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DOT/FAA/AM-94/5

Office of Aviation Medicine
Washington, D.C. 20591

Human Factors in Airway Facilities Maintenance: Development of a Prototype Outage Assessment Inventory

Robert E. Blanchard
Jennifer J. Vardaman

Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, Oklahoma 73125

February 1994

Final Report

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-94/5	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Human Factors in Airway Facilities Maintenance: Development of a Prototype Outage Assessment Inventory - Form A		5. Report Date February 1994
		6. Performing Organization Code
7. Author(s) Robert E. Blanchard and Jennifer J. Vardaman		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aeromedical Institute P.O. Box 25082 Oklahoma City, OK 73125		10. Work Unit No. (TRAIS)
		11. Contract or Grant No.
12. Sponsoring Agency name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, DC 20591		13. Type of Report and Period Covered
		14. Sponsoring Agency Code

15. Supplemental Notes

Prepared for: Program Office, Human Factors in Airway Facilities Maintenance, FAA Technical Center, Atlantic City, NJ.

16. Abstract

The airway facilities (AF) maintenance community is concerned with identifying ways of reducing both the incidence of equipment failure and the amount of time required to restore equipment to operational status following a failure. It is vitally important to identify the many components of downtime and contributors to a particular outage (equipment failure). Thus, the primary objective of this study was to develop a technique or tool with which to identify and map within a "systems" structure all potentially-significant contributors to AF maintenance downtime. The technique was designed to facilitate (a) the collection of maintenance-related data during an actual outage; (b) the entry of this data into a data base; and (c) the analysis of the data base in order to identify causal relationships. The secondary objective was to be able to make use of past outage data as a means for building the data base by determining whether overall outage time values can be apportioned among the contributors to downtime using subject matter experts (SMEs) who were intimately involved in restoring a given outage. SMEs from the Oklahoma City (OKC) General National Airspace System (GNAS) Airway Facilities Sector (AFS) and the Memphis GNAS AFS assisted in the iterative design and review process that produced the Airway Facilities Outage Assessment Inventory - Form A (AFOAI). Ten previous OKC GNAS outages and four previous Memphis GNAS outages were analyzed using the AFOAI - Form A, thus confirming that the inventory is a useful tool in identifying specific contributors to AF maintenance downtime. Recommendations were to continue to refine the format of the AFOAI and to install it on a trial basis to test its usefulness in collecting and analyzing data on factors and conditions contributing to facility outages.

17. Key Words •Airway Facilities •Data bases •Corrective maintenance •Human factors •Quantification •Maintenance reporting	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 26	22. Price

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGMENTS

This project was sponsored originally by ASM-200 with direction and support provided by Mr. Cogan Marshall (ASM-201). Later, sponsorship was assumed by ANS 3.1 with Ms. Brenda Boone as point-of-contact. Program managership was provided by Mr. John Wiley, ACD-350, FAA-Technical Center.

Numerous individuals within the Oklahoma City Airway Facilities Sector, Bethany, Oklahoma, and the Memphis Airway Facilities Sector, Memphis, Tennessee, provided support by supplying technical information and guidance, and by serving as subject matter experts during the process of designing and testing the Outage Assessment Inventory - Form A. Within the Oklahoma city Airway Facilities Sector, the valuable support and guidance provided by Mr. Jack Oxford, Sector Manager, and Mr. Ernie Hosack, Assistant Sector Manager, is gratefully acknowledged. In addition, the efforts of Mr. Vince Preston, Sector Manager, Jacksonville Airway Facilities Sector, Jacksonville, Florida, were of considerable value in reviewing draft editions of the inventory. Finally, the efforts of many of the staff of the Oklahoma City Airway Facilities Sector were vital to the review and initial operational test of the inventory, as follows:

Mr. Bill Jessee, Manager, Will Rogers NAVCOM Sector Field Office

Mr. Ray Carter, Manager, Will Rogers Airport Radar Sector Field Office

Mr. Charlie Youngblood, Proficiency Development Specialist

Mr. Dennis Rice, Assistant Manager for Technical Support

Mr. Jeff Lyons, Technical Support Staff

Mr. Chris Dumesnil, Technical Support Staff

Within the Memphis Airway Facilities Sector, Mr. Jim Sanford, Sector Manager, and Mr. Ted Stratton, Manager, Memphis Sector Field Office, were particularly helpful. The assistance provided by others on staff at the Memphis Airway Facilities Sector is gratefully acknowledged, as follows:

Mr. Gerald Vowell, MCC Supervisor

Mr. Bill Willard, Supervisor, NAVCOM Unit

Mr. Bill Strickland, Supervisor, Radar Unit

Mr. Larry Morrow, Supervisor, Environmental Support Unit

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HUMAN FACTORS IN AIRWAY FACILITYES MAINTENANCE: DEVELOPMENT OF A PROTOTYPE OUTAGE ASSESSMENT INVENTORY – FORM A

PURPOSE

There is continued interest within the airway facilities (AF) maintenance community in identifying ways of reducing both the incidence of equipment failure and the time required to restore equipment to operational status following a failure. The result is improved availability of the airways navigation and control system, with the attendant enhancement of aviation safety. Within the National Airspace System (NAS), AF maintenance duties are performed by two types of organizations, the General NAS (GNAS) Airway Facilities Sector (AFS) and the Air Route Traffic Control Center (ARTCC) AFS Sector. The two organizations are similar in that they essentially perform the same types of maintenance duties, including fault diagnosis (troubleshooting), repairing or replacing equipment/parts, confirmation (retest), recertification, and reporting the failed facility as operational. There are, however, two major differences between the GNAS and the ARTCC. The main difference between the two organizations is that all of the facilities for which the GNAS is responsible are out in the field or remote from the sector building, whereas all of the facilities for which the ARTCC is responsible are in the same building. Thus, the GNAS is a field operation, while the ARTCC is a more central (localized) operation. The second difference between the two organizations is that the GNAS provides the ARTCC with system status data on the radar operability. The ARTCC uses these data from the field sectors to manage Center equipment resources. Important to the goal of enhanced system availability is thorough consideration of human factors issues that may, in some fashion, influence performance of the maintenance function. An important philosophical consideration is that this problem must be perceived from a *maintenance system viewpoint* and not limited to scrutiny of any one component as a sole contributor to system downtime.

