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A Human Factors Review of the Operational Error Literature

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16. Abstract

This report reviews available documents concerning research and initiatives to reduce operational errors (OEs). It provides a brief history of OE investigation and reporting. It describes 154 documents published from 1960-2005 and 222 OE reduction initiatives implemented from 1986 to 2005. Materials are classified by 1) type of study and 2) human and other contributing factors (using the JANUS taxonomy). An analysis of the literature identified several consistent findings. OEs were related to the amount of traffic (measured nationally rather than by position, early time on position, and pilot/controller miscommunications (especially hearback/readback errors). Initiatives included developing national and local QA activities, providing resources to supervisors to help them perform their jobs, and skills training to address controller mental processes. Many ATO initiatives involved controller training, teamwork, and communications. Research and operations seemed to focus on the same 6 areas: a) training and experience, b) teamwork, c) pilot-ATC communications, d) Human Machine Interaction (HMI) and equipment, e) airspace/surface, and f) traffic. This review concluded that, historically, much (sometimes redundant) research was conducted that generated little new information about why OEs occurred. Similarly, many initiatives were implemented, but the lack of a systematic follow-up prevented us from learning which were effective. This cycle will continue unless relevant data are obtained that can address underlying causal dimensions typically associated with human errors. Better data will allow conducting more informative, theory-based analyses. ATO must also continually assess the effectiveness of OE mitigation strategies. Research efforts, operational initiatives, and program outcomes must be monitored to avoid wasting resources by repeatedly conducting the same analyses, re-discovering the same intervention strategies, and addressing only the easy problems. Development of a safety culture requires obtaining better data about circumstances surrounding OEs; identifying individual, supervisory, and organizational contributions; and measuring the effectiveness of interventions.

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A Human Factors Review of the Operational Error Literature

EXECUTIVE SUMMARY

Purpose. To support the Federal Aviation Administration's (FAA's) Air Traffic Organization (ATO) goal to reduce operational errors, we were asked to review existing research literature on operational errors (OEs) so that candidate mitigation strategies could be identified for immediate deployment.

Method. This report covered the following areas:

- A brief history of OE investigation, classification, and reporting.
- Collection of 154 OE-related documents covering a 45-year span from 1960-2005.
- Documentation, review, and classification of 222 OE prevention and reduction initiatives implemented from 1986 to 2005.
- Classification of all materials using two methods
  - Type of study.
  - HF categorization using JANUS taxonomy.
- Identification of knowledge gaps in research studies and initiatives.
- Development of recommendations.

Research Results. We identified several findings by analyzing the literature. Some consistent research findings included:

- The amount of traffic measured on a national basis is the single most important determinant of the frequency of OEs. However, while the amount of traffic increased at overall in the NAS, the amount of traffic in a sector when an OE occurs has generally remained unchanged.
- A relatively high percentage of OEs occurred during the first 20 minutes on position. That relationship was consistent across options and during much of the day. While this result was often linked with position relief briefings, only a small percentage of OEs were attributed to the causal factor in the OE reporting form related to position relief briefings.
- Pilot/controller miscommunications were historically identified as a primary causal factor associated with OEs and hearback/readback errors were studied most often. Although analysis of recorded communications revealed that few hearback/readback errors resulted in an OE, a sizeable proportion of OEs were attributed to hearback/readback errors. One set of studies found a strong relationship between the complexity of the controller's transmission and the probability of a readback error in the en route and TRACON environments.

Less-frequent, but also important findings include:

- One study found a statistically significant relationship between the decline in supervisory staffing and the overall increase in OEs.
- Another study found that higher percentages of OEs occurred in moderate to heavy traffic complexity conditions, suggesting that the interaction of the amount of traffic with traffic complexity may affect OEs more than the amount of traffic alone. Other studies also identified sector complexity as a factor contributing to OEs.
- Several studies have found that controllers with five years or less experience (after certification) were more susceptible to OEs than were more experienced controllers.
- Several studies related OEs to problems with perception and vigilance. However, a lack of information about these factors on the OE reporting form prevented an in-depth analysis of these causal factors.
- Although memory failures were associated with OEs in all ATC environments, much of the memory literature relevant to OEs was in the context of runway incursions. Several studies found memory failures to be the most frequently cited causal factor of tower OEs.

Results of Initiatives. Initiatives related to organizational and management issues primarily dealt with development and review of national and local QA activities. Initiatives described concerns about resources available to supervisors to accomplish their jobs and recommended additional supervisory training. Some initiatives focused on mental processes, especially those efforts addressing skills training.

Most initiatives introduced by the air traffic organization that related to contextual conditions involved controller training, teamwork, and communications. Both the research reports and OE reduction initiatives emphasized the same six contextual conditions (although not necessarily in the same order): a) training and experience, b) teamwork, c) pilot-ATC communications, d) Human Machine Interaction (HMI) and equipment, e) airspace/surface, and f) traffic. Although the specific topics addressed by research and the OE reduction interventions appeared to differ, trend comparisons suggested that research and operations focused on the same general areas.

We also identified several roadblocks to OE reduction. These are briefly noted here and an expanded discussion is presented in the report.

Initiatives: The legacy Air Traffic Service (ATS) identified and implemented national, regional, and facility level OE reduction initiatives. These initiatives addressed error conditions identified through analysis of OE reports. While the reports indicated that several of these initiatives were successful, we found little documentation to support those claims. Without a method to track the effectiveness of initiatives, it is not possible to learn from past successes and failures.

Historical OE Database: The legacy ATS collected an extensive amount of information about OEs during their investigation process that was useful for guiding previous OE mitigation strategies.

- Incomplete data. The information historically gathered during the OE investigation process did not address many of the underlying causal dimensions typically associated with human error.
- Narrow research focus. Despite the complexity and dynamic nature of a controller's tasks, most research focused on only one or two factors. For example, the conditions of the complex air traffic environment that make a controller more vulnerable to making mistakes versus remaining "error free" are unclear. Furthermore, objective measures of controller performance besides OEs are not available.
- Similar analyses. Similar analyses have been repeatedly conducted on OE data that resulted in the same findings as previous analyses of those data. Analysts must be encouraged to review previous work and conduct analyses to examine how multiple factors interact to produce OEs. Cognitive models of controller performance should be used to guide these analyses.

Recommendations. A workgroup consisting of members of both the operational and research communities should be convened to address these 3 recommendations:

1. Expand OE data available for analysis
   a. Improve the OE data collected to better identify human factors associated with OEs.
   b. Collect baseline data about normal air traffic operations to better evaluate conditions surrounding OEs.
   c. Develop objective measures of controller performance.
2. Improve research and analyses
   a. Account for the interactive nature of factors contributing to OEs.
   b. Identify high impact causal factors where the payoff for mitigation is high.
   c. Examine OEs relative to a safety culture.
3. Monitor interventions
   a. Develop and execute a method for tracking and evaluating OE intervention strategies.

Conclusions. Identification of OE causal factors is difficult because they occur in a very small percentage of ATC operations. This review has shown that, historically, much (sometimes redundant) research was conducted that generated little new information about why OEs occurred. Similarly, many initiatives were implemented, but the lack of a systematic follow-up prevented us from learning which were effective. This cycle will continue unless steps are taken to 1) obtain relevant data to conduct more informative, theory-based analyses and 2) continually assess the effectiveness of OE mitigation strategies. The ATO must monitor research efforts and operational initiatives to avoid "reinventing the wheel" (repeatedly conducting the same analyses and initiatives) and "picking the low hanging fruit" (continuing to address apparently easy problems) and, thus, wasting increasingly scarce resources. The ATO must develop a safety culture by obtaining better data about the circumstances surrounding OEs and identifying the relative importance of individual, supervisory, and organizational contributions.

A Human Factors Review of the Operational Error Literature

INTRODUCTION

The Federal Aviation Administration's (FAA's) Air Traffic Organization (ATO) has a five year performance goal of reducing the annual number of serious operational errors (OEs) from a total of 637 in 2005 to no more than 563 by the end of 2009, equivalent to a rate of 3.18 per million activities (ATO, 2005). An OE occurs whenever there is a violation of aircraft separation minima that is the result of an element within the air traffic system (e.g., a facility procedure or an air traffic control specialist). A violation of separation minima may involve a) two or more aircraft, b) an aircraft and terrain or obstacles, or c) an aircraft landing or departing on a closed runway after receiving air traffic authorization to do so (FAA, 2006R).

The ATO seeks to implement initiatives to reduce OEs. To best develop effective OE reduction strategies, it is important to look at past efforts to understand and mitigate OEs. In this report, we seek to a) review and classify past research reports according to type of study and human factors (HF) categories, b) identify HF categories not addressed by the literature, and c) review previous OE reduction initiatives.

We first describe the development of the FAA OE investigation process and the resulting data archive, because the data collected during the investigation dictate much of what is known about OEs. We then review the scientific literature regarding OEs and describe selected OE reduction initiatives. Finally, the discussion will integrate information from the review of the scientific literature and the OE reduction initiatives to identify targets of opportunity for further research and mitigation efforts.

History of OE Investigation, Classification, and Reporting

This section describes the history of the processes used to identify, investigate, classify, and report OEs. After describing the OE investigation and classification processes, including several indices used to rate OE severity, we will discuss a process for analyzing the causal factors of OEs, called JANUS, which will be used to classify the OE literature.

OE Identification

For a number of years, OEs (then called system errors) were identified through pilot reports, supervisor observations, reports from another controller, and self-reports from an involved controller. This led to considerable speculation about how many errors actually occurred and how severe they were.

