For example, extending the durations of selected activities in the schedule more than 500 working days had no effect on the project finish date.</p> <p>Unless the schedule is fully horizontally integrated, the effects of slipped tasks on succeeding work cannot be determined. Horizontal integration demonstrates that the overall schedule is rational, planned in a logical sequence, accounts for interdependencies between work and planning packages, and provides a way to evaluate current status. When schedules are not horizontally integrated, relationships between different program</p>

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<b>Best practice</b>	<b>Explanation</b>	<b>Extent to which criterion was met</b>	<b>GAO analysis</b>
			teams cannot be seen and product hand-offs cannot be identified. Vertical integration traces the consistency of data between work breakdown structure elements within the layers of the schedule—master, intermediate, detailed. Without schedules that are vertically integrated, lower-level schedules cannot be clearly traced to upper-tiered milestones, and, as a result, total schedule integrity is compromised. This can hamper the ability of different teams to use the schedule to manage expectations.
6. Establishing the critical path for all activities	Scheduling software should be used to identify the critical path, which represents the chain of dependent activities with the longest total duration. Establishing a project's critical path is necessary to examine the effects of any activity slipping along this path. Potential problems along or near the critical path should also be identified and reflected in scheduling the duration of high-risk activities.	Substantially met	Program officials said the schedule contained a critical path. Our analysis traced several critical paths in the schedule. Though we found lags and deadlines, which create an interruption in the various critical paths, the schedule's logic, reasonable durations, and low total float estimates allow the scheduling software to calculate a valid critical path.
7. Identifying reasonable float	The schedule should identify the float—the amount of time by which a predecessor activity can slip before the delay affects successor activities—so that a schedule's flexibility can be determined. As a general rule, activities along the critical path have the least float. Total float is the total amount of time by which an activity can be delayed without delaying the project's completion, if everything else goes according to plan.	Substantially met	Of the 154 remaining detailed tasks, 148 or 96 percent, have float values of less than 100 days. The other 6 activities, or 4 percent, have float values of between 106 and 299 days. Though we found some negative float values in the schedule and a few activities with float values greater than 100 days, the logical sequencing of activities, realistic durations, and evidence of accurate updating demonstrate that the total float values in this schedule are reasonable.
8. Conducting a schedule risk analysis	A schedule risk analysis should be performed using statistical techniques to predict the level of confidence in meeting a project's completion date. This analysis focuses not only on critical path activities but also on activities near the critical path, since they can affect the project's status.	Minimally met	<p>Program officials said there is no contractual requirement to conduct a schedule risk analysis and said that FAA has never expressed an interest in conducting such an analysis. Regarding managing and assessing risks in the schedule, program officials said they use a monthly risk management board process through which they address schedule risk with FAA. Program officials said that, going forward, they plan to conduct a Monte Carlo analysis of their schedules.</p> <p>In our analysis, we found that the contractor's schedule includes a 22-day "buffer" activity; this is a placeholder activity with a duration of 22 days that is intended to be used as contingency should delays occur within the release 3B effort. However,</p>

**Appendix IV: Assessments of Four FAA  
Program Schedules**

Best practice	Explanation	Extent to which criterion was met	GAO analysis
			<p>our analysis found that the buffer does not produce 22 days of savings when removed from the schedule. Removing the buffer from the schedule saves 3 days because the buffer is not on the current critical path.</p> <p>A comprehensive schedule risk analysis is an essential tool for decision makers. A schedule risk analysis can be used to determine a level of confidence in meeting the completion date or whether proper reserves have been incorporated into the schedule. A schedule risk analysis will calculate schedule reserve, which can be set aside for those activities identified as high-risk. Without this reserve, the program faces the risk of delays to the scheduled completion date if any delays occur in critical path activities.</p>
9. Updating the schedule using logic and durations to determine the dates	The schedule should be continuously updated using logic and durations to determine realistic start and completion dates for program activities. The schedule should be analyzed continuously for variances to determine when forecasted completion dates differ from planned dates. This analysis is especially important for those variations that affect activities identified as being in a project's critical path and can influence a scheduled completion date.	Partially met	<p>Our analysis found that the schedule has a valid and current status date. Our analysis also found there are no activities with start or finish dates in the past that are missing actual start and actual finish dates, and there are no activities with actual start and actual finish dates in the future. Program officials said that schedule updates are provided by the control account managers. The scheduler, who is certified in earned value management and has been doing scheduling for 2 years, provides the control account manager with a status update template that provides the scheduler with in-progress and percentage-complete activities. The scheduler then reviews this information with the control account manager for clarity and completeness.</p> <p>In addition to schedule updates, program officials said they maintain a list of logic changes, which include changes to the sequencing of activities or delays in starting planned work. Program officials said that they track both start and finish variances in the Microsoft Project file as well as those tasks whose status is unreported or that are late. Program officials also said the schedules are archived daily, weekly, and monthly. Though program officials provided testimonial evidence that they adhere to best practices when updating their schedule, they did not provide any documentation to validate these assertions.</p> <p>As a best practice, the schedule should be continually monitored to determine when forecasted completion dates differ from the planned dates. This information can be used to determine whether schedule variances will affect downstream work. Maintaining the integrity of the</p>

