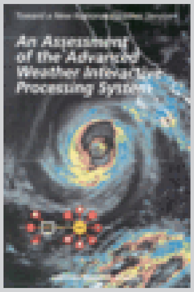

An Assessment of the Advanced Weather Interactive Processing System: Operational Test and Evaluation of the First System Build

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Toward a New National Weather Service

An Assessment of the Advanced Weather Interactive Processing System after Operational Testing of Build 1

National Weather Service Modernization Committee

Commission on Engineering and Technical Systems

National Research Council

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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Cover Photo: The GOES-9 satellite picture features Hurricane Linda at 1900 universal time on September 13, 1997, courtesy of the Air Force Weather Agency, Offutt Air Force Base, Nebraska. The diagram superimposed on the satellite picture represents data gathered by the National Weather Service and integrated with data from local sources using AWIPS workstations. The diagram infographics were provided by John Grimwade, Popular Science Magazine.

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NATIONAL WEATHER SERVICE MODERNIZATION COMMITTEE

RICHARD A. ANTHES *(chair)*, University Corporation for Atmospheric Research, Boulder, Colorado
WILLIAM E. GORDON *(vice chair)*, NAE, NAS, Rice University (retired), Houston, Texas
DAVID ATLAS, NAE, Atlas Concepts, Bethesda, Maryland
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KENNETH C. CRAWFORD, Oklahoma Climatological Survey, Norman
DARA ENTEKHABI, Massachusetts Institute of Technology, Cambridge
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ALBERT J. KAEHN, JR., U.S. Air Force (retired), Burke, Virginia
JENANNE L. MURPHY, Hughes Information Technology Corporation, Vienna, Virginia
VERONICA F. NIEVA, WESTAT, Inc., Rockville, Maryland
DOROTHY C. PERKINS, National Aeronautics and Space Administration, Greenbelt, Maryland
PAUL L. SMITH, South Dakota School of Mines and Technology, Rapid City

Technical Advisors

CHARLES L. HOSLER, Pennsylvania State University, University Park
DAVID S. JOHNSON, National Research Council (retired), Annapolis, Maryland
ROBERT J. SERAFIN, NAE, National Center for Atmospheric Research, Boulder, Colorado

Advanced Weather Interactive Processing System Panel

JENANNE L. MURPHY *(chair),* Hughes Information Technology Corporation, Vienna, Virginia
WILLIAM D. BONNER, National Center for Atmospheric Research, Boulder, Colorado
KENNETH C. CRAWFORD, Oklahoma Climatological Survey, Norman
GEORGE J. GLEGHORN, NAE, TRW Space and Technology Group (retired), Rancho Palos Verdes, California
ALBERT J. KAEHN, JR., U.S. Air Force (retired), Burke, Virginia
DOROTHY C. PERKINS, National Aeronautics and Space Administration, Greenbelt, Maryland

VERONICA F. NIEVA, WESTAT, Inc., Rockville, Maryland
ARTHUR I. ZYGIELBAUM (technical advisor*)*, California Institute of Technology, Pasadena
ROBERT J. KATT, technical writer, consultant

Staff

FLOYD F. HAUTH, study director
MERCEDES ILAGAN, study associate
WANDA PRIESTLY, project assistant

Preface

Since 1991, the National Weather Service Modernization Committee (NWSMC) of the National Research Council has been continuously involved in reviewing the plans for the development of the Advanced Weather Interactive Processing System (AWIPS). A panel of the committee was asked to gather data and to report to the full committee to help complete formal reports. The panel includes seven NWSMC members, a former committee member (and former panel chair) as advisor, and a consulting technical writer.

The committee appreciates the cooperation and assistance provided by the National Oceanic and Atmospheric Administration (NOAA), the National Weather Service (NWS), and the staff of several forecast offices and river forecast centers. Special thanks to Louis Boezi and Mary Glackin, of NWS, and Stuart Williams, of NOAA, for their presentations and other support for the report. I also want to give special recognition to Jenanne Murphy, chair of the panel, and Arthur Zygielbaum, former chair and current advisor to the panel, for their leadership, and to the other members of the panel who helped monitor AWIPS development and participated in the operational test and evaluation (OT&E).

On behalf of the committee, I express our appreciation to Floyd Hauth, study director, and Mercedes Ilagan, study associate, for their expert organizational and logistical support, and to consultant Robert Katt for his extensive assistance in the OT&E and in preparing this report.

RICHARD A. ANTHES
Chair, National Weather Service
Modernization Committee

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Executive Summary

The last major technical system required to complete the decade-long modernization of the National Weather Service (NWS) is the Advanced Weather Interactive Processing System (AWIPS). When commissioned for operation, AWIPS will be a distributed data processing system used at NWS field offices, regional offices, and headquarters to integrate information received from all other observational and analytical elements of the modernized system. AWIPS will support the work of hydrologists and meteorologists by delivering state-of-the-art forecasts and warnings. AWIPS will also provide a nationwide communications network, with the NWS offices as its nodes.

In 1995, NWS adopted an incremental approach to developing and deploying AWIPS, an approach in which increasingly capable software "builds" are deployed to increasing numbers of field offices. With each build, the system grows in terms of both operable functions and the number of nodes in the operating network. Each deployment of a major new build requires a period of field testing by real users (forecasters) engaged in real operations. The results are fed back to AWIPS program managers and developers to guide subsequent incremental development and deployment (IDD). The first operational test and evaluation (OT&E) occurred in the fall of 1996 when AWIPS Build 1 was installed at 12 sites, 9 of which are NWS weather forecast offices or river forecast centers. In this report, the National Weather Service Modernization Committee (NWSM Committee) presents a retrospective evaluation of the first OT&E as an essential component in bringing AWIPS to maturity and a prospective commentary on key issues raised by the OT&E.

BUILD 1 OPERATIONAL TEST AND EVALUATION

The results of the OT&E were gathered from on-site teams; formal questionnaires prepared by AWIPS users; teleconferences among field staff, program managers, and developers; and formal reports of the network control facility (NCF), which acts as the network manager for the entire AWIPS. These mutually reinforcing modes for OT&E feedback contributed greatly to its success. The following major system improvements, made in response to OT&E results, highlight the value and effectiveness of the OT&E process:

- Intermittent problems with reception of the satellite broadcast signal that conveys satellite data, weather model data, and other information from the NCF to field sites were diagnosed and now appear to have been corrected.
- The workstation processes for retrieving weather model data for display were confirmed to be too slow for use in operations. NWS managers relied on these and other OT&E results in deciding to replace the user interface portion of the Build 1 AWIPS with an alternative that had been developed in parallel with the main design. The alternative interface will be incorporated in AWIPS Build 3.
- Problems with NCF performance will be addressed partly by the previously planned addition of automated trouble detection and recovery processes in later builds and partly by changes in staffing.
- The procedures and automated tools used during the OT&E to catalog and track reported problems have evolved into an effective change management process and configuration management tool for the AWIPS program.

Based on these observations, the NWSM Committee concludes that the OT&E process is an effective, valuable, and necessary element in the incremental development and deployment of a system capable of fulfilling the objectives of the NWS modernization program.

RECOMMENDATIONS ON THE OPERATIONAL TEST AND EVALUATION PROCESS

Recommendation. The AWIPS program should continue, and perhaps expand, a deployment strategy of maximizing the diversity of weather office forecasting operations to test the performance ranges and to identify site-specific and systemic improvements as early as possible.

Recommendation. The AWIPS program should, as already planned, include a formal OT&E when each major build is deployed to ensure that operational performance continues to improve.

PROSPECTIVE ISSUES

Looking beyond the Build 1 OT&E, the NWSM Committee suggests improvements in two areas as the NWS proceeds with work on AWIPS. These two areas are systems engineering and operational risk management.

Systems Engineering

An AWIPS systems engineering team was named in May 1997, but a committee-like team may not be able to perform all of the functions normally undertaken by a project systems engineer and a team of subsystem engineers who have been assigned specific responsibilities and authority. As the NWSM Committee understands the current AWIPS organization, no single individual has the assigned responsibility and the delegated authority to act as a system-wide, comprehensive systems engineer. Nor does the AWIPS program have a hierarchical systems engineering team composed of subsystems engineers. Instead, members of the systems engineering team appear to have been assigned to represent organizational entities. The AWIPS contractor's systems engineer is not a regular member of the AWIPS systems engineering team.

Among the outstanding issues that call for a strong systems engineering approach are (1) problems related to locally developed code, which is application software written by NWS field office staff for local use but attached to the AWIPS software system, and (2) the difficult task of transferring development and maintenance responsibilities for major software modules from the development group that initially writes the software to another group (i.e., the transfer of ownership of AWIPS software). The second problem is most obvious in the transfer of ownership of the new workstation interface and data retrieval modules from the Forecast Systems Laboratory, which developed them, to the NWS Office of Systems Development.