Following the initial computerization of the nation's en route air traffic control system, the FAA embarked on the development of conflict alert software. The resulting conflict alert system was designed to notify controllers of an eminent loss of separation between aircraft. On January 9, 1976, the conflict alert system was implemented at the 20 en route air traffic control centers (ARTCCs) for all aircraft flying above 18,000 feet. In December 1978, the system was modified to cover all aircraft in en route airspace. Meanwhile, in early 1978, the first Terminal Radar Approach Control (TRACON) conflict alert system was established at the Houston terminal. By April 1978, the system was expanded to cover 62 facilities (FAA, 1998b).

During the mid 1980s, the Operational Error Detection Patch (OEDP, also known as the "snitch patch") was introduced in en route facilities to alert Area Managers when a loss of standard separation occurred. The manager then determined who was responsible for the loss of separation. Thus, at en route facilities today, operational error detection and reporting is automatic.

In TRACONs and towers, error detection is based on either self-reports or a report from another controller, supervisor, or pilot. The Department of Transportation Office of the Inspector General (OIG) issued a report (DOT, 2003) expressing concern over the potential for underreporting of errors at facilities where OEs are self-reported. ATO shares this concern and is working toward an automated system for the TRACONs that will help detect OEs. However, for now, the variability in OE reporting (and presumed underreporting in the terminal environments) needs to be taken into account when interpreting available OE data.

OE Investigation Process

An approach for documenting and classifying air traffic control errors was developed in 1965 and described in FAA Order 8020. The Air Traffic Service (ATS) System Error Reporting Program established a formal process to investigate and classify what were then called system errors. As O'Connor & Pearson (1965) indicated, a reporting program for system errors should recognize the dynamic and complex nature of the air traffic system. It should take into account issues associated with equipment, personnel, procedures, and aspects of decision-making that influence performance. Since that time, periodic attempts have been made to update the OE reporting form to ensure that sufficient information is gathered to assess system safety and identify error-prone events, conditions, and procedures that could be modified to mitigate OEs.

Currently, when an OE occurs, a two-stage investigatory process is initiated consisting of a preliminary and final investigation. As specified in FAA Order 7210.56 (2002), an employee who is aware that an OE may have occurred must immediately report the occurrence to any available supervisor or Controller-in-Charge (CIC). After the OE has been reported, the area supervisor will conduct a preliminary fact-finding exercise to determine the validity of the suspected OE. If validated, the area supervisor follows the procedures listed in FAA Order 7210.56 and records the information on the preliminary investigation report (Form 7210-2), which includes a limited checklist of OE causal factors. After the preliminary investigation report is submitted, air traffic management (ATM) at the facility determined to be responsible for the OE designates an Investigator-In-Charge (IIC) to conduct a more thorough analysis of the factors that contributed to the OE. The results of the IIC's investigation are detailed in a final investigation report, which includes a checklist of OE causal factors comprising data posting, radar display, aircraft observation (at towers), communication, coordination, and position relief briefings. In addition to the information provided by the IIC, the manager may also offer comments about what may have led to the error.

An OE may be associated with more than one causal factor. Based on data from the final investigation report, an OE Severity Index (SI) score (described below) is calculated by the ATO-Safety Office of Investigations using a standardized methodology and included in the final report. OEs in categories A (high severity) and B (high moderate severity) are subjected to greater organizational scrutiny than those in categories C (low-moderate severity) and D (low severity).

OE Classification

Simpson (1982) was one of the first individuals to attempt to classify the risk associated with OEs. He defined three collision risk zones based on the amount of vertical and horizontal separation between involved aircraft. A "near miss" was considered to occur if two aircraft passed within 500 feet in both directions. The near miss had subzones of "critical near miss" (within 100 feet) and "potential near miss" (between 100 and 500 feet). From the edge of the near miss zone to 1,000 feet vertical and 3,000 feet horizontal separation was designated as the "near approach zone." The last zone, called the "separation infringement" zone, extended to the limits of vertical and horizontal separation that apply to the airspace.

As part of a subsequent OE investigation report (FAA, 1985), the Air Traffic Quality Assurance Staff introduced a system that classified errors as major, moderate, or minor, based on the amount of separation loss. Points were assigned for the degree of loss of horizontal (10 points) and vertical separation (10 points). A separate rating was provided for nonradar/Oceanic positions. A major error (20 points) involved less than ½ mile horizontal separation and less than 500 feet vertical separation. Moderate errors involved several different combinations of horizontal and vertical separation loss (14-19 points). An example would be 2 to less than 2 ½ miles of horizontal separation (5 points) and 500 feet to less than 600 feet of vertical separation (9 points), for traffic under flight level (FL) 290. Minor errors were assigned between 1-13 points. The total points used to classify severity for operations requiring less than 3-mile separation (i.e., in TRACON airspace) were slightly different. This process was only used until November of 1988.

In their initial report, the FAA Office of Aviation Safety (ASF) described a measure of potential risk using proximity (also called Root Mean Square, RMS, distance; Rodgers, Mogford, & Mogford, 1998). The proximity metric was calculated by computing the square root of the sum of the squares of the minimum horizontal and vertical separations between the aircraft involved. This is equivalent to the Euclidean distance between the two involved aircraft. Analysis of this measure suggested that the vast majority of OEs occurred at 5,000 feet of proximity or greater. This was true for ARTCCs, TRACONs, and control towers (FAA, 1988).

OE Severity Index

In 2001, an assessment of the safety risk associated with OEs was added to the OE investigation process. The 100-

point SI is based on four categories: Category A - high severity, Category B - high moderate severity, Category C - low moderate severity, and Category D - low severity. Classification of severity is based on the following factors: vertical and horizontal separation distances, relative flight paths, cumulative closure rates, and the level of ATC control. Because most of these factors are based on operationally relevant criteria associated with providing ATC services, the IIC is typically able to calculate the severity of ATC separation losses during the OE investigation. However, personnel assigned to the ATO Safety Office at FAA headquarters are responsible for making a final decision regarding the severity of each OE. As noted earlier, the ATO uses Category A and B events as organizational performance metrics.

RISC Model

The Runway Incursion Severity Categorization (RISC) model is an automated approach to categorizing the severity of the outcome of runway incursions (RIs) whether they are classified as OEs, pilot deviations, or vehicle/pedestrian deviations. The RISC model (Cardosi, Hannon, Sheridan, & Davis, 2005) reflects the likelihood that an RI could have resulted in a collision. The paths of the aircraft or vehicles involved in an RI are reviewed, and the closest horizontal and vertical proximity is determined. The model also takes into account avoidance maneuvers, visibility at the time of the RI, the types of errors made by the pilot and controller, and the time available for the pilot to respond. Cardosi pointed out that the RISC model should not be considered as a rating of "the adequacy of the ATC services or the severity of the operational (OE) that resulted in the incursion (pg. 2)." The levels of risk of collision range from Category D, which have little or no chance of collision but met the definition of a runway incursion, to Category A, in which a collision is narrowly avoided. Events are assigned to these categories based on five operational definitions: a) available reaction time, b) the need for evasive or correction action, c) environmental conditions, d) aircraft or vehicle speed, and e) proximity.

The goal of the automated rating model was to analyze recorded events and identify OE severity in a way that resembled the expertise of a group of Subject Matter Experts (SMEs). Cardosi et al. (2005) conducted an initial validation study that compared the ratings generated by the model with ratings provided by SMEs from the Office of Runway Safety and Operational Services. The ratings of the model matched the group's ratings in 67% of the cases. However, when the C & D categories were combined, there was only a 5% disagreement between the model and the SMEs. The model has since been refined and FAA continues the validation process.

OE Reporting

Recording of OE investigational data began when the investigation process was initiated in 1965. In 1984, the Office of Aviation Safety (ASF) designed the National Airspace Information Monitoring System (NAIMS) and implemented it in 1985. One element of the larger automated NAIMS database is the Operational Error System (OES), which includes information derived from the OE reports, including possible causal factors. Since 1985, as part of their safety oversight, ASF has prepared annual reports that analyze the OES. The reports describe many variables of interest with regard to OEs: overall error rate, error rates by facilities, causal factors, and characteristics of errors/error rates by facility (FAA, 1988).

The form used to obtain information about the background and causes of OEs has changed over the years, and the database containing that information has been maintained by different organizations. Changes in the form necessarily result in changes to variables included in the OES database.

OE Research Considerations

An issue that must be considered when conducting research on OES data is that some data fields recorded on the forms have changed over the years as AT investigators, analysts, and managers changed their information requirements. For this reason, any analyses of the database should include checks to ensure that findings are based on characteristics of the underlying data rather than reflecting changes made to the form. Reports resulting from these analyses should indicate the authors' actions to minimize errors resulting from changes to information in data fields. An assessment is currently underway to document when changes to the form (and thus to the database) occurred. Similarly, checks should be implemented to identify data entry errors.

Another issue associated with research in this area is that, although several previous attempts have been made to quantify the level of risk associated with an OE, most of the reports included in this review (especially studies that examined the OES database) involved OEs that were studied without regard to the associated level of severity. Thus, the nature of the OE review and classification process limits data analysis and constrains interpretation of the results. Certain questions about HF issues cannot be addressed within the limitations of the existing database.

METHOD

This section describes our classification of the OE reports reviewed for this project. First, the documents we acquired are described, followed by a discussion of two dimensions used to classify the documents: a) type of study conducted and b) an HF OE classification method. Categories within each dimension are described below.