One should note that the AF maintenance community uses the terms "downtime" and "time-to-restore" synonymously. The term "outage" is used to mean (1) the onset of an equipment failure (or out-of-tolerance situation) or (2) the duration of time which elapsed before the equipment or facility was restored. Hence, "outage" may mean "failure," "time-to-restore," or "downtime." An outage begins when a detection agent (AFS, Pilot, Air Traffic Control [ATC], Flight Service Station [FSS]) reports an operational failure. An outage ends when the facility is properly returned to service and all required reporting is accomplished.

There are many components of downtime or contributors to the duration of a particular outage. These could vary from test equipment availability, physical accessibility of the failed facility, current weather, availability of useful technical data, availability of replacement parts, and so forth. Of course, availability and capability of assignable maintenance technicians is also an important factor. The point is that responsive treatment of the problem of facility outages cannot rest solely with attention to but one or two components: the attempt must be made to provide a structure by which all major classes of components or contributors can be identified. It may not be possible to precisely quantify their relative contributions, but their potential role in influencing downtime must be identified. Therefore, the primary objective of this study was to develop a technique or tool that identifies and maps within a "systems" structure all potentially-significant contributors to AF maintenance downtime. Furthermore, this technique should facilitate (a) the collection of maintenance-related data at the required level of detail during system restoration (including the assignment of outage time values as they actually occur); (b) the entry of those data into a data base; and (c) the analysis of the data base for purposes of identifying causal relationships. Ultimately, the technique should provide for the identification of alternatives or cost-effective "countermeasures" for reducing restore times, with the attendant gains in system availability. It was also important that the technique have immediate usefulness and value to the AF community, and be adaptable as AF operations become increasingly more automated and centralized in the future. A secondary objective of the study, which was consistent with the immediate-usefulness goal noted above, was to be able to make use of past outage data as a means for building the data base by determining whether overall outage time values can be apportioned among the contributors to downtime using subject matter experts (SMEs) who were intimately involved in restoring a given outage. Thus, the apportionment process would involve post hoc, after-the-fact analysis of outages.

APPROACH

Meeting the above objectives meant developing an instrument that was sufficiently sensitive to the AF maintenance process to identify human factors and system variables that may contribute significantly to system downtime. What was needed first was a means for mapping the components of downtime operationally based on a "systems" structure that would allow all possible (or most) potential contributors and their interrelationships to be identified. Further, it was important to be able to apportion to those components their specific shares of downtime; that is, to be able to apportion a "cost level" to their contribution. Such data would be important in assessing a particular outage (or series of outages) with respect to causal factors and their interactions. Finally, by having a thorough understanding of most (if not all) factors involved in a given outage, it would be possible to identify cost-effective alternatives to reduce failure rates and restore times, and improve availability.

Emphasis in the study was devoted to the GNAS. As indicated above, the technical approach followed the "systems" viewpoint to allow attention to conditions and circumstances surrounding maintenance performance involving equipment design, technical data, support and work environments, and logistical support, as well as the human maintainer.

Electronics Maintenance System Performance Factors

The literature on models and structures for appraising electronics maintenance performance from a "systems" viewpoint was reviewed. Elapsed time required to restore (correct) equipment (system, suite, unit, facility) to operational status was adopted as the measure of performance. The early work of Rigby and Cooper (1961) was considered for general guidance in assessing maintainability. Other approaches for assessing maintainer performance were obtained from Towne, Johnson & Corwin (1983). Literature derived from studies conducted on military systems was scrutinized particularly to identify a useful process/event model for detailing linear functions in corrective maintenance. In this regard, information on kinds of maintenance errors committed on military systems was located in the work of Orlansky & String (1981). The following well-established corrective maintenance functions were extracted from the literature for use in this study: (a) fault detection; (b) fault recognition; (c) fault localization; (d) fault isolation (troubleshooting); (e) fault correction; and (f) confirmation test.

Parker and Dick (1985) performed research relevant to this study in identifying factors found to be contributors to downtime in complex Navy electronics systems. These factors were organized into categories useful in developing the assessment instrument, as outlined below. Note that some categories relate directly to quality of maintainer performance while others involve hardware design factors, logistical factors, impediments due to geographic location, difficulty in obtaining physical access to equipment, and corrective maintenance factors such as test equipment operability and replacement part availability.

Corrective Maintenance Factors

1. Human behavioral processes
    a. Information sensing, collection, interpretation
    b. Specific/general knowledge base of electronics
    c. Deductive/inductive problem solving
    d. Planning and strategy formulation
    e. Action-taking/decision-making
    f. Reevaluation and assessment

2. Personnel factors
   a. Training and experience levels
   b. Skills, knowledges, abilities
   c. Personnel availability
   d. Personnel assignability
   e. Staffing levels
   f. Shift scheduling
   g. Management
3. System/Equipment Design Factors
   a. Equipment reliability (Failure rate)
   b. Internal accessibility
   c. Level (if any) of built-in-test
   d. Level of automation
   e. Test point availability
   f. Degree of automatic switching (redundancy)
4. Logistic Factors
   a. Maintenance philosophy (repair/replace)
   b. Parts sparing philosophy and location
   c. Part availability (repair pipelines)
   d. Quality/availability of technical manuals, data
   e. Availability of job performance aids (JPAs)
   f. Availability and operability of test support equipment
5. Physical Environment Factors
   a. Geographic distance
   b. Temperature
   c. Illumination
   d. Wind
   e. Physical impediments

From an overall systems' viewpoint, the above-listed factors (among others) could act singly or in combination to limit or impede the process of corrective maintenance (outage reduction).