Recommendations for Systems Engineering

Recommendation. The NWS should establish the position of AWIPS project systems engineer with system-wide, comprehensive responsibility and delegated authority for performing the functions detailed in this report.

Recommendation. The NWS should formally establish an AWIPS systems engineering team led by the AWIPS project systems engineer and composed of systems engineers for each subsystem.

Recommendation. The AWIPS contractor's systems engineer should be formally and directly included on the AWIPS engineering team, and the contractor's systems engineering processes should be included in the overall AWIPS systems engineering functions.

Recommendation. The AWIPS systems engineer should ensure that processes are in place to (1) accommodate locally developed code, including programming support, testing support, and regression testing to ensure that commissioned functions continue to perform as expected; (2) provide sufficient resource margins to accommodate a reasonably expansive scenario of local code development; and (3) manage the system configuration, including locally developed code.

Recommendation. Under the leadership of the AWIPS project systems engineer, AWIPS management should establish a process for transferring responsibility for, and the detailed knowledge of, software elements from the developing organization to the deploying organization and subsequently to the operating organization. If the complexity of the system, its components, or its interfaces precludes a complete transfer, the AWIPS project systems engineer and AWIPS managers should, through formal agreements, ensure that support will continue to be available.

Operational Risk Management

The AWIPS program has already adopted a number of risk management practices that have been valuable in reducing development risks. As work progresses for Build 4, risk management for operational performance of the full, multisite AWIPS network is becoming the focus of risk management. The NWSM Committee has specific suggestions to offer on several aspects of continuing risk management.

First, even with the current contingency plans for the AWIPS satellite broadcast network, the committee is concerned that the master ground station in this network is a potential single point of failure for the entire AWIPS. Second, although plans have already been made for improving the performance of the NCF (by addressing problems with its troubleshooting and recovery functions for active AWIPS nodes), the committee encourages the NWS to demonstrate that these corrections will provide a reasonable margin of safety for the fully implemented AWIPS. Third, the automated processes and operator procedures for a neighboring site backing up a “down” field site and for recovering operational capability at the down site should be carefully reviewed and tested for the possibility of cascading failures, which could bring down many sites. Fourth, the mechanisms in place for emergency replacement of critical hardware components should be tested periodically. Fifth, physical threats to external communications systems that support AWIPS or unauthorized access to AWIPS can jeopardize operational performance and should be included in the risk management plan.

Recommendations for Operational Risk Management

Recommendation. A realistic operational test of the contingency plan for failure of the master ground station should be planned and conducted well before AWIPS is commissioned. The AWIPS risk management program should include (1) an exploration of scenarios under which the alternative uplink is unavailable and (2) an evaluation of remedial actions.

Recommendation. NCF performance should be watched closely to ensure that necessary improvements are forthcoming. This monitoring should be a top priority in the Build 3 time frame.

Recommendation. If improvements in the Build 3 time frame do not bring NCF performance up to operational standards, the AWIPS program should begin a risk reduction program to find a systemic solution to NCF performance problems. The NWS should consider reevaluating the design assumptions for monitoring and problem solving and should explore a wider range of solutions. At a minimum, NWS should reexamine the feasibility of the fundamental design concept for the NCF in light of experience since the Build 1 deployment.

Recommendation. To assess NCF performance and evaluate the NCF design concept, particularly as the number of active nodes in the AWIPS network increases, current or alternative NCF operations to perform designated emergency recovery functions should be tested under realistic conditions.

Recommendation. The AWIPS team should develop a plan to test the backup and recovery scenarios for AWIPS sites under field conditions. Documented procedures should be used to ensure that the system will perform as designed. A comprehensive analysis of failure modes for AWIPS as a system should be performed to identify all potential failure modes and develop preventive measures and recovery procedures to protect the system.

Recommendation. The site backup and recovery testing planned in the Build 4 time frame should include a thorough evaluation of the potential for the cascading failure of nodes. As many conditions under which such failures might occur as can be identified should be included in tests of the system's ability to detect and limit cascading failures.

Recommendation. Some form of periodic "drill" to test vendors' capability to replace system-critical hardware within the contractually agreed upon time should be included in the AWIPS risk management plan.

Recommendation. Detailed contingency plans for countering external threats to the integrity of the AWIPS system should be an integral part of the AWIPS risk management plan.

1

Introduction

NATIONAL WEATHER SERVICE MODERNIZATION COMMITTEE AND THE AWIPS PANEL

The National Research Council established the National Weather Service Modernization Committee (NWSM Committee) in 1990 to review and evaluate the modernization program of the National Weather Service (NWS) under Public Law 100-685, Title IV (1988). Since the NWSM Committee's inception, reports have been published under the series title *Toward a New National Weather Service*. Starting with the first report (NRC, 1991), the committee has commented on the status of the Advanced Weather Interactive Processing System (AWIPS), emphasizing the key role of this computer-based communications and data processing system in integrating information from all other elements of the modernized system and delivering properly interpreted forecasts, warnings, and other products to the public. A subgroup of the full NWSM Committee, identified as the AWIPS panel, has been assigned to keep abreast of the details of AWIPS development and report on them to the full committee.

In keeping with the rules of the National Research Council, the work of the AWIPS panel and of the full NWSM Committee has been restricted to making technical and scientific assessments within the scope of the committee's statement of task. Members of the committee are unpaid volunteers selected and approved by the National Research Council, not by the NWS or any other government agency. The conclusions and recommendations of the committee are presented to NWS only through written reports that have undergone a rigorous external peer review supervised by the National Research Council.

This is the committee's second report focusing entirely on AWIPS, although recommendations urging attention to delays in this vital component of the modernized weather service have been included in four other committee reports (NRC, 1991, 1992, 1994, 1996a). As AWIPS development and deployment proceeds over the next several years, further reports will be forthcoming.

THE COMMITTEE'S ROLE IN OPERATIONAL TEST AND EVALUATION

The original plan for AWIPS was based on sequential, temporally distinct phases of design, development, and deployment. In light of the problems with AWIPS development—problems frequently encountered in the development of complex, integrated systems—and as recommended by an independent review requested by the National Oceanic and Atmospheric Administration (NOAA) (Kottler, 1994), NOAA and the NWS adopted a more evolutionary approach to AWIPS development, in which increasingly complex "builds"[1] of the system will be deployed incrementally (see Appendix B). Each deployment is followed by field testing of the functions in that build. Test results and user reactions under operational conditions are then used to guide succeeding stages of system development. The formal, systematic testing and gathering of information on the performance of a newly deployed build is called operational test and evaluation (OT&E). In an incremental approach to system development, an OT&E period should follow the deployment of each major build.

In February 1996, the NWSM Committee agreed to participate in the planning and execution of the OT&E for the first deployed build of AWIPS (Build 1) by providing an independent, outside review (Appendix A). Although the committee's AWIPS panel continued to act as the principal "eyes and ears" of the committee, other committee members also participated in meetings with NWS staff and on-site visits. Prior to the actual OT&E, committee members reviewed several rounds of draft OT&E planning documents, discussed the documents and the planning approach with NWS staff to clarify what was being done and why, and visited the system test facilities at both NWS headquarters and the prime contractor's facilities. During the early weeks of OT&E, teams of committee members visited four of the nine field sites at which AWIPS Build 1 had been installed. During these visits, the committee members observed the OT&E firsthand, watched NWS field staff as they worked with the new system, and discussed users' reactions to AWIPS Build 1 and the OT&E process.

In September 1996, the NWSM Committee issued a preliminary assessment of the Build 1 OT&E and an evaluation of the AWIPS incremental deployment approach that could be used as input to a key deployment decision for the AWIPS program by the secretary of commerce (NRC, 1996b). Since that preliminary assessment was issued, the full NWSM Committee has been briefed at its four

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[1] A build is a series of hardware and/or software upgrades that increases the functional capability of AWIPS.

regular meetings by NOAA and NWS staff and by the AWIPS panel on the continuation of the OT&E. These briefings included reports on efforts by NOAA/NWS and the AWIPS contractor to incorporate lessons learned from the OT&E into program decisions, system redesigns, and the ongoing development of AWIPS Build 2 (primarily communications and infrastructure software upgrades) and Build 3 (integration of an improved workstation user interface). AWIPS panel members and committee staff met with NWS and NOAA staff and the contractor on four additional occasions and were present at the formal design review for AWIPS Build 3. Panel members and staff have also monitored the periodic (initially weekly) teleconferences among staff from the AWIPS Build 1 field sites, NWS and NOAA staff responsible for the program, and the software developers.

The information obtained through these sources is the basis for the committee's evaluation of the Build 1 OT&E and of responses to the OT&E by NOAA/NWS. Chapter 2 is the committee's general evaluation of the OT&E processes implemented for Build 1 and the overall response to OT&E results. Chapters 3 and 4 focus on specific issues in AWIPS development the committee believes are important enough to the long term success of AWIPS—and therefore to the success of the NWS modernization—to warrant more detailed comments.