Best practice	Explanation	Extent to which criterion was met	GAO analysis
			schedule logic is not only necessary to reflect true status, but is also required before conducting a schedule risk analysis. Without a documented, consistently applied schedule change control process, project performers can continually revise the schedule to match performance, thereby hindering the project manager's understanding of the project's true performance. Good documentation helps with analyzing changes in the program schedule and identifying the reasons for variances between estimates and actual results. It thus contributes to the collection of cost, schedule, and technical data that can be used to support future estimates.

Source: GAO analysis of WAAS contractor-prepared schedule.

<b>Schedule Risk Analysis</b>	<p>A best practice that the WAAS contractor schedule did not meet is conducting a schedule risk analysis, which is not required by FAA’s schedule specifications. FAA officials told us that they do not conduct schedule risk analysis. In August and September 2011, we performed our own schedule risk analysis on the WAAS contractor schedule, through which we analyzed the latest version of the contractor’s schedule available to us at the time of the analysis.</p> <p>A schedule risk analysis uses statistical techniques to predict a level of confidence in meeting a program’s completion date. This analysis focuses on critical path activities and on near-critical and other activities since any activity may potentially affect the program’s completion date. The objective of the simulation is to develop a probability distribution of possible completion dates that reflect the program and its quantified risks. From the cumulative probability distribution, the organization can match a date to its degree of risk tolerance. For instance, an organization might want to adopt a program completion date that provides a 70 percent probability that the program will finish on or before that date, leaving a 30 percent probability that it will extend beyond, or overrun that date, given the schedule and the risks. The organization can thus adopt a plan consistent with its desired level of confidence in the overall integrated schedule. This analysis can give valuable insight into what-if drills and quantify the effects of program changes.</p> <p>In developing a schedule risk analysis, probability distributions for each activity’s duration have to be established. Furthermore, risk in all activities must be evaluated and included in the analysis. Some managers focus</p>
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only on the critical path, but because we cannot be certain how long activities will take, we cannot know the true critical path. Consequently, it would be a mistake to focus only on the software-calculated critical path (those activities in which, if delayed, will negatively impact the overall project completion date) when some off-critical-path activity might become critical if a risk were to occur. Typically, three-point estimates—that is, best, most likely, and worst-case estimates—are used to develop the probability distributions for the duration of workflow activities.

Once the distributions have been established, a Monte Carlo simulation uses random numbers to select specific durations from each activity probability distribution and calculates a new critical path and dates, including major milestone and program completion dates. The Monte Carlo simulation continues this random selection thousands of times, creating a new program duration estimate and critical path each time. The resulting frequency distribution displays the range of program completion dates along with the probabilities that these dates will occur. Table 17 provides a range of dates and the probability of the project's completion on those dates or earlier, based on our 3,000 iterations that are chosen at random during the Monte Carlo simulation. For example, according to our schedule risk analysis, there is a less than 5 percent chance that the project will be finished on or before September 13, 2012. Likewise, there is an 80 percent chance that the project will be finished on or before November 13, 2012.

Because completion on any date is uncertain, it is more realistic to show a range of possible completion dates than to focus on a single date. In deciding which percentile to use for prudent scheduling, there is no international best practice standard. The chosen percentile depends on the riskiness and maturity of the project. For some projects, we emphasize the 80th percentile as a conservative promise-of-completion date. While the 80th percentile may appear overly conservative, it is a useful promise-of-completion date if a number of new but currently unknown risks (i.e., “unknown unknowns”) are anticipated. The 50th percentile date may expose the project to overruns.