Source Documents

One hundred fifty-nine OE-related documents were collected, covering a 45-year span from 1960-2005. We searched six aviation technical report databases to identify the relevant literature, using key words included in the phrase "air traffic control operational errors." The six databases included: a) the European Organization for the Safety of Air Navigation Report Database, b) the University of Illinois Institute of Aviation's Aviation Research Laboratory Report Database, c) the W.J. Hughes Technical Center Technical Reports Database, d) the Civil Aerospace Medical Institute (CAMI) Technical Report Database, e) the National Aeronautics and Space Administration (NASA) Technical Report Database, and f) the National Transportation Safety Board (NTSB) Report Database. Ovid software was also used to search the scientific literature contained in the American Psychological Association's PsychINFO® database. PsychINFO® is a comprehensive international bibliographic database of psychology that contains citations and summaries of peer-reviewed journal articles, book chapters, books, dissertations, and technical reports written in the field of psychology and other reports addressing the psychological aspects of related disciplines. Proceedings from scientific sessions were also examined, as were unpublished internal FAA documents acquired through a network of professional contacts within the ATO. (To date, there is no centralized repository of internal FAA reports describing the implementation or evaluation of OE interventions.) We included internal FAA documents in this report if they addressed causal factors of OEs and not those solely focused on ATC or aviation safety.

Figure 1 shows the distribution over time of documents included in the literature review. The increase in the number of research reports published after 1985 may be due, in part, to an interest in assessing the recovery and safety of the NAS following the ATC strike and resulting loss of 11,500 controllers in August 1981.

Although the graph suggests that most studies were conducted since 1980, it should also be noted that it was difficult to identify and obtain information about studies conducted before that time. The difficulty stemmed from the lack of a central repository for OE research reports. It is possible that early studies were conducted but were not archived for future reference. Thus, we may find ourselves initiating OE studies to rediscover what once was known but has been lost from institutional knowledge. Without an ongoing systematic means for archiving OE research reports, as they are made available, the institutional memory of past work is lost.

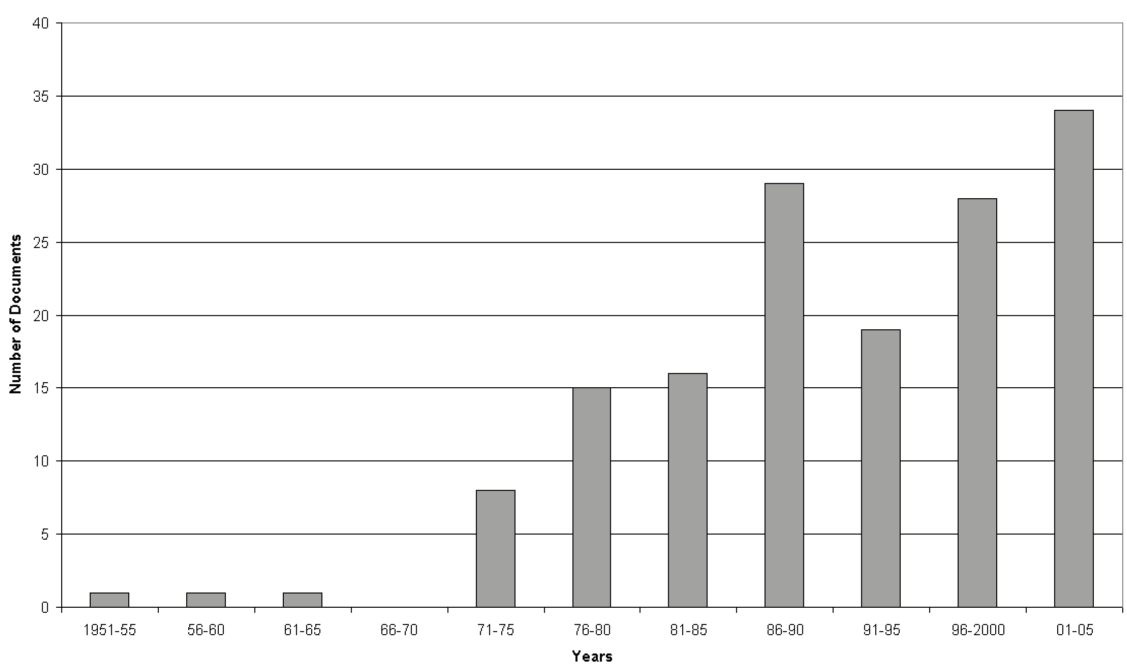

Figure 1. Distribution of OE-related documents by year of publication.

Classification Procedures

Each document was reviewed and classified along two dimensions. The first was the type of study conducted. The second involved a comparison of the content with a set of human factors-related categories included in a recently developed OE analysis method called JANUS. Definitions of all classification categories are provided below. The results of the classification processes appear in Appendices A and B.

Type of study

Studies were classified into one of four types: Descriptive studies (database analysis), theory-based studies, field studies, and experiments. This classification system was based on the way scientific inquiries are conducted—describe the phenomenon of interest, then develop a theory to understand what has been observed, then conduct field studies and experiments to better understand the mechanisms that affect the phenomenon. Each approach has advantages and disadvantages, depending on the goal of the study. Each report was classified into only one category based on the major thrust of the article. These were defined as follows:

Descriptive study (database analysis)

A report was classified in this group if it described information contained in the OE database and did not necessarily test hypotheses. This category also includes exploratory studies (i.e., database analysis) performed on OE data to try to discover underlying trends and associations between variables of interest (e.g., association between the amount of traffic activity and the number of OEs).

Theory-based study

A report was classified in this group if it presented and interpreted information about OEs in the context of a particular way of thinking (e.g., interpreted OE causal factors from an information processing perspective, from a perspective based on previous experience, or according to a predetermined organizing rationale [i.e., a taxonomy]). Using this definition, a theory-based report can range from a "thought piece" in which the author(s) speculates about cause and effect mechanisms based on his/her knowledge of the issue to a more formal model based on the results of empirical research. Examples of the former would be a "lessons learned" report written by a former certified professional controller (CPC) or the reflections of an HF researcher who has spent a career studying OEs. An example of the latter would be using a human error taxonomy (e.g., JANUS) to organize data so that additional insight can be gained about the OE.

Field Study

A report was classified in this group if it described a study conducted under actual job conditions, although the nature of the tasks being observed and data being collected may vary. An example would be a time and motion study of actual ATC equipment usage conducted while controllers are actively controlling traffic, rather than participating in ATC simulations. Another example would be analyzing routinely recorded ATC data to establish a baseline of operations before a new piece of equipment is introduced. Because the data collections are conducted in actual working conditions, it is often difficult to manipulate the variables of interest to make cause and effect determinations. Thus, most ATC field studies fall under the category of observational research or baseline/ trend analyses and are often used to assess the acceptability of changes in equipment and/or procedures.

Experiment

A report was classified in this group if it presented a study conducted in an experimental setting, such as an ATC simulation, and used the scientific method to investigate the effects of independent variables (i.e. predictor variables such as situation awareness, often called SA; or working memory) on OE occurrence (the criterion of interest). When the scientific method is strictly applied, experiments enable researchers to control the experimental setting, allowing measurement of the direct effects of predictor variables on the criteria. In other words, experiments enable researchers to test for cause-and-effect relationships.

JANUS as an Organizing Framework

The current OE reporting process produces enormous amounts of data about each OE. The resulting OE reports are largely descriptive of the circumstances involved in the events and do not provide a systematic approach to understanding the underlying causal human factors. When we began our literature review, we needed a method to organize the large number of OE reports identified in the literature search. Many of these reports are based on analyses of the OES database.

To organize the OE reports, we borrowed the taxonomy from JANUS (Pounds & Isaac, 2002, 2003), a technique that integrated two aviation error classification systems: a) the Human Factor Analysis and Classification System,

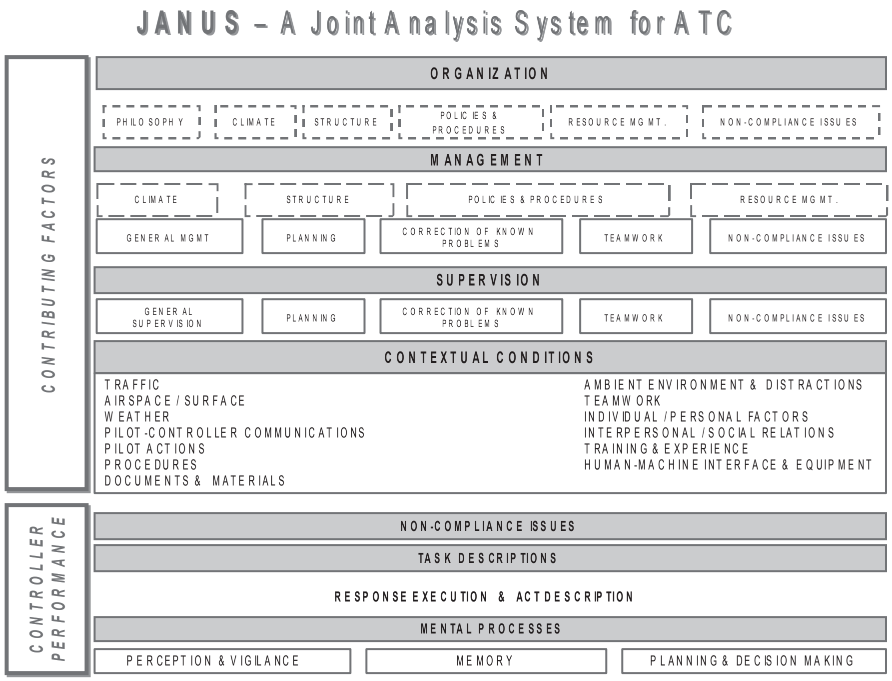

Figure 2. JANUS, a comprehensive HF framework for analyzing OEs.