2

Operational Test and Evaluation for AWIPS

The OT&E process implemented by the AWIPS development team is an effective, valuable, and necessary element in the incremental development and deployment (IDD) of a system capable of fulfilling the objectives of the NWS modernization program. The remainder of this chapter explains the basis for this conclusion by first reviewing the basic structure of the Build 1 OT&E and then presenting the significant results for the AWIPS IDD and the long-term success of AWIPS in the modernized National Weather Service.

STRUCTURE OF THE OPERATIONAL TEST AND EVALUATION

The OT&E for AWIPS has two complementary parts: a system evaluation and a services evaluation. The system evaluation focuses on system performance and its impact on forecasting operations. The services evaluation assesses the broader impact of the new capabilities on forecasts and other products and services. The system evaluation was designed not only to test the system against its contractual performance requirements in operational conditions but also—as an appropriate and necessary part of an IDD process—to evaluate whether the system's performance is satisfactory for users. The evaluation included questionnaires on site installation, checkout, and training, as well as the forms used to gather data on functional tests of system performance and user reactions during the period of intensive OT&E surveying for each site. The Build 1 services evaluation was based primarily on a questionnaire that asked AWIPS users in field offices to compare AWIPS performance with current systems. In the OT&E for later AWIPS builds, the services evaluation will also include substantial input from users of field offices' services and products.

Each part of the Build 1 OT&E had its own national evaluation team, its own questionnaires, and its own on-site teams, which were responsible for involving field office staff in the tests and evaluations and ensuring that the questionnaires were completed and forwarded to headquarters for the national evaluation. In addition to structured-response questions, all of the OT&E questionnaires included room for, and encouraged, free-form comments from users.

The OT&E period at each site started after installation and checkout of the AWIPS Build 1 system and a week of on-site training for the local staff. The on-site evaluation teams were most active during the first week or so after this training week. Installation at the nine field offices was staggered over six weeks, so the intensive week of OT&E activity overlapped at two sites, at most, at any given time.

SATISFACTION OF OPERATIONAL TEST AND EVALUATION OBJECTIVES

The OT&E for AWIPS is intended to evaluate the effectiveness and suitability of each incremental build to support field services for warnings and forecasts. The objectives of the OT&E process specified in the OT&E plan are to:

- evaluate the effectiveness and suitability of AWIPS to the NWS mission and operations
- identify necessary modifications or improvements in AWIPS or in NWS operational procedures
- provide information on organizational and personnel requirements for logistics, maintenance, and real-time support
- verify the adequacy of manuals, documentation, and training
- verify that the system and all interfaces function as required in an operational environment

Based on the review of the OT&E plans and procedures, observations of OT&E implementation, participation in regular teleconferences, and a review of OT&E systems and services evaluation results, the NWSM Committee concluded that the OT&E process has accomplished its objectives. Although some major problems were found with Build 1 during the OT&E, these problems were uncovered precisely because it was tested under operational conditions. In addition to identifying necessary improvements, the Build 1 OT&E led to substantial improvements in the practices and procedures for making AWIPS operational.

One of the primary reasons for adopting the IDD approach (Kottler, 1994) was to allow for frequent evaluations of system performance and to provide early feedback. The NWSM Committee considers the OT&E process to be crucial to the success of AWIPS operation and strongly supports the NWS plan to conduct an OT&E at the time each major system build is deployed (NWS, 1996).

As a follow-up to the review of the OT&E process, the committee also reviewed the actions taken by NWS in response to problems identified during the OT&E. The objectives of this review were to determine whether the problems were resolved in a timely manner and whether the fixes actually improved operational performance. Based on the committee's review of the work-off rates of discrepancy reports (DRs), the installations of intermediate builds, and modifications to processes and procedures based on the results of the OT&E, the committee believes that NWS actions in response to problems were appropriate and did improve the operational performance of the AWIPS.

MAJOR SYSTEM IMPROVEMENTS

This section summarizes some of the major product and process improvements that resulted from the Build 1 OT&E.

Detection and Resolution of Satellite Interference

Early in the OT&E, satellite signal interference was encountered at some of the field sites. The problem was severe at Dodge City, less severe at Wichita and Topeka, and did not occur at the other sites. An initial analysis suggested that the cause was interference from local radio frequencies. However, as the OT&E continued to collect data and identify possible causes, engineering analysis indicated that there were systemic weaknesses in the design for signal processing and coding and in the ground-site antenna covers intended to protect the antenna dish from precipitation. A number of participants in AWIPS, including AWIPS OT&E staff and program managers in NWS, the AWIPS Acquisition Office in NOAA, the network control facility (NCF), the prime contractor, and several subcontractors, cooperated in working out the analysis and ensuring that corrective actions were taken to solve the problem completely. The solutions—broadcasting the signal via a different transponder with a better noise environment and changing the design for melting snow off the antenna—have now been tested in the operational environment and have greatly improved signal reception. In addition, demodulators to improve error correction algorithms are in production and are scheduled to be installed at field sites after the Build 3 OT&E.

Operational Limitations of the Workstation User Interface

Several major performance issues associated with the Build 1 workstation user interface first identified during the development and test of Build 1 were subsequently confirmed by the OT&E as significant operational problems. For example, the performance of AWIPS Build 1 when retrieving model data was unacceptable in operation, particularly when multiple data sets were requested. The Build 1 AWIPS system was designed to be completely flexible on the number and types of parameters that could be requested by a forecaster. This design feature turned out to have serious performance problems—such as long delays—

when multiple data sets involving derived parameters were requested for assimilation into a single loop display.

To resolve this problem and others related to the response times of workstation operations and the layout of the graphical interface, NWS decided to incorporate the superior user interface features of the AWIPS prototype known as "WFO-Advanced" into the formal AWIPS delivery baseline.[1] WFO-Advanced was developed by the NOAA Forecast Systems Laboratory (FSL) as a risk reduction prototype with the principal objective of ensuring the technical feasibility of writing software to encode the algorithms for meteorological applications envisioned for AWIPS. This prototype evolved from more than a decade of exploratory development and testing by FSL and thus had already incorporated significant user feedback on the format and content of display interfaces.

Some NWS staff at various Build 1 field sites, as well as AWIPS program staff, were already familiar with WFO-Advanced, and some had been able to use the prototype system at FSL or other locations. Even before the Build 1 OT&E, AWIPS program staff had known about features in WFO-Advanced that seemed superior to corresponding features in the AWIPS user interface. The responses of users during OT&E provided overwhelming confirmation that certain aspects of the AWIPS Build 1 interface were not well suited to users' needs and preferences (not "user friendly"). Also, the data storage and retrieval techniques used in WFO-Advanced were judged to be better than the AWIPS Build 1 design for some functions, particularly for the rapid retrieval and display of model data distributed over the satellite broadcast network (SBN).

In the NWSM Committee's interim report (NRC, 1996), the committee made the following recommendation:

> To meet the full operational requirements of AWIPS, the NWS should take advantage of alternative solutions such as the functional capabilities demonstrated in WFO-Advanced.

In truth, the committee's recommendation was just one of many suggestions and recommendations from various sources. The comments and evaluations from users during OT&E provided hard data supporting the change. By mid-November 1996, the decision had been made to incorporate the WFO-Advanced user interface with its superior information handling capabilities and more robust data reception and storage capabilities into the AWIPS system.

The technical approach adopted by the AWIPS Program Office in NWS[2] and approved by the AWIPS Acquisition Office in NOAA required FSL to prepare a

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[1] WFO is the acronym for weather forecast office, the name for meteorological forecast field offices of the postmodernization NWS. The second type of field office is a river forecast center. When the decision was made to incorporate WFO-Advanced into AWIPS, the incorporated version was renamed Forecast Office-Advanced because it would be used in both kinds of field offices.

[2] Since this decision was made, the AWIPS program manager has become the modernization systems manager as well, and the AWIPS Program Office is now the Modernization Systems Management Office.

"deliverable" version of its workstation software, referred to now as "Forecast Office–Advanced" or FOA. The Office of Systems Development in NWS has been assigned the technical lead in integrating the FOA code into the AWIPS site software, with FSL and the prime contractor playing supporting but critical roles.[3] The first integrated version will be deployed in AWIPS Build 3. Thus, the Build 1 OT&E provided the basis for a major change in the AWIPS design.

Performance of the Network Control Facility

The NCF, which is located near NWS headquarters in Silver Spring, Maryland, began performing its duties as AWIPS network administrator when the first AWIPS site became active. NCF's duties include remote monitoring via the network of the AWIPS servers and workstations at each field site; taking calls from field sites when problems are encountered; diagnosing and solving problems; acting via the network or through directions to field office staff to correct problems found by either route; and maintaining records of problems (by writing up trouble tickets). The role of the NCF as trouble-finder and trouble-fixer for all nodes in the AWIPS network is a key element in the NWS plan to maintain high levels of performance and reliability without burdening the field office staff with system administration and maintenance duties.