Functional Framework

The above-listed corrective maintenance factors are general to most corrective maintenance applications. To be of use in the present application, these factors needed to be represented in a functional framework describing the AF maintenance process at the GNAS. To provide that structure, a functional framework, composed of 11 first-order functions, was devised that was bounded by the sequential progression of events, beginning at the onset of a facility outage, and ending when the facility is returned to service.

A taxonomy for classifying types of human errors was developed and embedded in the functional framework as First-Order Categories 6.0, 7.0, 8.0, and 9.0. The work of Drury (1987), in developing task-based frameworks, and that of Rouse (1990), in accounting for sources of human error, was considered in this task. Drury's (1991) attempt to develop a task and error taxonomy for aircraft inspection was also reviewed for possible use. The first-order functional categories selected to define the inventory are reported below.

1.0 Outage Causes (Coordinate With Cause Codes)
2.0 Outage Detection
3.0 Schedule Delay of Maintenance Action
4.0 Locate and Assign Technician
5.0 Travel Time to Site
6.0 Preparation for Corrective Maintenance
7.0 Fault Diagnosis
8.0 Fault Correction (Repair or Replace Equipment/Parts)
9.0 Confirmation/Certification
10.0 Recertification - Flight Inspection
11.0 Return Facility to Service/Reporting (Log Entry)

Development of the Outage Assessment Inventory (OAI)

Utilizing the above-noted maintenance factors and functional framework, various experimental forms of an outage assessment device were developed and tested. GNAS facility managers and technical personnel at the Oklahoma City (OKC) GNAS Sector Field Office (SFO) and the Memphis GNAS were consulted, and available maintenance reporting data were reviewed. Through this iterative process, the basic inventory was evolved, extended, and refined. This resulted in a preliminary form of an assessment device, which was labeled, Outage Assessment Inventory (OAI) - Form A. Heading information for this preliminary form of the OAI (which is included in Appendix A) includes (a) Facility/Service; (b) Ident. code; (c) Duration (of the outage); (d) Open Date (of the outage); (e) Cause

Code (from Order #6040.15C); (f) Recorder (name of person[s] who recorded the outage time values); (g) Open Time (of the outage); (h) End Date (of the outage); (i) End Time (of the outage); and (j) Remarks (about the outage).

It became clear during this process that the geographic location of the responding technician had a substantial impact on downtime; that is, whether the technician was located at the site, at the SFO, or elsewhere had a significant effect on downtime. In the latter instance, travel time became an important contributor to downtime. At this juncture, it became obvious that separate assessment inventories would need to be tailored for the GNAS and the ARTCC, in that the circumstances for responding and supporting corrective maintenance activities differ significantly between the two types of organizations, particularly in proximity to the failed facility or system. Also, it became apparent that the particular guidance followed in scheduling restore action was of critical importance in that ATC guidance on repair scheduling could result in considerable additional downtime.

As indicated above, the OAI was to provide first for mapping the specific circumstances (factors, conditions, or events) involved in a particular outage, and second for apportioning or assigning a downtime value to each component contributing to an outage. Consequently, application of the OAI would require two steps: (1) specific factors, conditions, or events relevant to the outage occurrence and detection would be identified and checked in the appropriate Check box; and (2) a portion of total downtime considered appropriate for each factor, condition, or event identified in Step 1 would be entered in the appropriate Outage Time box.

The hierarchical nature of the OAI allows for level of detail about any given outage to be determined by the amount of information available for a particular factor. The data recorder can penetrate quickly to that level of specificity commensurate with the amount and quality of information available. This protects against the "all or none" basis of data collection in which information on a factor is lost if not available at the most specific level. For example, Factor 10 concerns Flight Inspection (FI) recertification (if necessary) after equipment restoration. The following levels of analysis are available:

10.0	Recertification - Flight Inspection
10.1	Decision concerning whether or not to recertify
10.1.1	Did not initiate process (timely manner)
10.1.2	Performed process unnecessarily
10.2	Scheduled delay of Flight Inspection (FI) Aircraft
10.2.1	Limited availability of FI aircraft
10.2.2	Weather-related delays
10.2.3	Scheduling delays at busy airports
10.3	Flight Inspection (Duration)
10.3.1	Poor communications between AF and FI
10.3.2	Poor technical coordination between AF and FI
10.3.3	Process frequently interrupted but completed
10.3.4	Process incomplete; required rescheduling

At the highest order of detail, outage time data need only be available for total time cost for recertification (10.0). The next hierarchical level allows penetration to time costs for decision - making (10.1), scheduling FI aircraft (10.2), and performing the flight inspection (10.3). If additional data are available or can be obtained, the analysis can penetrate to a third hierarchical level and identify costs due to (a) the specific nature of the error in decision making (10.1.1-10.1.2); (b) the specific reason for the time cost in scheduling FI aircraft (10.2.1-10.2.3); and (c) specific causes for extended duration of the flight inspection process dealing predominately with AF/FI interaction and interference at the site (10.3.1-10.3.4).

INITIAL APPLICATIONS

Preliminary test applications of the OAI - Form A were conducted at both the OKC GNAS and the Memphis GNAS, in which the two objectives of the study were addressed. The primary objective was addressed by determining the degree to which the inventory accounted for all identifiable, time-relevant factors

Table 1. Test Outages Used in Initial Applications of OAI - Form A

No.	Cause Code	Duration (Hrs.)	Facility/Service
01	80*	2.05	RCAG
02	80	50.80	VOR
03	80	8.46	MALSR
04	80	5.40	ARSR
05	82**	1.60	CD
06	80	6.85	CD
07	80	0.05	ARSR
08	82	0.30	ATCRB
09	80	0.20	ARTS
10	80	0.90	TRAD
11	80	2.10	ALS
12	80	4.00	ARSR
13	89***	4.00	LDA
14	80	7.25	VOR

*80 = Equipment Failure
**82 = Prime Power Failure
***89 = "Other"

contained in a given outage. The secondary objective was addressed by determining the facility with which SMEs could apportion a time duration value for a particular outage to all contributing components.