(HFACS; Shappell & Wiegmann, 2000b), and b) Human Error Reduction in Air Traffic Management, (HERA; EATMP, 2000) to enhance identification of OE causal factors. JANUS provides an inclusive HF framework that captures an extensive array of potential OE causal factors (see Figure 2). Using the JANUS taxonomy, the *human factors* associated with an OE can be classified in terms of the person performing a specific task with a particular piece of equipment in a specific environment, extending to supervisory and organizational influences that may affect the person's performance. Using the categories and factors from this technique provided us with a comprehensive framework for classifying the reports included in the literature review.

Although originally developed to analyze ATC OEs, the JANUS framework has two useful properties that we exploited to organize the OE literature. First, the JANUS taxonomy enabled the literature to be classified into several HF-related areas. Thus, by simply classifying the literature according to the JANUS categories, one can see which human factors-related areas (e.g., mental processing, contextual conditions, supervision, or organizational influences) have received the most attention and which have been neglected. Second, when the type of study conducted (i.e., experiment, field study, descriptive, or theoretical) is used to classify the literature, it is possible to identify the amount of scientific rigor that has been dedicated to a given human factors-related area.

When classifying the literature using the JANUS taxonomy (see Appendix B), topical categories (defined by factors) were used instead of formal definitions. When a report addressed several important research topics, multiple JANUS categories were used to classify it. The JANUS categories were defined as follows:

Organizational Influences

A report was classified in this group if it described organizational factors contributing to OEs (e.g., organizational climate, structure, national or regional policies and procedures, and/or resource management). Organizational issues involve FAA Headquarters, Service Areas (formerly called FAA Regions), etc.

Management

A report was classified in this group if it described management factors contributing to OEs (e.g., facility policies and procedures, general management planning, correction of known problems). Management issues involve facility managers, facility Operations Managers (OMs), and staff.

Supervision

A report was classified in this group if it described factors related to controllers' operational supervisors and discussed how they might contribute to OEs (e.g., general supervision, planning, correcting known problems, teamwork, and supervisory non-compliance).

Contextual Conditions

A report was classified in this group if it described the context in which OEs occurred. The 12 categories of contextual conditions used were traffic/airspace, weather, pilot actions, pilot/ATC communications, procedures, documents/materials, ambient environment, teamwork, individual/personal conditions, interpersonal and social conditions, training and experience, and Human-Machine Interaction (HMI)/Equipment.

Non-compliance[1] Issues

A report was classified in this group if it addressed purposeful disregard of rules or procedures.

Task Descriptions

A report was classified in this group if it described activities in which the controller was primarily engaged at the time of an OE, such as communicating with a pilot, control room communication, radar monitoring, tower observation, giving a position relief briefing.

Response Execution

Response execution refers to the outputs or actions based on the earlier processes, that is, how choices and plans were enacted as actions (either verbally or manually).

Mental Processes

A report was classified in this group if it described controllers' thought processes associated with OEs. These processes included: a) perception and vigilance, b) memory, c) planning and decision-making, and d) response execution.

RESULTS

The results are organized into two sections. The first describes the classification of OE reports according to type of study. We follow with the coding of the literature according to the HF categories contained in JANUS. A description is provided for some of the studies contained in the JANUS categories that were most frequently addressed by research.

The second section describes available information about AT initiatives that have been developed nationally, regionally, and at individual facilities to reduce operational errors. Once again, we review these interventions as they relate to the various JANUS categories.

Literature Review

Classifying the Literature by Type of Study

Appendix A lists the research documents classified according to the type of study conducted. The distribution showing the number of each type of study is shown in Figure 3. The majority of documents collected were classified as descriptive studies (database analysis; 44%), followed by theoretical studies (36%). Looking at the distribution in Figure 3, it is apparent that the more scientifically rigorous HF methods (experiments, 9%, and field studies, 11%) have seldom been employed to study OEs and their causes.

Descriptive Studies (Database Analysis)

Given that most of the empirical information available about OEs and their causes has come from descriptive analyses, it is imperative to examine that literature with an eye toward the quality of the information contained within the respective OE databases.

Eight databases that contain OE-related information were referenced in the descriptive literature. These were the: a) National Airspace Information Monitoring System (NAIMS), b) NASA's Aviation Safety Reporting System (ASRS), c) NTSB's Aviation Accident and Incident Data System, d) AT Quality Assurance Analysis and Reporting (QUASAR) database, e) the FAA's System Effectiveness Information System (SEIS) database, f) FAA's Operational Errors System (OES) database developed from preliminary and final OE reports, g) OE databases at individual FAA facilities, and h) the non-specific archival FAA OE database. Several of these databases are based on earlier versions of the current OES database. Although it is beyond the scope of this report to describe each of these databases in detail, it is important to note that there is no centralized quality assurance (QA) process that governs the quality of the data in each of the respective databases. This becomes especially problematic when trying to compare the results of OE studies that extracted data from different databases. For example, how might

[1] In the initial work with EUROCONTROL, the term "contravention" was used instead of "non-compliance." When FAA air traffic controllers reviewed the JANUS materials, they preferred to use the term "non-compliance" for this concept.

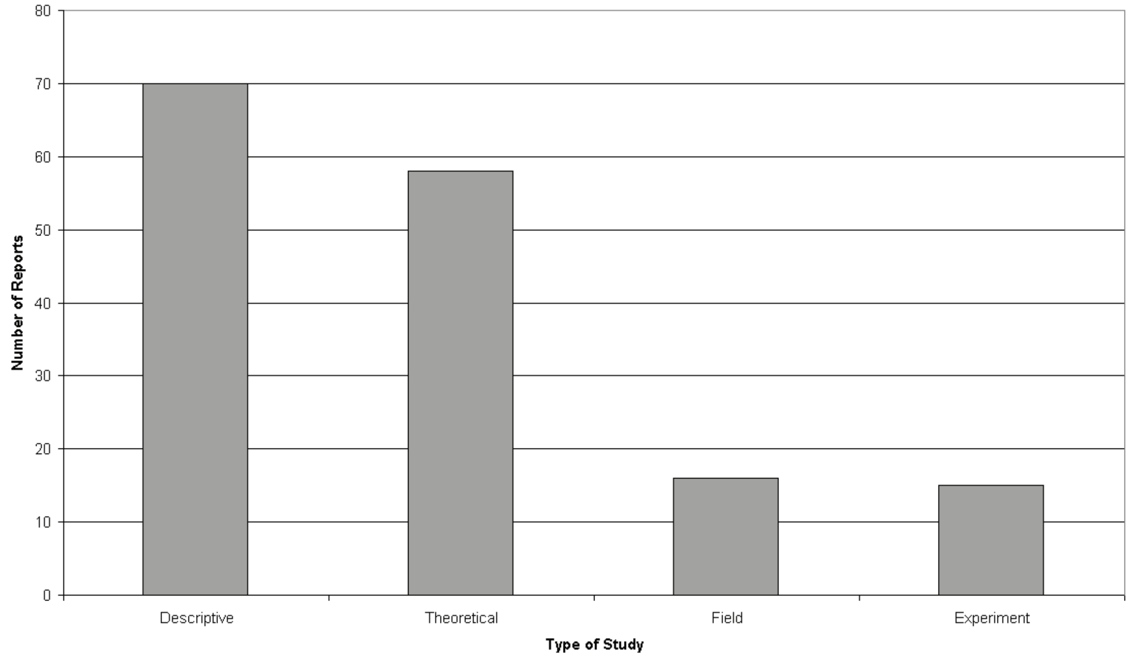

Figure 3. Distribution of OE-related documents by type of study.

one equate studies that used information from the ASRS (which includes only self-reports of incidents) or from a generic FAA OE database at a field facility (which contains only data specific to that facility) with studies that used information from the NAIMS (which contains information about OEs from all FAA facilities)?

Theory-based Reports

The authors of theory-based reports apply human factor principles and models of human error to speculate about the underlying causes of OEs. For example, Reason's (1990) model and Rasmussen's (1986) information processing model both propose generic models of human error. The merit of using generic models of human error to understand the underlying HF causes of OEs was discussed as early as 1977. Kinney (1977c) noted that to some degree, all OEs involve the basic human failings of memory, attention, and judgment, regardless of the situation. Thus, by developing interventions to address common human error vulnerabilities in general, the ATC system should experience an overall decline in the number of OEs. However, one of the shortcomings of this line of thinking is that generic models assume that humans are interchangeable. The problem comes when attempts are made to apply generic models to address specific events surrounding an OE. Generic models produce generic solutions and must be customized to the individual controllers/facilities/sectors to solve a particular problem.

Most of the theory-based reports we reviewed served as heuristics for designing and conducting HF experiments and/or field studies, rather than addressing a particular operational problem or recommending strategies for error mitigation. However, the recommended experiments and/or field studies were seldom completed.

Field Studies

In the field, it is neither possible nor desirable to manipulate working conditions to assess their influence on the likelihood of committing an OE. For that reason, none of the field studies identified for this literature review directly examined the causes of OEs but, instead, addressed OE precursors such as traffic volume (Hurst & Rose, 1978a), sector complexity (Hurst and Rose, 1978b; Grossberg, 1989), problematic communications (Burki-Cohen, 1995; Cardosi, 1993; Cardosi, 1994; Cardosi, Brett, & Han, 1996; Prinzo, 1996), SA (Endsley & Rodgers, 1994), and the ATC culture (Jones, 1997). There is a large body of literature that addresses many of these and other HF issues where the emphasis is more about the effects of these factors on performance rather than on the occurrence of OEs. While these investigations provided us with greater insight into some of the complexities associated with the operational ATC environment, they provided little, if any, information about the linkage of these factors to OEs.