During and after the formal OT&E, field office staff reported problems with NCF's performance of its designated troubleshooting and recovery functions for the active AWIPS nodes. The NCF failed to meet its design concept and, more important, the operational needs of the field staff at AWIPS nodes.

According to the current design concept, AWIPS users report problems to the NCF (over the wide area network or by telephone), and the NCF fixes the problem. Users do not have to rely on a system manager or an on-site information systems specialist to diagnose the problem and perform the appropriate recovery procedure. For many problems with workstations or servers, the NCF staff can perform the recovery procedure remotely. In fact, the network infrastructure has enough built in automated monitoring and control so that it is technically feasible for NCF operators to identify and resolve many problems before the site staff is even fully aware of them. A crucial argument in favor of this design concept is that it will substantially reduce system life cycle costs, particularly with regard to constraints on site staff under the NWS Modernization program, compared to systems in which individual sites must handle most of their own monitoring and recovery.

The performance of the NCF improved as factors contributing to the inadequate initial rate of response were identified and corrective actions were taken. For example, the NCF software in place for the OT&E required a much higher

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[3] The prime contractor retained overall responsibility for integrating the site segment with the network segment.

level of operator attention to site activity and more manual entry of commands for recovery sequences than was planned for a fully functioning AWIPS. NCF staff have also had experience with the AWIPS monitoring and control functions and with their own administrative responsibilities and action sequences. The latest in a series of build-by-build increments to automate NCF monitoring and control functions, including firmware called MC/ServiceGuard, was incorporated into Build 2, which was released in May 1997.[4]

The procedures for reporting problems also revealed staffing difficulties at the NCF, including high turnover, staff who were not knowledgeable enough to address routine problems efficiently, and insufficient staff on all shifts to handle problems even at the current AWIPS and Pathfinder sites. Although the contractor has taken steps to correct these deficiencies and improve NCF staff performance, much remains to be done before NCF performance can be considered adequate. (See Chapter 4 for the committee's assessment of NCF's current status.)

Periodic Teleconferences

The FOA integration into AWIPS is the most significant product improvement to result from the Build 1 OT&E, but the periodic teleconference is the most significant process improvement. During the approximately six weeks of intensive OT&E, daily teleconferences were held for all parties involved at that point in the AWIPS OT&E. The participants included the AWIPS program manager, the evaluation team leaders (often with other team members present), one or more key technical managers for the prime contractor, someone from the NCF, and one or more staff members at each of the nine field site where AWIPS Build 1 was operational. These teleconferences were candid reports of what was happening—good and bad—at each field site, with no-holds-barred discussions of what needed to be done, what priority it should have, and who should do it. The teleconferences continued after the period of intensive OT&E but became less frequent, changing from daily to weekly during the latter part of the formal OT&E and then becoming less frequent by the spring of 1997 (six months after the beginning of Build 1 OT&E).

The significance of the teleconferences is in the way they are used. They have been open forums with broad participation (especially important is the participation by field office staff), serious attention from decision makers, and follow-through on the issues raised. Although teleconferences are held

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[4] In Build 2, MC/ServiceGuard firmware was added to the AWIPS site units, but the corresponding NCF software build to make full use of the ServiceGuard capabilities has only been installed recently (September 1997). When ServiceGuard is in operation, it should significantly improve automated monitoring by the NCF and automate much more of the recovery process for routine problems. The prime contractor has also increased the programming resources committed to automating test and recovery sequences with scripts that will be run by NCF operators to replace manually entered multi-step command sequences.

less frequently between formal OT&Es, the "open forum" culture has been maintained reinforcing the continuing, constructive involvement of busy field staff members as "operational testers" and ensuring that managers and technical leads receive steady feedback, both positive and negative, on results of IDD.

Teleconferences since the Build 1 OT&E formally ended in October 1996 have been used to plan and review releases of software between builds, as well as the Build 2.O release in May 1997. The teleconference culture has also been used to good effect by the geographically dispersed participants engaged in developing and testing the FOA-integrated AWIPS (Build 3). An assumption of the IDD approach to system implementation is that tough problems that require close cooperation among participants are bound to arise throughout the process. The robust systems engineering functions described in Chapter 3 are crucial to solving these problems within temporal and financial constraints. The teleconference culture that emerged during the Build 1 OT&E should play an important role by bringing problems and issues to the early attention of systems engineers and by providing a sounding board for proposed solutions.

Change Management and Configuration Management

As used in this report, a "change management process" is primarily an administrative process based on human actions and interactions, with bookkeeping and testing implemented through software. A change management process includes recording conditions that may require changes to a managed system, deciding if changes are needed and analyzing options, overseeing the execution of changes, and testing changes for resolving the initial problem. Change management processes usually make use of various automated systems, such as databases, electronic mail systems, project management and support tools, and an automated management tool called a "software configuration management tool." Although the automated tool is often thought of as a complete configuration management system, in fact the rules established for its use are also part of the system. These rules include, for example, giving one person (the configuration manager) supervisory control of the automated tool and establishing the rules software developers are supposed to follow when checking out modules and when checking them back in after changes have been made and the unit tested.

Prior to the Build 1 deployment, the AWIPS prime contractor's change management process included a software configuration management tool, a configuration management database for hardware configurations, documentation, and specifications. NWS units that were developing AWIPS software modules had different procedures and tools for configuration management. The procedures met the immediate needs of each developer-group as long as they worked independently, within the traditional model of software system implementation. However, in the spring of 1996, the AWIPS panel was concerned that the program as a whole did not have a change management process that encompassed all participants, including access to a shared configuration management tool that could stand up to the rigors and complexity of an IDD process. The panel addressed a number of questions to the program staff to clarify the situation. The program staff subsequently briefed the panel and the NWSM Committee indicating that progress had been made toward implementing a better system. Nevertheless, some of the glitches that occurred during the deployment of Build 1, particularly at the early sites, resulted from weaknesses in the change management process.[5]

An effective change management process covering all *current* AWIPS IDD participants has now emerged in response to the OT&E discrepancy reporting process. The preparations for the formal OT&E included a system for deriving a formal discrepancy report (DR) from trouble reports filled out by users at field sites, from NCF trouble tickets, and from other formal and informal user responses during the OT&E. Problems reported might involve AWIPS hardware, software, telecommunications, or documentation. The software DRs were entered and maintained in a software configuration management database using the same management tool (package) that the contractor had been using, but broadened in administrative scope to include configuration management of all the AWIPS codes, including programs and modules that were the responsibility of NWS or NOAA entities. After determining whether a software DR represented a deficiency in meeting an AWIPS specification or would require an enhancement, a review board assigned the DR a priority and incorporated the planned fix into the schedule of AWIPS interim and major builds. The software DR was then distributed to the entity responsible for developing that software—either the contractor or one of the NWS units preparing government-furnished software.

The difficult part of creating an effective change management system, in the view of the NWSM Committee members, was to make the system comprehensive. To be effective, a change management system must capture as input all of the modes of indicating an operational problem. It must trace each problem to a (suspected) root cause in hardware or software (documentation deficiencies are easier to analyze), assign a priority, designate someone to fix the problem, and ensure that the problem is fixed. Throughout the problem report life cycle, the system must ensure that all parties follow rules for repairing each and every deficiency and ensure that modifications do not create new problems. As new participants are brought into the circle of AWIPS developers (such as FSL when the decision was made to incorporate FOA into AWIPS Build 3), the change management process must be modified to include them.

Based on observations to date, the NWSM Committee concludes that the change management process implemented during the Build 1 OT&E has been a

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[5] The problem highlighted in the committee's interim report involved UNIX scripts (NRC, 1996). It is instructive (and typical in the software development industry) that the problem was not a failure of the configuration management tool but of the change management process. The troublesome scripts had not been placed under configuration management; that is, the tool had not been used to control changes to them.

practical success in meeting all of the operational objectives described above. Maintaining the effectiveness of this system as AWIPS deployment expands, in terms of both capabilities and the number of field sites, will be critical to the success of AWIPS. A highly effective change management process is essential to keep the systems engineering components of the AWIPS team (see Chapter 3) abreast of emerging problems so they can assess them accurately and implement tested solutions. A particular concern of the committee, discussed in Chapter 3, is how the change management process will be expanded to cover "locally developed" software applications.

AWIPS Development Team

To appreciate the significance of the Build 1 OT&E, one must understand how many organizational entities are now "players" in the overall process of AWIPS development and the complex relations that have evolved among them. One prime contractor is still responsible for developing important subsystems of the software, integrating all the software and hardware into a baseline system, physically installing the system, operating the NCF, and training users (NWS staff at field offices, headquarters, and other sites). The prime contractor oversees and has contractual responsibility for the work of several subcontractors for the SBN and the production, installation, and maintenance of system hardware.