Selection of Test Outages

GNAS sector managers and supervisors were consulted, along with available maintenance reporting data to identify candidate outages for the test. An attempt was made to represent facilities with relatively wide ranges of outage records and also to represent various types of equipment (e.g., radar, power, communications). Using this procedure, 10 previous OKC GNAS equipment outages and four previous Memphis GNAS equipment outages were selected for analysis. Outages varied from .05 hours to 50.80 hours, with 10 different types of facilities represented. Table 1 summarizes the details of the test outages.

Mapping Outage Factors

Using the test outages listed in Table 1, the component structure of the OAI - Form A was reviewed and refined through an iterative process involving SMEs from Oklahoma City and Memphis GNAS facilities. The primary object of this step was to determine the completeness and sensitivity of the OAI. It was important that the component structure be thoroughly descriptive of the possible contributors to downtime without being redundant. Also, the hierarchical structure of the inventory was verified, ensuring that the level of information was consistent throughout. Through the continuing process of refinement, the inventory was developed into a tightly-organized set of potential components of downtime, which could be used effectively in mapping the causal circumstances of a given outage. The final, revised form is included in Appendix A.

Apportioning Outage Time Values to Downtime Components

In accordance with the study's main objective, when actually used, the inventory would serve as a data reporting and recording tool, and outage time values would be assigned as they occurred, essentially in real time. However, to meet the study's second objective, it was necessary to determine the ease with which outage values could be apportioned to the components previously identified as contributors to downtime or to restore time cost. This was accomplished by using the overall ***outage time*** obtained from SFO reporting data. That value was apportioned among all factors identified as contributing to a given outage using SMEs with direct knowledge of the outage to be assessed. Total outage time currently is the only quantitative record kept of the duration of a particular outage.

Initially, we believed that 0.10 hour (6 minutes) would be sufficient as the smallest apportionable unit. However, initial trials quickly indicated that a smaller unit was required. Consequently, 0.0167 hours (1.0 minutes) was finally accepted as the smallest apportionable or assignable unit of time. Outage value assignment or apportionment to contributing components is widely variable, ranging from a matter of days in some instances (for example, awaiting a part or the availability of a FI aircraft), to a matter of seconds (for example, in checking settings on a piece of test support equipment for correctness).

Outage time values are not assigned or apportioned to all first-order functions. Function 1.0 deals with onset of the outage and any related inducing factors, while Function 2.0 concerns the circumstances surrounding the detection of the outage. Assignment or apportionment of outage time values is initiated with Function 3.0, Schedule Delay of Maintenance Action.

During the apportionment process, SMEs were essentially asked to reconstruct the circumstances of a particular outage from memory using available reporting materials and to apportion completion time values to those components contributing to the outage.
AF supervisors who had been directly involved with the restoration of a particular outage served as SMEs and performed the apportionment task. Supervisors were felt to have the broadest knowledge base and level of comprehension concerning the circumstances surrounding a given outage within their area of responsibility. For the most part, comprehensive knowledge of a given outage was limited to the supervisor and perhaps the technician who performed the maintenance; hence, it was not possible to obtain measures on a given outage for more than one SME.

SMEs were encouraged to review their actions and make whatever changes, reappraisals, or reapportionments they desired. Objectives were to obtain (1) as thorough a representation as possible in the OAI - Form A of the circumstances and conditions surrounding a given GNAS outage; and (2) to obtain a reasonably accurate apportionment of the total duration time of the outage to contributing components of the maintenance system, also identified in the OAI - Form A. SMEs were instructed to perform the apportionment step in hierarchical order, beginning with the higher-order categories, and penetrating to progressively lower-order (more detailed) factors and components. A useful technique was for the SME to ask the following question when considering each factor: "Did this factor or outcome cost additional outage time?" The concept of "outage time cost" seemed to facilitate the apportionment process.

Results

All 14 GNAS initial-application outages were analyzed using the inventory. SMEs had little difficulty reconstructing the circumstances and events surrounding a given outage. This process seemed to have been greatly facilitated by the detailed structure of the inventory. SME completion time for each of the 14 outages varied from five to 30 minutes, with an average time of 12 minutes. All SMEs expressed a high confidence level in their time apportionments and indicated that the inventory added significantly to their understanding of the system components that contributed at varying levels to overall outage time. Many commented on the thoroughness of the inventory, and were surprised at the exceedingly large number of factors, conditions, and events that could influence downtime.

A narrative description of each of the 14 outages analyzed is included in Appendix B. At some future point, software could be developed to generate much more definitive descriptions of outage restoration activities from the data collected by the OAI. Also, statistical analysis software could be employed to summarize and test various trends and relationships in the data obtained.

During the apportioning process, additional insights were obtained, which resulted in further revisions and modifications to the component structure of the OAI - Form A. One significant problem noted with the approach was that, due to the remoteness of many of the equipment facilities under a GNAS, several of the maintenance actions are performed by a technician without supervision. For example, 6.0 - Preparation for Corrective Maintenance, 7.0 - Fault Diagnosis, 8.0 - Fault Correction, and 9.0 - Confirmation/Certification are usually performed remotely by a single technician. Under such circumstances, there is no ready source of "objective" data; the inventory becomes essentially a "self-reporting" device. It seems unrealistic to assume that a technician would essentially put him or herself "on report," so to speak, for an error or errors committed that had contributed to downtime associated with a particular outage.