Table 17: Probability of Project Completion

	Baseline	5 <sup>th</sup> percentile	50 <sup>th</sup> percentile	80 <sup>th</sup> percentile	95 <sup>th</sup> percentile
Finish date	Sept. 6, 2012	Sept. 18, 2012	Oct. 23, 2012	Nov. 13, 2012	Dec. 6, 2012
Calendar days beyond scheduled finish date	-	12	47	68	91

Source: GAO analysis of contractor data

In the case of the WAAS contractor schedule, our analysis concluded that management should realistically expect cutover, or completion, between October 23, 2012, and November 13, 2012, the 50th and 80th percentiles, respectively. The artificial must-finish date constraint of September 6, 2012, built into the schedule is unlikely. Our analysis shows the probability of completion by September 6, 2012, is less than 5 percent likely with the current schedule without risk mitigation. There are two reasons why the planned end completion date is not likely to occur, according to the results of our schedule risk analysis. First, most risks are threats only. Only two opportunities were identified during the analysis: (1) the estimating error of the schedule may be between -10 percent and 15 percent, and (2) there is a 65 percent chance that the 11-day formal shadow test will not be needed. Second, there are parallel paths within the structure of the schedule that lead to merge points. If several paths converge to one milestone, the latest merging path determines the date. This “merge bias” cannot accelerate schedule dates and usually adds structural risk to the schedule.

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## Identified Risks

The contractor supplied six different risks that are currently identified in the project’s risk register. Using these risks as a basis for discussion, we interviewed 16 experts familiar with the project, including prime contractor officials, FAA officials, and technical FAA consultants to identify any other risks. Each interviewee was asked four questions to address four related points.

- *To estimate the probability that an identified risk will occur on the project in such a way that some activity durations are affected. The estimated probability is translated into the percentage of iterations that are chosen at random during the simulation. For example, if the expert estimates weather will have a 10 percent chance of affecting some activities, then, on average, weather risk will occur in 10 percent of the Monte Carlo iterations.*
- *If the interviewee believed the identified risk was likely, the interviewee was asked to identify which activities’ durations would be affected. For example, activities related to steel erection or concrete pouring may be affected if the weather risk is realized and bad weather occurs.*
- *After the interviewee identified affected activities, the interviewee was asked to provide a three-point estimate of the risk’s effect on duration—low, most likely, and high. Estimates were provided as*



percentages, which were applied to the activity durations in the Monte Carlo simulation if the risk occurred. For example, if bad weather occurs, the duration of a 10-day steel erection activity may be affected a minimum of 110 percent, a most likely of 150 percent, or a maximum of 200 percent. These percentages translate into increases in the activity's duration of 11 days under a low-risk scenario, 15 days under the most likely risk scenario, and 20 days under the maximum risk scenario. If the risk is not realized, there is no change to the activity's original estimated duration.

- *Finally, the interviewee was asked to identify any unaccounted for risks.*

We began the interviews with 6 risks and, through the interview process, identified 16 more risks. During data analysis, some risks were consolidated with others or eliminated because of limited data. In all, 14 risks were identified and incorporated into the Monte Carlo simulation. These include 9 risk drivers, 4 existence risks, and 1 schedule duration risk.<sup>1</sup>

The final risk drivers used in the schedule risk analysis are as follows:

- Some software Release 3B problem reports require testing with a live geostationary satellite; software simulation environment may not be able to test all requirements.
- Potential difficulty repairing Fullerton contractor's lab safety computers.
- Software delays in software Release 3A and additional changes to software Release 2B are likely to delay the 3B schedule.
- Parallel implementation of Releases 2B, 2C, 3A, and 3B create competition for FAA resources.
- Release 3B problem report testing is more complex and subject to uncertainty.

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<sup>1</sup>The schedule duration risk is applied to each activity's duration to represent the inherent inaccuracy of scheduling.

- FAA WAAS personnel move around, and inexperienced staff must be trained on WAAS.
- Workshare strategy between FAA and its prime contractor affects the schedule for on-the-job training learning curve.
- Changes to the simulation tools may be more difficult or more time-consuming to implement than anticipated.

The final existence risks are as follows:

- FAA performs formal software release 3B shadow test.
- Late problem report may come from FAA.
- FAA program office is resource-limited.

Inserting existence risk activities does not affect dates within the baseline schedule because the activities initially have zero duration. The activities have duration only if they happen to occur during an iteration of the simulation.

The final uncertainty risk is schedule without buffer may be optimistic.

Most risks were identified by multiple respondents during the interviews. During data analysis, data from the interviews are combined and analyzed to create ranges and probabilities for each of the 14 risks.