Application software is also being developed at the NWS Office of Hydrology and the Technique Development Laboratory. With the decision to integrate FOA into AWIPS, FSL became another major "development player," and the NWS Office of Systems Development took on additional responsibilities as the integrator for all government-furnished software. The Modernization Systems Management Office (formerly the AWIPS Program Office), which is administratively under the NWS, and the AWIPS Acquisition Office, administratively within NOAA, continue to provide joint overall program management for the entire development team, including contractors and "in-house" members.

With the Build 1 OT&E, staff at field offices where AWIPS is installed also became important players in the ongoing IDD process. Two field offices, where the earlier Pathfinder prototype system had been installed in 1995, were already participants, to a limited extent. However, regular interaction between AWIPS users and other members of the team increased dramatically with the Build 1 OT&E and its periodic teleconferences. Status reports back to field offices through the AWIPS change management process, along with a reasonably good record for following through on user-reported problems, have kept system users involved in the IDD in ways that have contributed to the overall success of AWIPS.

The flow of information and products through this multicentered organizational network is not hierarchical although there are, necessarily, hierarchical trees for administrative, contractual, and decision-making purposes. But information, products, and cooperative efforts cut across the up-and-down hierarchies. The network will continue to change as players come and go and, more importantly, as roles change. For example, the roles of the various developers will change as AWIPS matures. And field office staff (at least some of them) will begin to act as highly decentralized developers, as well as system users and testers. Specific issues related to the role of field office staff in local development are addressed in Chapter 3.

CONCLUSIONS AND RECOMMENDATIONS

Based on the review of the OT&E plans and procedures, observation of how OT&E was conducted, participation in regular teleconferences, and a review of results of OT&E systems and services evaluations, the NWSM Committee has drawn the following conclusions regarding the OT&E process as implemented for the ongoing IDD of AWIPS.

Conclusion. The OT&E process implemented by the AWIPS development team is an effective, valuable, and necessary element in the IDD of a system capable of fulfilling the objectives of the NWS modernization program.

Conclusion. Continued success in the IDD process requires that each major AWIPS build be deployed at operational sites and evaluated in operational conditions.

Conclusion. The deployment of AWIPS at an increasing number of field offices with each new build is especially important for testing the system's functionality and multisite interactions and revealing problems early so they can be corrected in subsequent builds.

Conclusion. Further deployment and OT&E of AWIPS at this stage of development is appropriate and essential to the ultimate success of the NWS modernization.

Recommendation. The AWIPS program should continue, and perhaps expand, a deployment strategy of maximizing the diversity of weather office forecasting operations to test the performance ranges and to identify site-specific and systemic improvements as early as possible.

Recommendation. The AWIPS program should, as already planned, include a formal OT&E when each major build is deployed to ensure that operational performance continues to improve.

3

Systems Engineering

The AWIPS project has responded to increasing organizational and system complexity by appointing a systems engineering team. The NWSM Committee recognizes the value of this team as a forum for resolving systems issues but believes that further improvements are vital to ensure that AWIPS can be successfully implemented and maintained. In this chapter, the committee clarifies a concept of systems engineering for evolutionary systems development and recommends specific actions.

Systems engineering facilitates the coordinated design of systems that are made up of many elements and subsystems of elements so the system *as a whole* can meet the requirements and constraints imposed on it. The definitions of "systems engineering" and "systems engineer" vary by organization and area of application. In this report, these terms, the underlying principles, and the implementing organizations are characterized in the context of the development of complex information systems. The responsibilities of the systems engineer include compositing requirements, developing a system architecture, allocating requirements to subsystems and elements, identifying and managing performance and resource margins, and tracking the development process to evaluate results. Throughout the system life cycle, the systems engineer anticipates, recognizes, and solves problems to ensure that the system continues to fulfill requirements within project resources. System optimization may (and often does) entail the suboptimal design of some subsystems and elements. The systems engineer must have authority over the system/subsystem architecture, the allocation of requirements among subsystems, and the specification of interfaces between and among subsystems.

The designer-architect functions of the systems engineer are performed

TABLE 3-1 Generic Systems Engineering Functions and Their Roles during Incremental Development and Deployment

Generic Systems Engineering Function[a]	Applicability to Interbuild Phase of Incremental Development and Deployment[b]
Compile, composite, prioritize, and verify all customer requirements.	Reconfirm priority and specifics of requirements in light of user response to interim builds (e.g., respond to user input from OT&E and other field testing activity).
Define the system/subsystem architecture; derive requirements applicable to each subsystem; specify all internal (subsystem-subsystem) and external (system-environment) interfaces.	Ensure either (1) that the implementation remains consistent with the overall architecture, subsystem requirements, and interface specifications OR (2) that changes proposed to the architecture, subsystem requirements, or interface specifications in light of ongoing redesign decisions are applied throughout the system and that all implications are understood and accepted.
Determine the impact of all requirements on system, subsystems, and elements.	Monitor and allocate requirements, resources, and tolerances (margins) across subsystems and elements, with increasing precision as implementation proceeds; ensure that impacts of redesign decisions on these allocations are understood and planned for.
Derive an understanding of development risks, expendable resources, and costs.	Allocate and manage resource margins (contingency resources) as needed; continue to update and refine risk analyses for performance, schedule, and cost (implementation costs and life cycle costs); monitor and manage resource margins on the basis of latest test data; undertake risk reduction activities as indicated by results of risk analyses; maintain and update a life cycle risk management plan.
Conduct trade-off studies for optimizing the overall architecture to provide required robustness while minimizing risk, cost, and resource requirements consistent with system requirements.	Repeat and/or broaden trade-off studies when dictated by most recent assumptions.
Provide a model and mechanisms to test and ensure that subsystems meet the derived requirements and that the system as a whole meets the customer's requirements.	Continue testing incremental implementations (builds) to ensure that subsystems still meet their requirements; revise model and test mechanisms as required by redesign decisions, changes in system or subsystem requirements, or risk analyses that impact model assumptions; perform baseline regression testing.

continued

TABLE 3-1 *Continued*

Generic Systems Engineering Function[a]	Applicability to Interbuild Phase of Incremental Development and Deployment[b]
Monitor the progress of development; make systems design changes as appropriate to mitigate problems.	At each build deployment with an OT&E, monitor results for indications of problems that may initiate any of the systems engineering activities specified above; make design changes to future builds on the basis of results.

[a] The NWSM Committee wishes to acknowledge Frank Schutz (retired Deputy Director for Space and Earth Science Programs) and Arthur Zygielbaum (Senior Member of the Technical Staff and AWIPS Panel Advisor) of the Jet Propulsion Laboratory, National Aeronautics and Space Administration, for their assistance in formulating these generic systems engineering functions.

[b] The IDD functions were formulated by the NWSM Committee for relevance to the multibuild development and deployment process being used for AWIPS.

throughout the life cycle of the system, from initial specification through sustaining engineering. Because questions about the details of implementation and the allocation of resources and margins will continue to arise, initial systems engineering decisions must be revisited, refined, and expanded as experience is gained, uncertainties are resolved, and changes in design or initial requirements come up for consideration. This is especially important for an IDD process. In Table 3-1, principal systems engineering functions are listed (on the left) as they are commonly expressed. The NWSM Committee characterized these functions (on the right) as they apply to the “interbuild” phase of an IDD—the current state of AWIPS. The committee wishes to focus on the continuing need for systems engineering as characterized by the functions in the right-hand column.

SYSTEMS ENGINEERING FOR AWIPS

AWIPS is a complex system, and the AWIPS systems engineer must contend with many distributed elements, multiple sites, and intricate interconnections through multiple networks: the SBN (satellite broadcast network), the global network, local connections to radars and other data sources (for observations), links to the NOAA National Centers for Environmental Prediction (for forecast model data), and the National Environmental Satellite, Data, and Information Service (for weather satellite data).

In the development of a complex system, systems engineering is required at several levels. Engineering functions for each subsystem are equivalent to the functions performed for the entire system. The project systems engineer, who reports to the highest level of project management, typically heads a team that includes the subsystems engineers. The team helps the project systems engineer make design trade-offs, design the development and testing process, and track progress. A major concern of the NWSM Committee is that the hierarchy of system and subsystem engineering responsibilities for AWIPS has not been established with sufficient rigor to ensure that the functions listed in Table 3-1 can be performed when needed.

CURRENT SYSTEMS ENGINEERING STRUCTURE

Figure 3-1 summarizes the current systems engineering structure for AWIPS, along with organizational reporting and relevant functional flows.[1] The key organizational components of systems engineering for AWIPS are the systems engineering team, which is shown in the center of the diagram, and the systems engineering component of the contractor hierarchy, which is indicated by the flow of information from subcontractors through the prime contractor's director of engineering to the AWIPS acquisition manager. This complex organization may limit the NWS's ability to perform essential systems engineering functions. The committee's concern is not about which structure is developed but about how well the functions in Table 3-1 can be implemented now and throughout the IDD.