An exception to the typical limitations associated with field studies was the joint FAA-EUROCONTOL project conducted by Pounds and Isaac (2003) to test the JANUS technique. The FAA's test of the technique encompassed twenty-nine ATC facilities which volunteered to collect JANUS data in parallel with the FAA OE investigation process. This represented a concurrent test of the JANUS OE analysis process because researchers interviewed ATC personnel to collect JANUS data while the facility's staff conducted their investigation per FAA Order 7210.56. The technique was evaluated first based on the feasibility of the process and then for the information value of the data collected.

When asked for their feedback, participants in the data collection indicated that, after going through the process, they had an overall positive opinion about the JANUS technique and thought that the questions asked were relevant to OE causal factors. In a separate activity, FAA managers and NATCA facility representatives from the participating facilities indicated that the method could be a useful tool if implemented operationally. A separate group of ATC management and staff personnel who were not associated with the beta test rated the data output from JANUS as more comprehensive, informative, practical, specific, and useful compared with the output from the current process used to identify OE causal factors (as described in FAA Order 7210.56).

To assess information value of the JANUS technique, 79 OEs (64 from ARTCCS and 15 from terminals) obtained during the beta test (Pounds & Isaac, 2003) were used to compare the causal factors identified by JANUS with those identified by the current OE investigation process. One difference between the techniques is that the current FAA OE investigation process analyzes the OE as a unitary event whereas the JANUS technique permits splitting each OE into several "links in the chain" and analyzing each link separately.

In the sample of 79 OEs, 133 causal factor items were reported (an average of 1.7 causal factors per OE) and were distributed in the following categories found on the current OE reporting form: Data Posting (9.8%), Radar Display (58.7%), Aircraft Observation (Towers Only; 1.5%), Communication Error (25.6%), Coordination (4.5%), and Position Relief Briefing (0%). In this same sample, an average of 3.6 factors per OE was related to the mental processes of the controller working the traffic. The factors were distributed in the following categories: Perception and Vigilance (41%), Memory (15%), Planning and Decision Making (49%), and Response Execution (10%). (Because the JANUS technique permitted more than one category to be selected, the percentage summed across categories was greater than 100%.) Contextual factors that influenced the OEs were also identified for each "link" resulting in an average of 9.6 factors per OE. The factors were distributed in the following categories: Traffic & Airspace (49%), Weather (28%), Teamwork (26%), Pilot Actions (21%), Individual/Personal Factors (21%), Pilot-Controller Communications (20%), Ambient Environment/Distractions (18%), Workplace/Equipment/Human-Machine Interactions (13%), Procedures and Orders (11%), Training and Experience (10%), Supervision and Management (10%), Organizational Factors (10%), Interpersonal/Social Factors (5%), and Documents and Materials (0.3%).

Experiments

None of the experiments identified in the literature search studied OEs as the criterion variable of interest. Although it is possible to create an experimental manipulation in which the likelihood of committing an OE is high (but would not necessarily be guaranteed to occur), none of the experiments was designed in that manner. Instead, the focus was on assessing the impact of experimental manipulations on typical OE predictors, especially those related to SA, memory, and workload. The most common experimental manipulation involved varying traffic volume to assess aspects of controller performance.

The primary hurdle involved in using simulations in experiments to assess OE occurrence is the infrequency with which OEs occur. Given the vast numbers of communications and control actions issued correctly during the course of a single day, we would expect to see few OEs occur during the course of a two-hour (or even longer) simulation. When we conduct an experiment to assess the effects of the amount of traffic on controller performance, we can clearly measure how it might influence SA and radar scanning. However, are these performance changes predictive of OE occurrence? For example, suppose an SA experiment reveals that controllers' radar scanning and SA are degraded under conditions of high aircraft volume. Can we then extrapolate to say that reductions in the amount of traffic, which resulted in improved radar scanning and SA, are likely to reduce OEs? This conclusion would likely be invalid, since we already know that a significant number of OEs occur under lower traffic loads. Thus, organizational interventions designed to improve SA may be very successful at improving SA but appear to be ineffective in reducing OEs. Until we can identify aspects of controller performance that are predictive of OE occurrence, it is highly unlikely that we can utilize simulations and experimental methods to define effective OE intervention strategies. Some would argue that, given the dynamic nature of the air traffic environment, we are not likely to identify discrete performance predictors of OEs.

We do not argue that conducting experiments is unimportant. On the contrary, continued simulation-based studies are needed to improve our understanding of the relationships among OE predictor variables. As we enhance our understanding of the role of experience, techniques, and amount of traffic on controller performance, we will gain a better understanding of predictors and prevention methods for OEs.

Classifying the Literature by JANUS Categories

Figure 4 shows the number of reports that fell within each of the high-level JANUS HF categories. Because a document could address several JANUS categories, the total number of citations included in Figure 4 exceeds the number of source documents.

The OE literature fell primarily into two of the high-level JANUS categories: contextual conditions associated with an OE (44% of the reports) and mental processing of involved controllers (30% of the reports). The literature also addressed: organizational influences (7%), managerial influences (4%), supervisory influences (6%), controller non-compliance (1%), the controller task (1%), and controller's response execution to choice and plans (7%). Rather than serving as an indication of the relative importance of a given JANUS category in the investigation of OEs, these percentages instead reflect the general interest of the researchers, as well as the availability of information about the topic areas.

While a short description of the literature in each category will be provided, the high percentage of documents classified as belonging to the Contextual Conditions and Mental Processes categories allows more discussion about the literature in those categories. For a complete list of reports classified in each of the JANUS categories, refer to Appendix B.

Organizational and Management Factors

Using a structured interview process based on the HFACS aircraft accident classification system (Shappell and Wiegmann, 2000b), the National Aviation Research Institute (Conner & Corker, 2001) interviewed 109 controllers at AT facilities that had high or low error rates. They found that, while interviewees rated controller performance as the most important factor in error causation, organizational factors were also viewed as being of high importance. Their list of most important factors also included organizational climate.

In an unpublished work group report about the causes of surface incidents, Kaulia et al. (1987) stated that, in addition to factors related to controllers, various organizational factors needed to be addressed. These included: a) the lack of updated Standard Operating Procedures (SOPs), b) an insufficient number of trained supervisors, and c) supervisors overburdened with administrative duties.

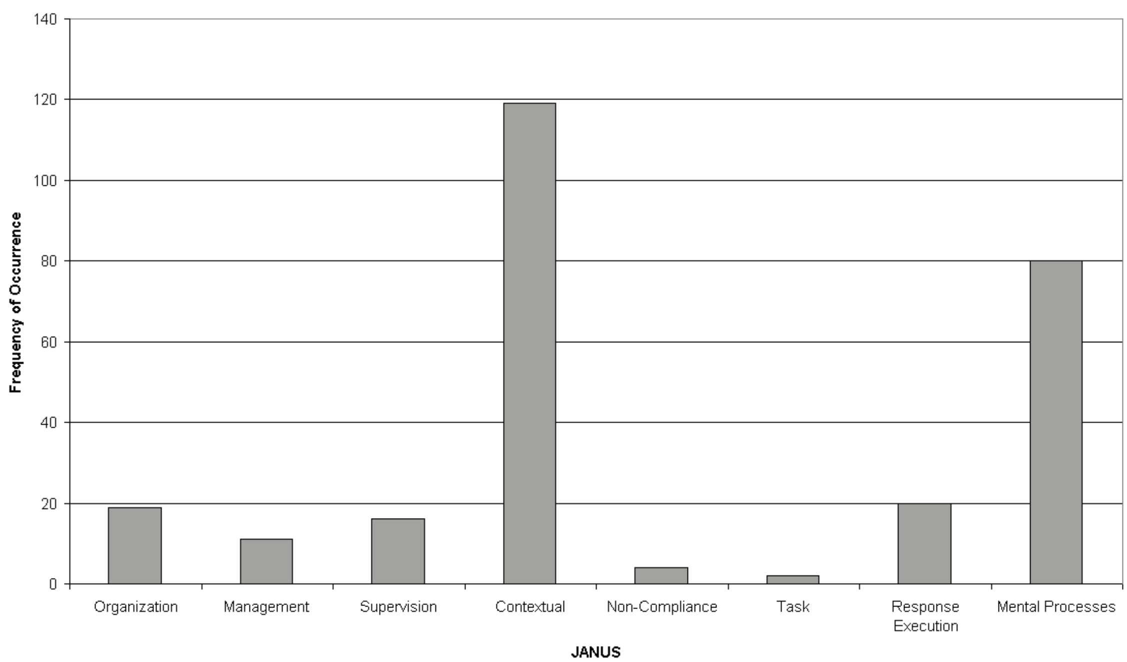

Figure 4. Distribution of OE-related documents by JANUS category.

Supervision

Going back as far as Kinney (1977b, 1977c), supervisory influences on ATC OEs were noted and echoed by various ATC work group reports that emerged in the 1980s following the PATCO strike. Kaulia et al. (1987) identified these supervisory concerns: The inability to a) correct the actions of unsafe controllers, b) monitor controller performance, and c) ensure that controllers were properly trained.

Another aspect of supervision that has received limited research attention, yet appears to have some potential for being a factor in reducing OEs, involves aspects of the supervisor's duties and responsibilities. As part of a survey of supervisors, Kirk, Mayberry, and Lesko (1996), asked for an indication of their time allocation across eight functional areas (supervisor operations, manage resources, monitor performance, provide training, maintain expertise, foster teamwork, collateral duties, and personnel issues) and then asked them to rate the importance of each of the above functions on a 5-point scale. Supervisor time was primarily allocated to one of four functions: enhancing operational effectiveness, managing resources, interpersonal skills, and miscellaneous assignments. Supervising the operation was viewed as the most important function across all facilities.