Because risks are multiplicative, several risks occurring on the same activity may overestimate the true risk. That is, by default in the Monte Carlo simulation, risks occur in a series, one after another, so that an activity that has several risks may be unrealistically extended if all risks occur. In reality, an activity may recover from two or more risks simultaneously, so that the actual risk is not multiplicative. Therefore, to avoid overestimation of risk, risks can explicitly be defined as occurring in parallel rather than in series. Risks that occur in a series will occur one after the other and add (or subtract) their respective effects on duration to the affected activity. If risks occur in parallel, on the other hand, only the maximum effect of all risks will affect the duration. For example, if the risk of complexity adds 3 days to the duration of software development and the risk of staff shortages adds 4 days, then development will extend 7 days if the risks are defined in series. However, the duration will extend only 4 days if the risks are defined as parallel. This definition of parallel

risks helps temper any risk overestimated by a multiplication of risk factors. We defined one risk in series: software delays in Release 3A and additional changes to Release 2B are likely to delay Release 3B schedule. All other risks were assumed to be parallel.

Most risks were assigned directly to existing activities in the schedule. However, some risks required adjustments to the schedule. These adjustments involved replacing lags with activities and inserting existence risk activities.

*Lags:* During our initial analysis of the contractor's schedule, we identified 25 remaining activities with lags and 21 remaining activities with leads (negative lags). While lags represent the passing of time between activities, they are often misused to put activities on a specific date or to insert a buffer for risk. That number was reduced to 20 activities with lags and 6 activities with leads with the "Rev 1" schedule that was altered by the prime contractor for our use in the schedule risk analysis. We replaced the 33-day lag between the R3B Start Cutover and R3B End Cutover activities with an actual activity, ID 258 "Cutover Task." Replacing lags with actual activities does not affect dates within the baseline schedule because the activities have the same duration as the lags.

*Existence risk:* We identified some risks that would add an indeterminate amount of time to the overall schedule if they were realized. For example, if the Tijuana facility is not ready because software requirements are misunderstood, it could add 4 to 26 days to the schedule in the form of additional facility work.

**Prioritizing risks and risk mitigation:** Risks can affect the schedule in several ways: They can have a high probability of occurring; have a large-percentage impact on the durations of the activities they affect; or they can apply to risk-critical paths, which may differ from the baseline deterministic critical path. Beyond applying 14 risks to the schedule, we were interested in identifying the marginal impact of each risk. That is, we were interested in identifying which risks have the largest impact on the schedule because these were the risks that should be targeted first for mitigation.

To find the marginal impact of a risk on the total project risk at a certain percentile, the Monte Carlo simulation was performed with the risk removed. The difference between the finish dates of the simulation with all the risks and the simulation with the missing risk yielded the marginal

impact of the risk. Table 18 gives the priority of risks at the 80th percentile and the marginal impact of each risk.

**Table 18: Prioritized Risks at the 80th Percentile**

Priority level	Risk	Marginal impact in calendar days
1	FAA program office is resource-limited	13
2	Software delays in Release 3A and additional changes to Release 2B are likely to delay Release 3B schedule	7
3	Release 3B problem report development and test are more complex than planned and subject to uncertainty <sup>a</sup>	7
4	FAA personnel move around and often get inexperienced people to train	8
5	Workshare strategy between FAA and prime contractor affects schedule for on-the-job training learning curve	15
6	Late problem report may come from FAA	7
7	Some Release 3B problem reports require testing with a live geostationary satellite; software simulation environment may not be able to test all requirements	6
8	Schedule without buffer may be optimistic	5
<b>Total</b>		<b>68</b>

Source: GAO analysis of WAAS schedule

<sup>a</sup>These are two separate risks but are assigned the same priority because they are correlated 100 percent in our analysis. That is, we assumed if complexity affected one, it would necessarily affect the other.

The marginal impact directly translates to potential calendar days saved if the risk is mitigated. Once risks are prioritized at the percentile desired by management, a risk mitigation workshop can be implemented to deal with the high-priority risks in order. The prioritized list of risks will form the basis of the workshop, and risk mitigation plans can be analyzed using the risk model to determine how much time might be saved. Project managers cannot expect to completely mitigate any one risk, and it is not reasonable to expect to mitigate all risks. In addition, risk mitigation will add to the project budget. However, some opportunities may be available to partially mitigate risks.

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# Appendix V: GAO Contact and Staff Acknowledgments

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## GAO Contact

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## Staff Acknowledgments

In addition to the contact named above, individuals making key contributions to this report include Edward Laughlin and Karen Richey (Assistant Directors), Lindsey Bach, David Brown, Pamela Davidson, Tisha Derricotte, Kevin Egan, James Geibel, Bert Japikse, Delwen Jones, Jason Lee, Dominic Nadarski, Josh Ormond, and Brian Welsh.

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