Systems Engineering Team as a Committee

The members of the systems engineering team represent several governmental organizations participating in the AWIPS IDD. This team is "under the direction of" the AWIPS technical manager, although its recommendations also go to the AWIPS program manager and acquisition manager. It is not clear to the NWSM Committee who, if anyone, has the responsibility and authority typically vested in the project systems engineer. It is also unclear if systems engineering responsibility and authority devolves to individuals on the team. The present structure is consistent with a committee approach, in which no one on the team is specifically accountable because no one has specific responsibility or authority to carry out responsibilities.

Good systems engineering requires the exercise of authority and the acceptance of responsibility within a technical hierarchy. The project systems engineer must report to the highest level of project management and must have clear, simple lines of technical authority and reporting that encompass the entire project. Systems engineering must be the full-time concern of this individual. The administrative hierarchy of the systems engineering team must be transparent in the sense that team members represent subsystems rather than organizational units.

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[1] Formation of the AWIPS systems engineering team was announced in a memorandum from the assistant administrator of weather services, NOAA, on May 9, 1997 (NWS, 1997). The operational role of the team was described as follows: "This team will function under the direction of the AWIPS Technical Manager and will be responsible for the resolution of system-engineering issues."

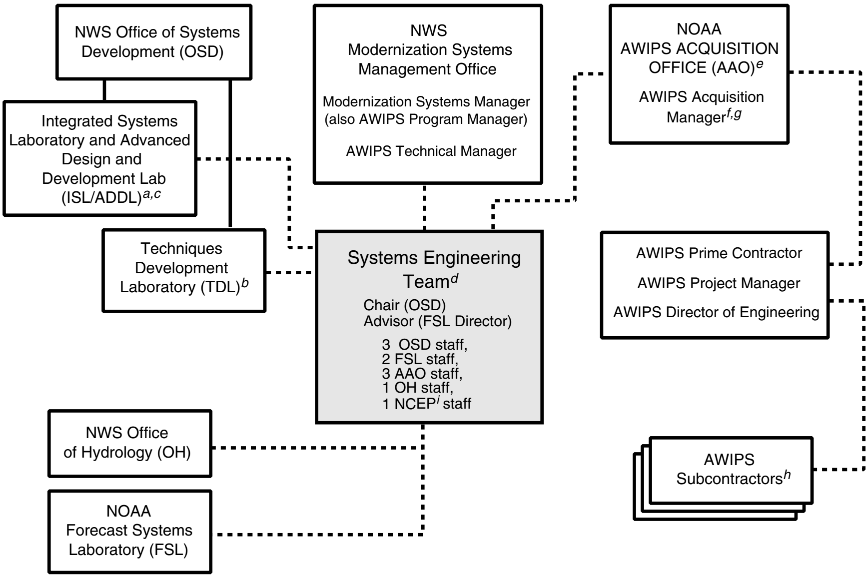

FIGURE 3-1 AWIPS developers and systems engineering organization.
[a]ISL/ADDL integrates and tests software from NWS and FSL developers and provides software to AWIPS contractor for integration and testing. [b]TDL, OH, and FSL give developed application software to OSD (ISL/ADDL) for integration and testing. [c]ISL/ADDL and TDL formally report to OSD. OH and FSL report to NWS and NOAA offices at a level higher than those shown here. [d]Systems Engineering Team is responsible for system design and evolution; and recommends baseline changes to accommodate new functionality and performance enhancements. AWIPS contractor support is provided as required. [e]AWIPS contractor reports to AAO and is responsible for design of network segment, operation, and management of NCF, integration and test of government furnished software, software builds and upgrades, field installation and testing of delivered systems, and maintenance and logistics services to field systems. [f]AAO manages AWIPS contract and acquisition budget and acts as government testing and quality assurance (QA) team. [g]Prime contractor formally reports to acquisition manager but takes technical direction from AWIPS technical manager. [h]Subcontractors provide hardware; design, install, and maintain hardware systems; and provide other technical support to prime contractor. [i]NCEP is the National Centers for Environmental Prediction (part of NOAA).

Engineering Responsibility for Software Subsystems

Systems engineering is necessary at all levels of a complex information systems development project. In modern practice, a subsystems engineer is responsible for all aspects of that subsystem, and the project systems engineer is responsibile for the entire system. He or she ensures that systems engineering functions are conveyed from “top to bottom” of the entire system. For AWIPS

Build 3, the prime contractor appears to retain the responsibility for integrating the hardware and software subsystems into the total AWIPS system and for integrating the software subsystem in its entirety. The NWS Office of Systems Development (OSD) is responsible for integrating all government-developed software, as well as for developing some code to integrate FOA into the AWIPS networking and communications "infrastructure" software. The hydrology and hydrometeorology applications being developed by the Office of Hydrology can be treated as a subsystem, but it may not be feasible—or effective—to define other subsystems to coincide with organizational units. Subsystem engineering responsibility and authority should coincide with functional subsystems.

Integrating the Prime Contractor's Systems Engineering Component

NWSM Committee members and advisors who have observed AWIPS development operations over the past several years report that systems engineering capability on the part of the prime contractor has improved greatly. Signs of improvement include the addition of an experienced senior systems-level engineer who has demonstrated the ability to understand and resolve system design issues and implement configuration control. As Figure 3-1 shows, the prime contractor's systems engineer (director of engineering) is in a position to oversee systems engineering internal to the prime contractor and by the AWIPS subcontractors.

The figure also illustrates the committee's concern about the integration of system-wide and team-wide systems engineering capability. The prime contractor's systems engineer does not have a formal position on the AWIPS system engineering team, which is supposed to recommend system decisions to high-level managers. Systems engineering issues will probably not fall neatly into issues that can be addressed by a government-developer-only team and issues that can be addressed by the contractors' systems engineers. Given the extent of integration of government-developed software and contractor-developed software and hardware subsystems, it seems appropriate and efficient that the contractor's systems engineer be included on the AWIPS systems engineering team.

Conclusions and Recommendations on the Current Structure

Conclusion. As the NWSM Committee understands the current AWIPS organization, no single individual is assigned the responsibility and given the authority to act as a system-wide, comprehensive systems engineer.

Recommendation. The NWS should establish the position of AWIPS project systems engineer with system-wide, comprehensive responsibility and delegated authority for performing the functions detailed in this report.

Conclusion. The AWIPS program does not have a hierarchical systems engineering team composed of subsystems engineers. Current members of the team appear to represent organizational entities.

Recommendation. The NWS should formally establish an AWIPS systems engineering team led by the AWIPS project systems engineer and composed of systems engineers for each subsystem.

Conclusion. The AWIPS contractor's systems engineer is not a member of the AWIPS systems engineering team.

Recommendation. The AWIPS contractor's systems engineer should be formally and directly included on the AWIPS engineering team, and the contractor's systems engineering processes should be included in the overall AWIPS systems engineering functions.

LOCALLY DEVELOPED CODE

The AWIPS requirements were designed to include the capability of NWS field staff to write their own application software to run on AWIPS workstations. This capability continues the historical role of NWS staff as developers of (1) experimental approaches to various hydrologic and meteorological analytic and forecasting tasks, some of which may ultimately be adopted across the NWS, and (2) tools to meet specific needs of a local forecast area that may not have wide applicability. From the perspective of systems engineering, allowing for locally developed code and supporting local developers who create and maintain it raises issues that must be addressed on a continuing basis.

First, local developers must have an environment in which they can efficiently create AWIPS-based applications without interfering with the commissioned system, either during the development and testing phase or while the application is being used. To support local developers, the applications programming interfaces (APIs) should provide access to commissioned AWIPS routines to avoid having to duplicate functionality and to minimize development and operations risk. The AWIPS design approach to providing both the APIs and the directions for using them is called "rules and tools." Although the general approach as described to AWIPS panel members seems reasonable, the design seems only to have been developed to a relatively early, conceptual level. The NWSM Committee is concerned that the APIs are not adequate to protect commissioned AWIPS functions from interference by locally developed code attached to the system.

Second, resources (for example, storage space and processing cycles) must be allocated for locally developed code. Allocation of resources, definitions of interface requirements and standards, and the other systems engineering activities related to optimizing the functioning of the entire system must include margins that will support locally developed code. The NWSM Committee has not seen evidence that such margins are available and appropriately managed.

Third, locally developed code presents special requirements for configuration management. Each site that supports local development must have a development environment separate from the AWIPS operating environment, just as the AWIPS software developers shown in Figure 3-1 must work in a development environment distinct from the operational AWIPS accessed by users. Operational libraries of local code must be kept separate from developmental versions. Perhaps the most difficult requirement is to establish an effective system for preserving libraries of locally developed code when the common, system-wide AWIPS is upgraded and for ensuring adequate regression testing of the operational local code with the upgraded system.

In discussions between NWSM Committee members and staff and AWIPS managers, these three issues were acknowledged as important for providing adequate local development capability in a mature AWIPS. These and other issues must be addressed as part of AWIPS systems engineering.