For en route centers, Kirk et al. examined the relationship between the importance ratings provided by the supervisors and OEs. Team supervisors who placed greater emphasis on the importance of managing resources and supervising the operation had fewer OEs. The emphasis the area supervisor in charge (ASIC) placed on several other functions (promotion of teamwork, monitor performance, provide training, and address personnel issues) was also significantly related to fewer OEs. The implication is that ASICs who rated the importance of these duties and responsibilities highly were more likely to have fewer OEs in their role as an ASIC. For example, 75% of the ASICs who said that managing resources was among the most important supervisory function had one OE or less in their role as a supervisor. Those who viewed managing resources as the least important supervisory function had a median number of two OEs. There was no evidence of a significant relationship between allocation of time between the supervisory functions and the occurrence of OEs. Additional research is needed to understand how these attitudes are translated into behaviors in the workplace. Using the OE database, Kirk, Mayberry, and Lesko (1996) suggested that there was no direct relationship between supervisory activity at the time of the error and the error's severity.

Kirk et al. (1996) also examined other aspects of the effects of supervisory, managerial, and organizational influences on OEs at en route centers. They based their assessment on: a) visits to selected en route centers, b) interviews with controllers, managers, and supervisors, and c) reviews of previous studies. Their extensive investigation of the role of supervisors involved several dimensions including supervisory duties, training and development, staffing changes, teamwork, supervisors' background, and empowerment. Their assessment of changes in staffing took into account the potential influence of a government-wide effort (NPR) to increase the span of control for supervisors. Within the FAA, this meant that efforts were focused on increasing the employee/supervisor ratios from around 7:1 to the proposed government-wide target of 15:1. Subsequent reorganization efforts at the larger en route facilities led to a significant reduction in first-line supervisor staffing. For example, from 1992 to 1995, supervisory staffing levels declined from around 11% at ZTL to nearly 40% at ZLC. Over this same time period, there was a gradual increase in the number of OEs. Kirk, Mayberry, & Lesko (1996) found that there was a statistically significant relationship between the decline in supervisory staffing and the overall increase in OEs (explaining 14% of the overall variance). The relationship was slightly stronger when they took into account the ratio of supervisors to controllers in each of the en route centers. A similar relationship was not found for the TRACON or Tower comparisons. As a result of their observations, interviews, and analyses, the authors made the following recommendations.

1. Develop a standardized way of measuring sector complexity so that sector staffing can be adjusted based on this metric instead of the amount of traffic.
2. Develop action plans for high-OE sectors, which included the need for more managerial attention to be directed to these sectors and an increase in the level of supervision.
3. Monitor the performance of less experienced controllers more closely.
4. Match controller work assignments to the amount of expertise required.
5. Identify the supervisor-controller factors that affect controller performance during an OE.
6. Minimize the amount of managerial turnover to stabilize the culture.
7. Improve the evaluation of controller training and performance.
8. Focus more attention on team training.

NARI (Conner & Corker, 2001) found that controllers tended to view supervisory practices as a significant factor

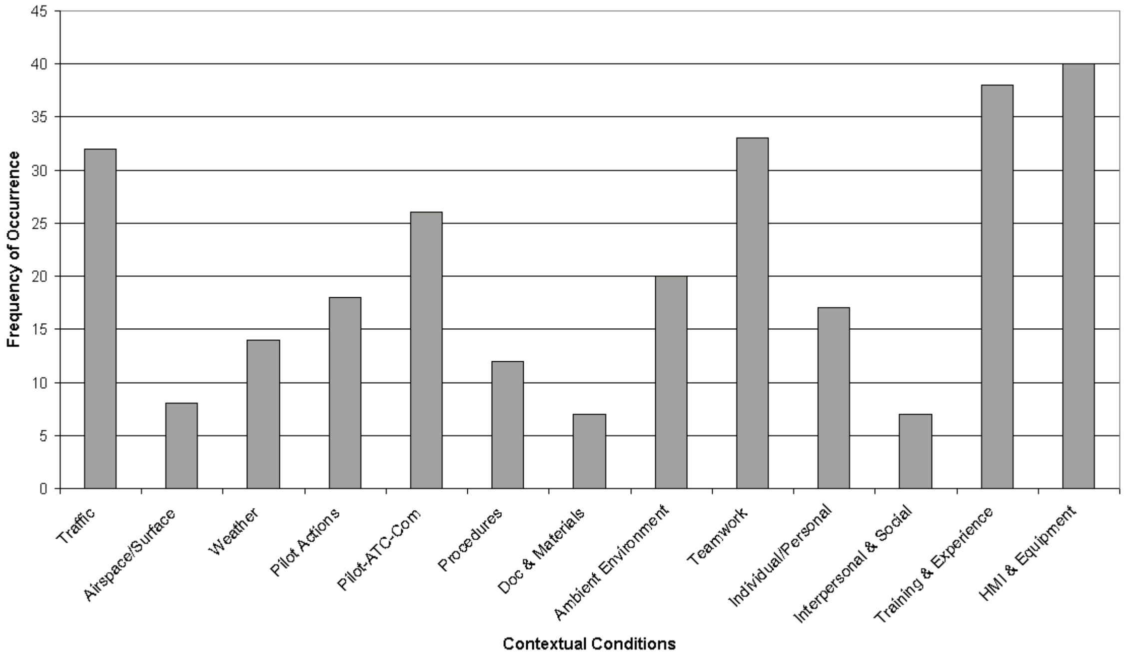

Figure 5. Distribution of OE-related reports by sub-categories of JANUS Contextual Conditions.

that both contribute to OEs and serve as a positive force to avoid OEs. Broach and Dollar (2002) provided an expanded look at the role of the supervisor-to-controller ratio (SCR) in OEs by also taking into account several organizational factors derived from the 1997 and 2000 FAA employee attitude surveys. Their analysis focused on en route OEs that occurred between 1997 and 2000. They reported that two organizational factors (employee perceptions of equipment/facilities and performance management) along with the SCR accounted for 50% of the overall variance in OE rates. Outcomes from Broach and Dollar (2002), Kirk, Mayberry, and Lesko (1996), and other studies clearly demonstrate the importance of a number of supervisory/ managerial/organizational factors in OEs. Additional efforts are needed to further identify and clarify the manner in which these factors influence OE occurrence.

Contextual Conditions

Forty-four percent of the OE-related documents fell under the JANUS Contextual Conditions category. Figure 5 shows the distribution of documents classified into the Contextual Conditions sub-categories. Five sub-categories accounted for 66% of the Contextual Conditions: a) the combination of the Traffic and Airspace[2] sub-categories (15%), b) Pilot-ATC Communications (10%), c) Teamwork (12%), d) Training and Experience, (14%), and e) Human Machine Interface (HMI) and Equipment (15%). The literature from each of these sub-categories will be discussed in some detail. For a listing of the reports classified as belonging to the remaining JANUS contextual conditions subcategories, the reader is referred to Appendix B.

Traffic/Airspace. Two contextual factors under traffic/airspace that have received the greatest attention since the 1960s are the amount of traffic and airspace complexity. Traffic is a dynamic factor, while airspace (including airport surface characteristics) is static, so these two factors will be discussed separately.

1) Amount of Traffic. Kershner (1968) conducted an initial study on the amount of traffic and its relationship with age, workload, and time-on-shift in 1965-66 OEs. Spahn (1977) looked at changes in air traffic levels from 1974 to 1976. Spahn pointed out that a higher percentage of OEs occurred under light and moderate traffic rather than during heavy traffic. From the 1970s through the early 1980s, the trend was toward an increased percentage of OEs under light and moderate versus heavy traffic. Using information from previous studies, Schroeder (1982) provided information regarding changes in the percentage of OEs occurring under the three traffic levels (see Figure 6). From 1965 through 1980, there was a gradual increase in OEs occurring under light traffic levels with a corresponding decline in the percentage occurring under heavy traffic levels. However, the categorization of air traffic required the investigator to make a subjective

[2] While discussed separately, we have combined the Amount of Traffic and Airspace sub-categories here because they are interactive in their effects.