This problem is often encountered in human performance measurement, where it may be possible to develop measures of a certain type of performance, but often quite a different matter to collect data on those measures. However, in the initial application of the OAI - Form A, there were several instances in which the supervisor had information concerning procedures used at the site, particularly Outage No. 05, in which lack of proper information necessary for troubleshooting was noted. Outages are critical events to an SFO, and to the various supervisors and organizations within that office. In a sense, each outage has its own personality composed of events, conditions, and circumstances that cause it to be distinct from other outages. Individuals, such as the supervisors who participated in this study, tend to have excellent recall of the circumstances of each individual outage, though some of the outages used in this study were nearly two years old, with the oldest one occurring four years earlier. Further, supervisor awareness of the OAI will provide a ready framework for recalling and organizing the events of an outage when apportionment is done at some later time.

In summary, it was found that the OAI - Form A was a highly effective instrument for mapping the events, circumstances, and conditions of a given GNAS outage necessary for use as an on-line data collection tool. Further, if data cannot be recorded in real time during the actual process of outage restoration, or if it is desired to use historic data to build an outage component data base, experienced maintenance supervisors seem quite capable of apportioning the associated total outage time to the various contributing factors.

RECOMMENDATIONS

Form A of the OAI is at a prototype level of development. Considerable additional work will be required if the concept of a systems-based, components-of-downtime approach to root-cause analysis of AF outages is to be brought to fruition. Following are some recommendations for future work.

1. Perform additional tests on Form A of the OAI within the GNAS community. Further confirm, extend, and refine the classification and taxonomic structure of the preliminary inventory, as required. Determine features, formats, and procedures that would render the inventory most useful to the AF community, with minimum requirements for additional administration time. Identify approaches for collecting data on maintenance activities performed at remote sites where one technician is assigned. Explore the possible use of any existing maintenance monitoring and reporting systems as a source of supporting data for the OAI.

2. Identify and evaluate possible avenues for installing and applying Form A of the OAI, such that it can be completed coincident with the occurrence of an outage by the various individuals involved. This would require the cooperation of a GNAS interested in exploring the potential of the OAI for their facility. Form A of the OAI would need to be installed along with procedures for incorporating it as an integral part of the outage restoration process. An evaluation would need to be conducted depending upon frequency and characteristics of outages occurring. Union support may be required for this step.

3. Explore possibilities for introducing the data collected by the OAI into the maintenance reporting and analysis system maintained by the AF community. At the very least, the OAI classification structure could be used as a means for encoding data for entry into a computer file. The results could be used to further explicate the cause code system currently used to classify outages. The results could also be used to analyze conditions and factors across outages, and within and between facilities to identify patterns of events and outcomes and to perform trend analyses.

4. Design or identify techniques for analyzing OAI data to identify cost-effective interventions for treating specific components of the AF maintenance process to effect overall gains in equipment availability. Countermeasures to problems discovered could be designed at any hierarchical level of the inventory, depending upon potential payoffs judged possible in improving facility availability. To be useful, data on a minimum number of outages of a particular classification would need to be collected. The technique could be based on some type of prioritization scheme, by which possible countermeasures could be assessed and recommended for action on the basis of cost benefits or payoffs in reducing facility downtime. This step also might be taken at a local GNAS initially to explore and test various possibilities.

5. Appreciate that for long term consideration, highly-specialized data collection formats, like the OAI, will require periodic review and revision as the AF support system is expanded and new technology added. Changes in functionality and increases in level of automation, with attendant shifts in responsibility between human and machine, will impact the structure of the OAI and will need to be considered to maintain its usefulness.

REFERENCES

Department of Transportation/Federal Aviation Administration. *Operational Requirements for the Remote Maintenance Monitoring System (RMMS).* Washington, D.C.: Federal Aviation Administration; 1984. FAA publication no. NAS-MD-792.

Department of Transportation/Federal Aviation Administration. *Facility Operation and Administration.* Washington, D.C.: Federal Aviation Administration Air Traffic Operations Service; 1989. FAA publication no. 7210.3I.

Department of Transportation/Federal Aviation Administration. *General Maintenance Handbook for Airway Facilities.* Washington, D.C.: Federal Aviation Administration Airway Facilities; 1991. FAA publication no. 6000.15B.

Department of Transportation/Federal Aviation Administration. *National Airspace Performance Reporting System.* Washington, D.C.: Federal Aviation Administration Systems Maintenance Service; 1991. FAA publication no. 6040.15C.

Drury, C. G. (1991). Errors in Aviation Maintenance: Taxonomy & Control. In *Proceedings of the Human Factors Society, 35th Annual Meeting,* Santa Monica, 42-56.

Drury, C. G. (1987). Task Analysis. In Salvendy, G. (Ed.), *Handbook of Human Factors* (pp. 370-401). New York: Wiley & Sons.

Orlansky, J., & String, J. (1981). *Performance of Maintenance Technicians on the Job.* Institute for Defense Analysis Paper P-1597, August.

Parker, E., & Dick, R. (1985). *Factors Responsible for Navy Electronic Equipment Downtime.* Technical Note 71-85-08, Navy Personnel Research and Development Center, May.

Rigby, L. V., & Cooper, J. I. (1961). *Problems and Procedures in Maintainability.* ASD Technical Note 61-126. Aeronautical Systems Division, USAF, October.

Rouse, W. B. (1990). Designing for Human Error. In Booher, H. R., (Ed.), *Manprint: An Approach to Systems Integration* (pp. 237-255). New York: Van Nostrand Reinhold.

Towne, D. M., Johnson, M. C., & Corwin, W. H. (1983). *A Performance-Based Technique for Assessing Equipment Maintainability.* Technical Report No. 102, Behavioral Technology Laboratory, USC, August.