Conclusion. The safe use of locally developed code requires that (1) commissioned functions not be adversely affected, (2) sufficient performance, storage, and other resource margins be available to accommodate both local code and commissioned code, and (3) the system configuration, including all locally developed code, be formally maintained through an appropriate change management process.

Recommendation. The AWIPS systems engineer should ensure that processes are in place to (1) accommodate locally developed code, including programming support, testing support, and regression testing to ensure that commissioned functions continue to perform as expected; (2) provide sufficient resource margins to accommodate a reasonably expansive scenario of local code development; and (3) manage the system configuration, including locally developed code.

TRANSFERRING OWNERSHIP OF SOFTWARE DEVELOPED BY THE FORECAST SYSTEMS LABORATORY

The integration of FOA into AWIPS Build 3 presents AWIPS program managers with a problem that will recur throughout IDD and, to a lesser extent perhaps, throughout the operating life of AWIPS. Although the FSL developed the FOA software, the responsibility for developmental modifications after Build 3 is supposed to pass to OSD (NWS Office of Systems Development). This will free FSL to continue developing application modules to be incorporated in later AWIPS builds.

Eventually, when a mature AWIPS is operating as an NWS commissioned system (some time after deployment of Build 4), continuing maintenance would pass to the Office of Systems Operation. These transfers of ownership would free

FSL programming staff from their responsibilities for continuing upgrades and maintenance, as well as for troubleshooting, for the components of AWIPS software derived from FOA and other FSL-developed modules. FSL could then return to its primary mission as a laboratory for developing new forecasting techniques and tools, and AWIPS would be brought within the standard organizational structure for maintaining commissioned NWS systems.

A proven mechanism for transferring ownership of FSL-developed code to OSD (or to another AWIPS player) must be established as soon as possible for the FOA code and for additional AWIPS software modules. Transferring ownership of complex software requires that "deep" or "tacit" knowledge of the code be transferred to the new owners. In the AWIPS program, this knowledge is transferred through face-to-face meetings, teleconferences, and written documentation for programmers.

Although progress has been made in the transfer of knowledge, the NWSM Committee is still concerned that the transfer does not appear to be as far along as it should be for FSL to be freed of troubleshooting and continuing developmental responsibilities for the FOA-derived code after Build 3 is deployed. The committee suggests that one or both of the following courses of action would avoid systemic problems as AWIPS matures:

- Designate a development-to-operations transfer team, including a team leader (who has appropriate authority and accountability for meeting objectives) and other personnel (those who know, those who need to know, and those who can help in the transfer), and establish a schedule for effecting the transfer. Create a list of the documentation required, including the person(s) responsible for creating each document and those responsible for understanding and updating the documents as the software is modified during AWIPS IDD and beyond.
- Accept as a reality that FSL will always have to play a supporting role for code it develops. Identify one or more persons in FSL who will be long-term "consultants" on FOA and other FSL-originated code that is incorporated in AWIPS.

Although the issue of transferring ownership is at present most visible with respect to FSL and the FOA code, it also applies to other developers of AWIPS software modules, including developers of local applications. AWIPS is expected to continue to evolve even beyond the series of builds now planned. Unless the systems engineering component of the AWIPS team can implement practices for capturing the developers' deep knowledge of their codes during development, increasing amounts of AWIPS software will, in time, end up as "orphan code" that cannot be improved or updated. The only option for improvement will then be to abandon the orphan code and redevelop the functionality—that is, write, test, and integrate new code for the system that does what the old code did as well as meets new requirements.

Conclusion. Although code responsibility is scheduled to be transferred from development organizations to OSD or the Office of Systems Operations, the NWSM Committee believes that an effective transfer process must be defined, established, and managed.

Recommendation. Under the leadership of the AWIPS project systems engineer, AWIPS management should establish a process for transferring responsibility for, and the detailed knowledge of, software elements from the developing organization to the deploying organization and subsequently to the operating organization. If the complexity of the system, its components, or its interfaces precludes a complete transfer, the AWIPS project systems engineer and AWIPS managers should, through formal agreements, ensure that support will continue to be available.

4

Operational Risk Management

AWIPS was originally to be developed using the traditional "waterfall" approach by which all requirements would be met prior to implementation (i.e., software programming or hardware assembly). This traditional, but now largely abandoned, approach to implementing information systems requires that all risks be identified, weighed, and eliminated during the requirements definition and system design phases, before a single line of code is ever written. The IDD (incremental development and deployment) approach provides opportunities for early evaluation of functionality under operational conditions, thereby providing operational feedback that can be used to improve the ultimate product. The incremental release of AWIPS functionality to an increasing number of sites mitigates the risk of installing a complete system that does not meet operational requirements. Under the IDD model, risk identification and management are intrinsic, continuous, and essential parts of the development process.

AWIPS risk management initiatives to date have been effective in reducing developmental risks. As discussed in Chapter 2, the WFO-Advanced prototype was an attempt to mitigate risk by demonstrating the technical feasibility of programming advanced operational algorithms for AWIPS. A secondary objective was to explore an alternative design for a graphical interface, which users judged to be superior. Incorporating the WFO-Advanced graphical interface significantly improved system "friendliness" and usability, thus mitigating risks associated with operator error and the delayed interpretation of information. Another successful risk mitigation measure was the deployment of the Pathfinder prototype system at two field sites, which made possible the early operational testing and validation of critical AWIPS interfaces to NEXRAD and data dissemination networks.

Risk mitigation measures have so far been focused on the performance of AWIPS at individual sites. As AWIPS is incrementally deployed during the interbuild phase, the focus on risk management will shift—as it should—to operational performance for the full, multisite AWIPS configuration. This section of the report identifies certain operational risks the committee believes warrant attention as part of Build 4 development. Build 4 includes most of the automated functions for system backup and recovery and will provide the capability to exchange data with local users. The OT&E for Build 4 is scheduled for June–July of 1998. Detailed plans of operational test scenarios that will fully exercise the backup and recovery capabilities should be developed now to ensure that potential failure and recovery modes are fully tested during the OT&E phases in all subsequent builds. This is especially important because operational procedures involving personnel at multiple sites are a major part of the backup and recovery capability. Problems associated with system backup and recovery procedures should be identified and corrected well before AWIPS is commissioned.

SINGLE POINTS OF SYSTEM FAILURE

A single point of failure is a point in a system where failure of a component makes major functions of the entire system unavailable. A single point of failure in the current AWIPS design is the master ground station, located at Fort Meade, Maryland, which is the uplink facility that transmits data from the NCF (in Silver Spring, Maryland) to the SBN communications satellite.[1] The current contingency plan for failure of the uplink is to reroute SBN traffic from the NCF to a commercially available (rented) transmitting facility. It is not clear to the NWSM Committee that tests of this contingency operation have been conducted or planned. A single alternative facility could also become a single point of failure. Hence, risk can be reduced further by exploring scenarios under which the alternative uplink might not be immediately available to the NCF, for physical, operational, or administrative (managerial/contractual) reasons.

Conclusion. The contingency plan for failure of the master ground station may prove to be satisfactory, but a realistic operational test would reduce the risk of failure of the contingency plan. Overall system risk can be reduced by providing more than one backup.

Recommendation. A realistic operational test of the contingency plan for failure of the master ground station should be planned and conducted well before AWIPS

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[1] NWS is reviewing the possibility of relocating the master ground station antenna to the roof of NWS headquarters in Silver Spring, Maryland, to reduce or eliminate the possibility of some failure modes for the SBN uplink. The argument for testing the contingency plan in case this uplink fails would still apply to the relocated master ground station.

is commissioned. The AWIPS risk management program should include (1) an exploration of scenarios under which the alternative uplink is unavailable and (2) an evaluation of remedial actions.

ERROR DETECTION AND RECOVERY BY THE NETWORK CONTROL FACILITY

As discussed in Chapter 2, the NCF performance of critical tasks (responses to problems, accurate diagnosis, and timely recovery) has been inadequate so far. Some steps have been taken to improve site monitoring and automate response procedures and to improve the quality of NCF staff. However, users at some field sites still have little confidence in the NCF's ability to handle problems quickly, particularly on the evening and night shifts. Some field staff say they no longer bother contacting the NCF when specific, locally correctable problems arise. If these attitudes and practices become widespread, the NCF design concept will be vitiated in operation. The addition of more AWIPS sites to the network will only increase NCF's workload, complicate the situation, and exacerbate the problems. If this situation continues, it could degrade operation of the system (as field staff attempt to find and fix problems themselves) or create unanticipated costs (to provide site-level personnel resources).

Planned improvements in NCF performance, scheduled for the Build 3 time frame, are expected to resolve or mitigate many of these problems. These improvements must still be demonstrated so that necessary corrections can be made to ensure NCF's compliance with contractual and operational standards. The objective must be to ensure a reasonable margin of safety in NCF performance for the fully implemented AWIPS.

Conclusion. Current NCF performance does not meet operational standards for the full AWIPS system. Attention to the performance deficits and a systems-level analysis and implementation of an effective solution is critical to AWIPS success.