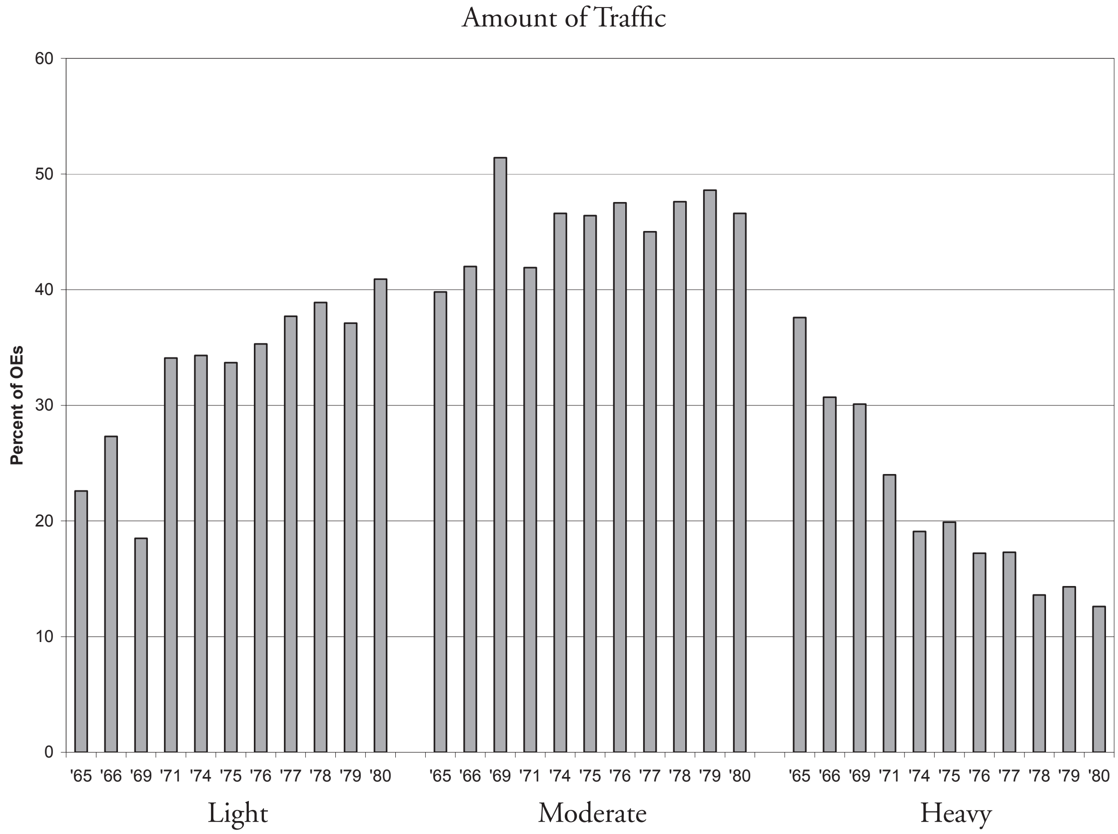

Figure 6. Distribution of amount of traffic associated with OEs by year.

rating. There was little assurance that investigators within and across facilities used the same criteria for judging the amount of traffic at the time of the OE.

As part of a MITRE study to assess the validity of common statements regarding the relationship between traffic and OEs, Lowry, MacWilliams, Still, & Walker (2005) conducted several analyses of the NAIMS 1999-2003 OE database. The percentage of OEs that involved only two aircraft was small (1% in en route, 4% in TRACONs, and 7% in towers). In en route facilities, 21% of the OEs involved 7-8 aircraft. Our analysis of the database suggests that this percentage has remained relatively consistent across time. While not discussed in their report, the figures used to relate OEs to traffic suggest that slightly more than 50% of the OEs in TRACONS and towers involved between 4-6 aircraft.

A second question addressed by Lowry et al. (2005) was whether OEs occur just prior to the traffic peak. To answer this question, the authors analyzed 52 OEs that occurred in FY02 and determined the traffic count 30 minutes prior to and 30 minutes following the OE. In 61% of the OEs, traffic had already peaked when the OE occurred, in another 30% of the cases the OE occurred prior to the peak in traffic.

As evident in reports that described aspects of the 1986 and 1987 OEs (FAA, 1988), trends in OE occurrence associated with the day of the week and time of day appeared to be related to overall changes in the amount of traffic. OEs tended to peak on Wednesdays and Thursdays, with the lowest OE rates evident on Saturdays and Sundays. Throughout the day, OEs increased with a peak around 9 to 10 a.m., leveled off, followed by a secondary and somewhat higher peak around 4 to 6 pm. With respect to the controller's 8-hour workday, the lowest number of OEs occurred during the seventh and eighth hour of the shift. These trends are generally consistent across years and are evident in the current OE database (Lowry et al., 2005).

2) Airspace complexity. Besides considering the role of the amount of traffic in OEs, Spahn (1977) also looked at the influence of traffic complexity. At the time, information included in the OE database about both the amount of traffic and traffic complexity required subjective judgments to be made by the investigator. These two measures, the amount of traffic and traffic complexity, are not independent. As the amount of traffic increases, there is generally a corresponding increase in traffic complexity. Spahn's (1977) data suggest an interaction between traffic complexity and the amount of traffic, with higher percentages of OEs occurring in moderate and heavy traffic complexity conditions. This suggests that the interaction of amount of traffic with traffic complexity may affect OEs more than the amount of traffic alone. However, there are significant questions concerning the definition and measurement of both traffic and airspace complexity.

Most of the research on airspace complexity has been targeted at developing measures of dynamic density, an indicator of future sector activity, rather than OEs. However, several reports have examined the relationship between sector complexity and OEs at en route facilities. For example, Grossberg (1989) found a correlation of .44 between an index of sector complexity based on the top four complexity factors (complex control adjustments, climbing and descending flight paths, large airspace, and mix of aircraft types) and the number of operational errors at sectors in the Chicago Center. Rodgers, Mogford, and Mogford (1998) related Mogford's (Mogford et. al., 1994) 16 complexity factors to the incidence of operational errors at Atlanta Center (ZTL) sectors. They found that a variable that characterized sectors as having a low, medium, or high incidence of OEs predicted several of the sector complexity factors. They also found that several sector complexity factors (notably radio frequency congestion and special use airspace activity) predicted the number of errors per sector in an analysis of ZTL data. Thus, they concluded that sector characteristics appeared to be related to OEs.

NARI (Conner & Corker, 2001) defined Operational Complexity as "the characteristics of air traffic control processes, environment, and the users who operate in it, including the airspace, equipment, traffic, weather, aircraft performance, military, information, frequencies, etc." Interviews conducted during the NARI OE study (2001) identified Operational Complexity as the second highest-rated OE causal factor. Moreover, Pounds and Isaac (2003) found that 49% of the errors identified in their JANUS validation study were related to either sector or traffic characteristics.

Lowry et al. (2005) conducted several analyses of the 1999-2003 database that focused on issues often included in assessments of airspace complexity (sector size, sector configuration, and traffic mix). With respect to sector size at en route centers, their analysis supported previous research by Rodgers et al. (1998) indicating that smaller sectors, with a volume of 50,000 or less volume units, comprised 50% of the sectors, handled 52% of the traffic, and experienced 64% of the OEs. With respect to traffic mix, neither regional jets nor business jets were involved in a disproportionate number of OEs. However, in terminal facilities the authors found that turboprops were disproportionately involved in OEs in three of the four facilities included in the analysis. An additional analysis was focused on the impact of a National Choke Point Initiative in which two sectors at the ZID and ZOB en route centers were redesigned to improve efficiency. While Massimini, Nene, Gormley, & Stevens, (2001) found that the redesign reduced demand on adjacent sectors and improved efficiency, Lowry et al. (2005) found that the OE rates two years prior to and two years following the redesign were the same.

Pilot-ATC Communications. Most empirical ATC studies have been conducted to assess the phraseology associated with Pilot-ATC communications. Initial studies involving analyses of the FAA/NASA Aviation Safety Reporting System (ASRS) database were conducted about 20 years ago (Grayson & Billings, 1981; Monan, 1980; Monan, 1983). Initial efforts were focused on factors associated with miscommunications (Grayson & Billings, 1981). They included pilot expectations, similar call signs, transposing numbers, garbled phraseology, and inaccurate or incomplete messages. Monan (1980, 1983) investigated the role of similar call signs as well as readback/hearback errors. Cardosi, Falzarano, and Han (1998) conducted a more recent review of the communications error information contained in the ASRS reports as a means of identifying factors that contributed to the errors. The most common factors involved similar call signs, pilot expectations, and high controller workload. While not focused solely on OEs, these studies provide an overall perspective for understanding some of the communications issues associated with OEs.

Cardosi and her colleagues performed much of the research focused on the role of voice communications as a critical safety link in the NAS. A recent report on the metrics of communication performance by Cardosi and DiFiore (2004) provides an excellent summary of their work, some of which is now a decade old and, thus, may represent a conservative estimate of communications in today's environments. The metrics incorporated in their studies included: (i) number of controller transmissions per minute, (ii) number of clearances issued per minute, (iii) characteristics of pilot responses to clearances, (iv) percentage of clearances that result in a pilot readback error, (v) percentage of readback errors that are not corrected by the controller, (vi) percentage of controller transmissions that need to be repeated due to pilot requests, (vii) factors associated with miscommunications, and (viii) the time required to successfully transmit an instruction to maneuver for traffic avoidance in the en route environment. Each of the studies involved an analysis of approximately 50 hours of voice tapes from tower cabs, TRACON, and en route air traffic control facilities (Cardosi, 1993; Burki-Cohen, 1995; Cardosi, 1994; and Cardosi, Brett, & Han, 1996).

We have elected to summarize the overall results described in Cardosi and DiFiore (2004) rather than describe more detailed outcomes from each of the studies. Evidence suggests that the number of controller transmissions varies by environment, from a low of just under 2 to 4.5 communications per minute in TRACONs and about 8 communications per minute for the tower Ground Control position. Of course the average number of communications for Ground Control may vary considerably from larger to smaller towers. Pilot responses to controller communications varied considerably; at en route centers some 70% contained a full readback, while at the tower Local Control position, less than 30% involved a full readback.

A consistent finding in Cardosi's work was that the rate of communication errors, defined as readback errors and requests for repeated communications, was low across facility types. The readback error rate was consistently less than 1%; requests for repeated transmissions was similarly low, with the exception of the en route environment, where the frequency was slightly higher, at 1.4%. While a readback error occurred once every 2.5 hours for local controllers, at TRACONs the rate was around one every half-hour. The vast majority of these errors were caught and corrected by the involved controllers.

Causal factors associated with communication errors (few of which lead to OEs) included attempting to convey too much information, frequency congestion, workload, speech rate, poor grasp of the English language by international pilots, and similar-sounding aircraft call signs. Analyses of the data by Cardosi and her colleagues suggest that there is a strong relationship between the complexity of the controller's transmission and the probability of a readback error in the en route and TRACON environments. For en route transmissions, the readback error rate doubled as complexity increased from three to four elements. While 4% of controller transmissions involved five or more elements, they contributed 26% of the errors in en route facilities. A similar finding was observed in TRACONs.