APPENDIX A

OUTAGE ASSESSMENT INVENTORY (OAI)

FORM A - GNAS

AIRWAY FACILITIES

OUTAGE ASSESSMENT INVENTORY - FORM A (GNAS)

FACTORS; CONDITIONS; EVENTS	CHECK √	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
1.0 Outage Causes (Coordinate With Cause Codes)			
1.1 Equipment malfunction/failure			
1.1.1 Hardware malfunction/failure			
1.1.2 Software problem			
1.1.3 Monitor alarm/shutdown			
1.2 Interruption of commercial (leased) services			
1.2.1 Commercial power failure			
1.2.2 Commercial telephone service failure			
1.3 Interruption of agency-provided services			
1.3.1 Power			
1.3.1.1 Prime			
1.3.1.2 Standby			
1.3.2 Landlines/Communications			
1.3.2.1 Landline			
1.3.2.2 Microwave			
1.4 Outage related to transient or intermittent condition			
1.5 Outage related to weather/storm (lightning strike)			
1.6 Outage related to vehicle collision or interference			
1.7 Outage related to previous maintenance action			
1.7.1 Outage related to authorized equipment modification			
1.7.2 Other: ______________________			
1.8 Interruption of another facility/service			
1.9 Interference due to atmospheric conditions			
1.10 Contractor-induced outage			
1.10.1 During equipment installation			
1.10.2 During scheduled maintenance			
1.10.3 During corrective maintenance			
1.10.4 During airport improvement project			
1.10.5 Other: ______________________			

FACTORS; CONDITIONS; EVENTS	CHECK ✓	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
1.11 AFS-induced outage			
1.11.1 During equipment installation	☐		
1.11.2 During scheduled maintenance	☐		
1.11.3 During corrective maintenance	☐		
1.11.4 Did not switch to standby equipment	☐		
1.11.5 Did not go to back-up	☐		
1.11.6 Inadvertent shutdown	☐		
1.11.7 Maintenance Control Console (MCC)	☐		
1.11.8 Other: ____________________	☐		
1.12 ATC-induced outage			
1.12.1 Did not go to back-up	☐		
1.12.2 Inadvertent shutdown	☐		
1.12.3 Selected use of out-of-service standby equipment	☐		
1.12.4 Other: ____________________	☐		
2.0 Outage Detection			
2.1 AFS (Non-RMMS)	☐		
2.2 AFS-RMMS/MCC	☐		
2.3 Pilot	☐		
2.4 Airport managers or other personnel	☐		
2.5 Air Traffic Control (ATC)	☐		
2.6 Flight Service Station (FSS)	☐		
2.7 Other: ____________________	☐		
3.0 Schedule Delay of Maintenance Action			☐
3.1 Repair scheduling priority considerations			
3.1.1 FAA restoration codes	☐		
3.1.2 ATC guidance	☐		
3.1.3 Criticality of need vs. cost	☐		
3.1.4 Other: ____________________	☐		
4.0 Locate and Assign Technician			☐
4.1 Technician availability/assignability			
4.1.1 Watch stander at failed facility	☐		

FACTORS; CONDITIONS; EVENTS	CHECK √	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
4.1.2 Watch stander at sector field office (SFO)			
4.1.3 Unable to contact technician on callback			
4.1.4 Certified technician unavailable			
4.1.5 Technician reassigned en route			
4.1.6 Technician assigned inappropriate for site			
5.0 Travel Time to Site			
5.1 Conditions/circumstances			
5.1.1 Picked up vehicle or materials at SFO			
5.1.2 Additional travel time due to weather en route			
5.1.2.1 Snow/sleet			
5.1.2.2 Heavy rain			
5.1.2.3 Limited visibility/fog			
5.1.2.4 Flooding			
5.1.2.5 Other: ________________________			
5.1.3 Remote site			
5.1.4 Limited accessibility to site			
5.2 Travel policies in effect			
5.2.1 Use of government vehicles			
5.2.2 Use of personal vehicle			
5.2.3 Overnight stay			
5.2.4 Limited travel funds			
5.3 Mode of transportation			
5.3.1 Government car/truck			
5.3.2 Boat			
5.3.3 Aircraft			
5.3.4 Off-road vehicle			
5.3.5 Snow cat			
5.3.6 Private vehicle (POV)			
6.0 Preparation for Corrective Maintenance			
6.1 Obtained technical data			
6.1.1 Necessary technical data not available			

FACTORS; CONDITIONS; EVENTS	CHECK √	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
6.1.2 Technical data incorrect			
6.1.3 Technical data incomplete			
6.1.4 Technical data not usable (level)			
6.1.5 Technical data difficult to access			
6.1.6 Did not obtain technical data			
6.1.7 Obtained/used incorrect technical data			
6.2 Obtained test equipment			
6.2.1 Proper test equipment not available			
6.2.1.1 Not available at site			
6.2.1.2 Not available at sector field office			
6.2.1.3 Not available in sector			
6.2.1.4 Not available in region			
6.2.2 Test equipment not appropriate (suitable)			
6.2.3 Test equipment incomplete			
6.2.4 Test equipment not working			
6.2.5 Test equipment out of calibration window			
6.3 Checked/set-up test equipment			
6.3.1 Did not check test equipment			
6.3.2 Checked or set-up test equipment incorrectly			
6.3.3 Test equipment internal checks/set-ups not working			
6.4 Obtained access to suspected equipment area			
6.4.1 Removed wrong access cover, subassemblies			
6.4.2 Equipment area not accessible			
6.4.3 Suspected assembly/LRU not physically accessible			
6.4.4 Necessary test points not available			
6.4.5 Necessary test points not accessible			
6.4.6 Necessary test points not clearly marked			
6.5 Additional preparation time due to site conditions			
6.5.1 Snow/sleet/hail			
6.5.2 Heavy rain			
6.5.3 Extreme temperatures			