Recommendation. NCF performance should be watched closely to ensure that necessary improvements are forthcoming. This monitoring should be a top priority in the Build 3 time frame.

Recommendation. If improvements in the Build 3 time frame do not bring NCF performance up to operational standards, the AWIPS program should begin a risk reduction program to find a systemic solution to NCF performance problems. The NWS should consider reevaluating the design assumptions for monitoring and problem solving and should explore a wider range of solutions. At a minimum, NWS should reexamine the feasibility of the fundamental design concept for the NCF in light of experience since the Build 1 deployment.

In addition to more or less routine monitoring and recovery functions, the NCF plays important emergency roles in distributing software fixes to all AWIPS nodes and returning a “down” node and its backup node to normal operations. In response to problems that arose during the Build 1 OT&E, the “emergency release” function of the NCF was exercised in what could be called “proof of concept” testing. NCF distributed and installed software with fixes for identified bugs with minimal involvement of field office staff. The NCF’s role in backing up an entire field office by a neighboring office, and subsequent recovery, will also be tested directly in a future software release. NCF’s responsibility for installing emergency releases and recovering the system underscore the importance of maintaining effective NCF operation, even if this involves modifying the original design concept.

Conclusion. The NCF plays crucial roles in making emergency software repairs and in conducting field-office backup and recovery operations that are critical to system recovery and preventing failure.

Recommendation. To assess NCF performance and evaluate the NCF design concept, particularly as the number of active nodes in the AWIPS network increases, current or alternative NCF operations to perform designated emergency recovery functions should be tested under realistic conditions.

SITE BACKUP AND RECOVERY

AWIPS is designed to operate as a system of interoperable nodes. Each site will have a backup site, so that if it becomes impaired, the backup site can absorb its workload. This backup capability is important to the overall capacity of the system to provide hydrologic and meteorological coverage to all areas with minimal interruptions, even in the event that an entire field office becomes inoperable. Nevertheless, the automated load-shifting implied by this backup mode could lead to cascading failures analogous to system failures in regional electric power grids, the telephone system, and even the Internet. Failure modes must be carefully analyzed during the design and development phase to ensure that proper safeguards are built into the design and maintained through subsequent changes.

NWS and the prime contractor have developed load tests to verify the ability of individual sites to operate under the most strenuous conditions, including performing backup operations in addition to their normal workload. These tests have increased confidence in the backup scenario. However, this is only a first step toward demonstrating that the system can recover gracefully from all potential failure modes. Operational tests must be conducted to ensure that the system can recover as expected when a failure occurs.

Conclusion. Plans for risk management for AWIPS should include a systems evaluation to identify conditions that could cause a cascading failure of nodes, a capability to detect these conditions within the time constraints of automated backup response to a node failure, and implementation of monitoring and response processes to prevent or halt cascading failures and recover full system capability.

Recommendation. The site backup and recovery testing planned in the Build 4 time frame should include a thorough evaluation of the potential for the cascading failure of nodes. As many conditions under which such failures might occur as can be identified should be included in tests of the system's ability to detect and limit cascading failures.

Conclusion. The operational procedures (including operator actions) required to initiate backup operations, and then to restore normal operations, must be thoroughly tested under "live conditions."

Recommendation. The AWIPS team should develop a plan to test the backup and recovery scenarios for AWIPS sites under field conditions. Documented procedures should be used to ensure that the system will perform as designed. A comprehensive analysis of failure modes for AWIPS as a system should be performed to identify all potential failure modes and develop preventive measures and recovery procedures to protect the system.

EMERGENCY REPLACEMENT OF HARDWARE

The NWS has contractual agreements that specify times within which critical hardware components must be replaced if failure occurs. The NWS should ensure that these conditions can be met, particularly if the vendor or contractor does not contract directly with the government. Periodic testing of a vendor's ability to meet replacement requirements would also allow AWIPS managers to observe the responses to the kinds of external threats discussed in the next section.

Conclusion. Risk reduction could be substantially improved by testing vendors' capability to replace system-critical hardware before an actual failure occurs.

Recommendation. Some form of periodic "drill" to test vendors' capability to replace system-critical hardware within the contractually agreed upon time should be included in the AWIPS risk management plan.

MALICIOUS ACCESS AND EXTERNAL THREATS

The risk management plan should include contingency plans for potential threats, such as unauthorized computer users (hackers) breaking into the system from the outside (despite the firewall architecture), malicious access from within a site, widespread failure of communications systems on which AWIPS depends, physical destruction, and power outages of various magnitudes (geographically and temporally). In short, the plan should include responses to anything that might interrupt the flow of information to the AWIPS field sites or compromise the field staff's ability to process information and prepare forecasts, warnings, and other priority products. For scenarios with high risks of system failure or degradation, contingencies for recovery, localizing effects, or graceful degradation rather than a complete crash should be investigated. A major benefit of preparing these plans is that someone would have to think through system-level effects and contingency plans for avoiding or ameliorating them.

Conclusion. Unauthorized or malicious access, as well as external events like the loss of supporting external communications systems or destructive acts, pose real threats to the operation of AWIPS.

Recommendation. Detailed contingency plans for countering external threats to the integrity of the AWIPS system should be an integral part of the AWIPS risk management plan.

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Acronyms

AAO	AWIPS Acquisition Office
API	applications programming interface
AWIPS	Advanced Weather Interactive Processing System
COTS	commercial off-the-shelf
DR	discrepancy report
FOA	Forecast Office–Advanced
FSL	Forecast Systems Laboratory (administratively within the National Oceanic and Atmospheric Administration)
IDD	incremental development and deployment
NCEP	National Centers for Environmental Prediction
NCF	Network Control Facility
NOAA	National Oceanic and Atmospheric Administration (within the Department of Commerce)
NRC	National Research Council
NWS	National Weather Service
NWSM	National Weather Service Modernization
OH	Office of Hydrology
OSD	Office of Systems Development (of the National Weather Service)
OT&E	operational test and evaluation

QA	quality assurance
SBN	Satellite Broadcast Network
TDL	technique development laboratory
WFO	Weather Forecast Office
WFO-Advanced	the version of UNIX-based, advanced forecaster workstation software developed by the NOAA Forecast Systems Laboratory that was in use at the time of the Build 1 OT&E

APPENDICES

APPENDIX
A

Statement of Task

The statement of task for the NWSM Committee's assessment of AWIPS, as approved by the Governing Board of the National Research Council on May 14, 1996, is shown below. The fourth subtask will be addressed in a future report. The NWSMC will also continue to monitor and evaluate plans for and implementation of successive builds and system improvements. Additional details will be provided covering the fifth subtask and other subtasks as appropriate.

STATEMENT OF TASK

The NWSMC [NWSM Committee] will assess the adequacy of current plans and activities in the design, development, testing, and evaluation of AWIPS as an integral element of the modernization of the National Weather Service. Specifically, the NWSMC will assess whether the methodology used by the NOAA and NWS is sufficient to ensure that AWIPS will be able to integrate high-resolution data from multiple sources and provide fast-response interactive analysis and display of the data for weather forecast and warning operations.

Subtasks include:

a. Review the adequacy of AWIPS risk-reduction activities in mitigating risks associated with national deployment (Risks, as defined by NOAA, include problems with such factors as a system responsiveness and flexibility, communications linkages, and backup capabilities, that are associated with bringing a major new system online operationally without degrading forecast and warning services.)

b. Review the plans for AWIPS operational tests and evaluations to ensure that established criteria are being met.
c. Evaluate the adequacy of the conduct of the AWIPS operational tests and evaluations and the results or actions taken by NOAA and NWS in response to the tests and evaluations.
d. Assess the AWIPS system security and robustness in light of system designs and the results of the operational tests and evaluations.
e. Evaluate the planned evolutionary development processes for future improvements, considering system extensibility and the ability to evolve system components.

APPENDIX
B

Summary of AWIPS Builds

AWIPS Build	Release Date	Major Functionality Added in Build
1	September 1996	Satellite broadcast and site acquisition (ingest) and processing (database management) of data from GOES weather satellites, NEXRAD radar, and national forecast models (gridded model data); graphical user interface and workstation applications; hydrometeorological applications; basic NCF monitoring and control capabilities for site workstations at 12 field offices.
2	May 1997	Upgrade to new versions of COTS (commercial off-the-shelf) infrastructure software (operating systems, database engine, NCF monitoring and site backup); automated backup for application and data servers; simple print capability.
3	October 1997	FOA workstation interface and data management software integrated with AWIPS communications software infrastructure.
4	June 1998	Ingest and display of ASOS (Automated Surface Observing System) data; initial local data acquisition and dissemination (LDAD); terrestrial wide-area network (point-to-point communications); site backup; full NCF monitor, control, and archive capability.
5/6	1999	Advanced versions of forecast product generators; user-defined functions (e.g., derived parameters for gridded data); additional advanced user applications; intersite coordination; advanced LDAD and external interface capabilities.