FACTORS; CONDITIONS; EVENTS	CHECK √	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
6.5.4 High winds			
6.5.5 Flooding			
6.5.6 Other: ____________________			
7.0 Fault Diagnosis			
7.1 Read/understood technical data			
7.1.1 Did not read/understand technical data			
7.1.2 Partially read/partially understood technical data			
7.1.3 Misinterpreted/misused technical data			
7.2 Used test support equipment			
7.2.1 Used wrong test points			
7.2.2 Used wrong electronic standards/tolerances			
7.2.3 Used wrong test equipment set-up			
7.2.4 Specialized test equipment inaccurate			
7.3 Diagnosed fault (troubleshooting)			
7.3.1 Used random approach/illogical reasoning			
7.3.2 Overlooked/misinterpreted symptoms			
7.3.3 Used wrong information/incorrect logic			
7.3.4 Used incomplete information			
7.3.5 Incorrectly diagnosed fault as "unknown"			
7.3.6 Spares not available for troubleshooting purposes			
7.3.7 Diagnostic incapable of determining problem			
7.4 Additional diagnostic time due to environmental conditions			
7.4.1 Snow/sleet/hail			
7.4.2 Heavy rain			
7.4.3 Extreme temperatures			
7.4.4 High winds			
7.4.5 Flooding			
7.4.6 Other: ____________________			
8.0 Fault Correction (Repair or Replace Equipment/Parts)			
8.1 Obtained spares			
8.1.1 At site			

FACTORS; CONDITIONS; EVENTS	CHECK √	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
8.1.2 At sector field office			
8.1.3 Within sector			
8.1.4 By order from supplier			
8.1.5 Part(s) in repair pipeline			
8.1.6 From prime equipment manufacturer			
8.1.7 Purchased locally			
8.1.8 Correct part(s) not available from any source			
8.1.9 Available spares not serviceable			
8.1.10 Ordered wrong parts due to misdiagnosis			
8.1.11 Did not order any parts due to misdiagnosis			
8.2 Restored system			
8.2.1 Repaired/modified part/module			
8.2.1.1 Did not repair/modify part/module			
8.2.1.2 Repaired/modified non-failed part/module			
8.2.1.3 Induced new fault			
8.2.1.4 Proprietary module (could not access)			
8.2.2 Replaced part/module			
8.2.2.1 Did not replace part/module			
8.2.2.2 Replaced wrong part/module			
8.2.2.3 Induced new fault			
8.2.2.4 Correct part/module unavailable			
8.2.3 Reset system			
8.2.3.1 Improperly reset system			
8.2.3.2 Did not reset system			
8.3 Coordination with non-AFS activities			
8.4 Additional restore time due to environmental conditions			
8.4.1 Snow/sleet/hail			
8.4.2 Heavy rain			
8.4.3 Extreme temperatures			
8.4.4 High winds			

FACTORS; CONDITIONS; EVENTS	CHECK ✓	SECONDARY OUTAGE TIME	PRIMARY OUTAGE TIME
8.4.5 Flooding			
8.4.6 Other: ______________________			
9.0 Confirmation/Certification			
9.1 Retest incorrectly confirmed that repair was satisfactory			
9.2 Retest not run			
9.3 Retest set-up incorrectly			
9.4 Retest run incorrectly			
9.5 Technician misinterpreted retest findings			
9.6 Did not certify repair			
10.0 Recertification - Flight Inspection			
10.1 Decision concerning whether or not to recertify			
10.1.1 Did not initiate process (timely manner)			
10.1.2 Performed process unnecessarily			
10.2 Scheduled delay of Flight Inspection (FI) Aircraft			
10.2.1 Limited availability of FI aircraft			
10.2.2 Weather-related delays			
10.2.3 Scheduling delays at busy airports			
10.3 Flight Inspection (Duration)			
10.3.1 Poor communications between AF and FI			
10.3.2 Poor technical coordination between AF and FI			
10.3.3 Process frequently interrupted but completed			
10.3.4 Process incomplete; required rescheduling			
11.0 Return Facility to Service/Reporting (Log Entry)			
11.1 Improper operational set-up			
11.2 Did not remove NOTAM			
11.3 Did not report equipment operational			
11.4 Log entry incorrect			
11.5 Unable to contact facility control point			
TOTAL OUTAGE DURATION			

[dwntme2a.reb]

APPENDIX B

NARRATIVE REPORT ON OUTAGE ASSESSMENT INVENTORY - FORM A

INITIAL APPLICATIONS

NARRATIVE REPORT ON ANALYSIS OF OUTAGES USED IN INITIAL APPLICATIONS OF OAI - FORM A

No.	Cause Code	Duration (Hrs.)	Facility/Service
01	80*	2.05	RCAG

Failure was induced by AFS technician during equipment installation which was related to a previous maintenance action. The outage was detected by ATC. Fault diagnosis required 1.20 hours, with 0.40 hours spent using test support equipment and 0.80 hours spent in troubleshooting. Restoration required 0.10 hours to repair a part or module, with 0.10 hours required to replace it once repaired. The system was retested, requiring 0.65 hours and was then returned to service.

02	80	50.80	VOR

Failure occurred during routine system operation and was detected by ATC. ATC guidance in scheduling maintenance delayed action for 44.80 hours. Distance to facility required 2.00 hours of travel time. Trouble required 0.30 hours to isolate. Replacement module was proprietary equipment and not repairable, which required an additional 2.00 hours to obtain new part from SFO. To install the part required 1.00 hours, with retest requiring 0.50 hours. The facility was returned to service, involving 0.20 hours.

03	80	8.46	MALSR

Failure occurred during routine operation and was detected by ATC, who requested a 1.50 hours delay in initiating maintenance action. Obtaining a AF technician with proper position description for the task required 2.76 hours, with 0.60 hours travel time needed to reach the facility, where another 0.10 hours was required to obtain access to facility. Severe environmental conditions at the site added 1.00 hours to the restoration. Maintenance involved use of test support equipment not available at the site, adding 0.10 hours to obtain equipment from truck. Obtaining access to suspected equipment area required 0.10 hours. Test support equipment was used 0.30 hours, with 0.70 hours spent in troubleshooting. Spares to correct fault were only available at the SFO, requiring 0.50 hours for delivery to site. Part/module replacement required 0.20 hours, with 0.50 hours needed for confirming by retest. Returning the facility to service required an additional 0.10 hours.

04	80	5.40	ARSR

This outage occurred as a result of a transient or intermittent condition and was detected by AFS. Restore action scheduling was guided by restoration codes. The technician available at the facility was not certified for the task which required a qualified technician to be dispatched by the SFO, requiring 1.50 hours travel time to the facility. Troubleshooting required 0.20 hours and with spares available at the site, the required module/part was replaced in 2.00 hours. Confirmation retest needed 1.60 hours, with 0.10 hours required to report the facility as restored for service.

No.	Cause Code	Duration (Hrs.)	Facility/Service
05	82**	1.60	CD

This outage was due to a commercial power failure and was related to a transient or intermittent condition. Failure was reported by AFS with restore action scheduling guided by restoration codes. A watchstander was available at the facility who was qualified to certify the equipment operational. Environmental conditions at the site added 0.60 hours to downtime. Troubleshooting involved 0.70 hours, which included some amount of additional time since the technician overlooked or misinterpreted certain symptoms, and used incomplete or wrong diagnostic information. Once the fault was isolated, correction required 0.10 hours. Confirmation test required another 0.10 hours and returning the facility to service also involved 0.10 hours.

06	80	6.85	CD

This outage was due to routine equipment failure and was detected by AFS. Restoration codes guided restore action scheduling. A watchstander was located at the facility who was qualified to certify the equipment as operational. The fault required the use of specialized test equipment which was found to read inaccurately, resulting in 2.00 hours additional in obtaining proper readings. Troubleshooting required an additional 2.15 hours, with 1.00 hours needed to repair the fault. Retest and recertification required 1.50 hours, with 0.20 hours needed to report the facility as operational.

07	80	0.05	ARSR

This equipment failure was routine and was detected by AFS. Restoration codes guided restore action scheduling. A watchstander was available at the facility with a proper position description to certify the equipment operational. Fault diagnosis required 0.02 hours, with 0.02 hours needed to correct the fault. The facility was returned to service in an additional 0.01 hours.

08	82	0.30	ATCRB

The fault, which resulted in the loss of commercial power, was induced by an AFS technician. ATC detected the outage and restore action scheduling was guided by restoration codes. A qualified watchstander was located at the SFO. Travel to the facility required 0.19 hours, with 0.05 hours required for fault diagnosis. The system was reset in 0.02 hours, with 0.02 hours required for confirmation test. The facility was returned to service in 0.02 hours.

09	80	0.20	ARTS

The failure was induced by AFS technician during performance of corrective maintenance. The outage was detected by AFS and the restoration codes guided restore action scheduling. A technician qualified to certify the equipment operational was located at the facility. Troubleshooting required 0.02 hours, with 0.16 hours required to reset the system. Confirmation test involved 0.02 hours and the system was returned to service.

No.	Cause Code	Duration (Hrs.)	Facility/Service
10	80	0.90	TRAD

The outage occurred due to routine equipment failure. ATC reported the outage and restoration codes were used in scheduling restore action. A qualified watchstander was available at the failed facility. Troubleshooting involved 0.50 hours, with 0.35 hours required to restore the system. Confirmation test involved 0.03 hours, with 0.02 hours necessary to return the facility to service.

11	80	2.10	ALS

The outage, which was detected by ATC, occurred due to commercial power failure. Use of FAA restoration codes caused a 0.17 hours schedule delay of maintenance action. Travel time to the site took 0.25 hours. Preparation for corrective maintenance involved 0.20 hours, with 0.05 hours needed to obtain technical data, 0.03 hours needed to obtain test equipment, 0.03 hours needed to check test equipment, and 0.09 hours needed to obtain access to the suspected equipment area. Fault diagnosis required 1.00 hours. Fault correction took 0.25 hours due to the fact that the technician obtained the spares at the site and then replaced the part/module. Confirmation/certification took 0.17 hours. Returning the facility to service/reporting required 0.06 hours.

12	80	4.00	ARSR

The outage, which was detected by AFS, occurred due to equipment failure. Locating and assigning a technician required 0.03 hours, while travel time to the remote site required 0.33 hours. Preparation for corrective maintenance took 0.42 hours, with 0.25 hours needed to obtain technical data, 0.08 hours needed to check the test equipment, and 0.09 hours needed to obtain access to the suspected equipment area. Fault diagnosis took 2.50 hours. Fault correction (restoring the system) required 0.50 hours. The facility was returned to service/reporting in 0.22 hours.

13	89***	4.00	LDA

The outage was related to vehicle/aircraft damage or interference. The airport manager detected the outage. The need to coordinate with the local power company delayed maintenance action for 1.17 hours. Locating and assigning a technician required 0.25 hours since the watch stander was at the sector field office. Travelling to the remote site in a government vehicle took 1.50 hours. Troubleshooting required 0.50 hours, as did fault correction (system restoration), which required 0.50 hours. Confirmation/certification occupied 0.08 hours.

No.	Cause Code	Duration (Hrs.)	Facility/Service
14	80	7.25	VOR

The outage occurred due to equipment failure. The RMMS/MCC detected the outage. Locating and assigning a technician required 0.25 hours. Travelling to the remote site in the technician's personal vehicle involved 1.00 hours. Preparation for corrective maintenance took 0.17 hours, while fault diagnosis took 3.00 hours (including 1.00 hours needed for using test support equipment and 2.00 hours needed for troubleshooting). Fault correction required 2.16 hours, with 1.84 hours needed to obtain spares at the sector field office and 0.42 hours needed to replace the part/module and reset the system. Confirmation/certification took 0.50 hours and the facility was returned to service/reporting after an additional 0.17 hours.

Cause Codes: *80 = Equipment Failure

**82 = Prime Power Failure

***89 = "Other"

Minimum outage duration unit = 0.0167 hours = 1.00 minutes

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