Although nearly all communications are free of errors, communication errors play a significant role in the overall OE process. Rodgers and Nye (1993) found that 36% of en route OEs involved communication errors. In the tower environment, Cardosi and Yost (2001) found that 41% of OEs involved communication errors, with 19% involving pilot-controller miscommunications.

Baseline field studies such as those conducted by Cardosi provide a necessary perspective on the infrequency of communication errors in the course of normal operations. For example, imagine an intervention designed to reduce hearback/readback errors. Using a pre- vs. post-intervention evaluation design, we could determine the effectiveness of the intervention at reducing hearback/readback errors. The effectiveness of the intervention is not based on the reduction of hearback/readback errors that occur during OEs. Rather, the intervention is being evaluated against hearback/readback errors that occur during all communication exchanges. Given that less than 0.5% of all communication exchanges between controllers and pilots result in uncorrected hearback/readback errors, and that only a fraction of this 0.5% of communications will actually involve an OE, it would be difficult in a field study to evaluate the effectiveness of such an intervention on the reduction of OEs, per se. This is an important factor to keep in mind as we review the literature. Causal factors commonly associated with OEs (i.e., data posting errors, radar display errors, tower observation errors, communication errors, coordination errors, and position relief briefing errors) occur at some base rate within normal operations. Even if an intervention reduces the base rate with which these errors occur, the extent to which the intervention will have a significant impact on OEs remains to be seen.

The safe and efficient flow of traffic in the NAS relies heavily on voice communications between pilots and controllers. As evident from the results presented earlier, OEs are frequently associated with readback errors. In their summary report, Cardosi and DiFiore (2004) indicated that communication errors appear to be closely linked with the complexity of the controller's transmission. While this research has been focused on the controller side of the communication link, less information is available about factors that contribute to a pilot's failure to understand and respond properly to a communication. The exception involves research focused on age differences in pilot responses to air traffic control instructions. While these studies were not focused on OEs, they provide insight into factors that can lead to miscommunications and possible OEs.

Since the complexity of a controller's transmission is linked with communication failures, we can assume that working memory capacity plays an important role in pilot controller communications. Research has demonstrated an age-related decline in working memory capacity (Baddeley & Hitch, 1974) and speed of processing (Salthouse, 1980) as well as an increased susceptibility to interference or distraction (Engle, Kane, & Tuholski, 1999). Research has focused on determining the extent to which pilot expertise may reduce the typical age-related decline in the recall of ATC communications. Previous research demonstrated that older pilots exhibited a slightly lower ability to recall ATC communications (Morrow, Leirer, & Yesavage, 1990; Morrow, Yesavage, Leirer, & Tinklenberg, 1993; Taylor et al., 1994; Yesavage et al., 1999). However, Morrow & Leirer (1997) and Morrow, Leirer, Altieri, & Fitzsimmons (1994) found that pilot expertise may moderate age differences in recalling ATC communications.

In a recent study (Taylor et al., 2005) the authors set out to assess the role of cognitive ability and domain-specific expertise as they influence age-related differences in pilot responses to ATC messages. In addition to assessing the role of pilot expertise, as determined by pilot ratings (VFR, IFR, and CFII/ATP), the authors varied the length and speech rate of the ATC instructions for pilots who were not allowed to write down the communications while flying a simulator. The 97 pilots in the study were split into two groups for the age comparisons (45 to 57 and 57 to 69). The results demonstrated that pilots recalled 2.05 of 3 instructions when the instructions were presented at a normal speech rate, but performance declined to 1.88 instructions recalled for the fast speech rate. Also, when 3 instructions were presented, an average of 2.05 was recalled, but longer ATC messages led to lower accuracy (only an average of 1.87 instructions was recalled). It would seem likely that pilots would recall ATC communications better if they were allowed to write down elements of the communications as is commonly done while flying.

While this study showed that expertise led to improved recall of ATC communications, there was little evidence that it reduced the age-related decline in performance. They found that the effect of age on recall accuracy was largely explained as an "age-associated decrease in working memory span, which in turn was explainable as decreases in both speed and interference control (pg. 117)." These results, along with those of Cardosi and her colleagues, can be used to support interventions designed to improve communications. The emphasis of these interventions should be on a standard speech rate and shorter instructional messages. The results also emphasize the importance of involving pilots in efforts to reduce hearback/readback and other communication failures.

Teamwork. ATC teamwork is generally discussed in the literature relative to either (a) controller task coordination, or (b) interpersonal skills. Discussions of task coordination primarily involve controller team members functioning within dyads, such as a radar controller and radar associate, a ground and local controller, or two controllers involved in inter-sector coordination. One of the more visible aspects of task coordination occurs during position changes.

Position Relief Briefings. One aspect of teamwork is the transfer of position responsibility that takes place when one controller relieves a second controller. This process is referred to as a position relief briefing. The current controller handbook (FAA, 2006) contains rather specific instructions regarding the process for accomplishing a position relief briefing. During this time, a relieving controller observes the traffic situation that he/she will be taking over. The controller being relieved then follows a checklist to ensure that all relevant information has been transferred to the relieving controller.

The current NATCA contract (FAA, 1998a) states, "Unless operational requirements do not permit, employees shall not be required to spend more than two (2) consecutive hours performing operational duties without a break away from operational areas." This means that during the course of a 24-hour day, several position relief briefings are conducted as one controller leaves a position and another takes over.

The identification of position relief briefings as a causal factor has been a part of the OE report form for many years. Kinney (1977b) indicated that inadequate position relief briefings were cited as primary and contributing causes of what were then called system errors (now called OEs). Their observations suggested that many position relief briefings were too short. At that time, he indicated that specific rules for position relief briefings "… are not in the training curriculum, not in Handbook 7110.65, and not on proficiency evaluation checklists. (p. 6-1)." He also noted that facility managers and supervisors have taken actions to improve relief briefings. Recommendations were provided to improve performance during position relief briefings.

Despite the concern surrounding position relief briefings, data extracted from the OE reports suggest that the frequency with which a position relief briefing is cited as a contributing factor to an OE is relatively small when compared with several other factors. Schroeder (1982), in his review of the 1979 and 1980 version of the OE database, found that position relief briefings were a direct cause in 0.89% (1979) and 0% (1980) of en route OEs.

For terminal operations, the percentages were only slightly higher (1.07% and 1.06%, respectively).
The later analysis of OEs conducted by the Office of Aviation Medicine in 1988 cited incomplete position relief briefings as a common, error-prone procedure. The most recent annual report from the NAIMS (FAA, 2003) indicated that position relief briefings were a factor in 12% of OEs. While an emphasis on position relief briefings has been a frequent intervention strategy, a survey of controllers, supervisors, and managers conducted by Mayberry et al (1995) suggested that less than 10% of controllers and supervisors viewed position relief briefings as one of the top reasons for an OE. Analyses by Lowry et al. (2005) also found that position relief briefings played a limited role in most OEs. While analyses of the database indicate that position relief briefings are causal factors in a small percentage of OEs, the consistent emphasis on initiatives related to this factor (which will be discussed later) suggest that operational personnel believe this is an important factor in OEs.

When teamwork addresses interpersonal skills, the notion of the team extends beyond a given dyad to include surrounding facility personnel. This extension is addressed through documents about team culture and plays a prominent role in the Air Traffic Team Enhancement program (ATTE). Although ATTE was not designed as an OE mitigation effort, per se, it has been used in some cases to address teamwork as an OE causal factor. Anecdotal information from ten facilities suggests that OEs were reduced when ATTE was successfully implemented—although other variables confounded these results and made clear interpretation difficult. The ATTE program is currently undergoing further refinement and testing.

Efforts to determine the relationship between time-on-position and the occurrence of an OE are often considered a part of the position relief briefing issue. However, there may be factors that contribute to the occurrence of OEs shortly after assuming a position other than the nature and length of the position relief briefing. In the first quarter report of the Air Traffic Quality Assurance Staff (FAA, 1986a), the analysis of 1985 OE data revealed that more than 20% of the OEs occurred in the first 15 minutes on position. Pounds and Ferrante (2003), in their review of the 1997 to 2000 OE database, indicated that 9% of OEs occurred within the first 5 minutes, 18% in the first 10 minutes, and 35% within the first 20 minutes on position. Lowry et al. (2005), in their effort to debunk myths associated with OEs, found in an analysis of the NAIMS OE database that about 15 to 18% of OEs occurred in each of the three 10-minute time periods during the first 30 minutes on position. The results were similar for en route, TRACON, and tower facilities. They correctly pointed out that it is difficult to fully interpret the implications of these findings without knowing the average time on position. They also pointed out that, in their opinions, there were two possible explanations—that the position relief briefings were inadequate or that the controller assumed the position during a busy traffic period. A subsequent review of OE narratives conducted in support of their study tended to refute the importance of the position relief briefings, as does the previous literature.

Our analysis of the OE database suggested that traffic volume remains relatively consistent across time on position. A possible alternative explanation to the Lowry conclusion is that a portion of these OEs could be attributed to the complexity associated with a controller "getting the picture" or "getting up to speed" when taking a position. Another possibility is that we do not adequately understand whether additional information needs to be communicated when a controller assumes a position. In either case, the data clearly demonstrate that the tendency for a high percentage of OEs to occur early on position has been consistent for the past two decades. However, there is little evidence to document the extent to which the position relief briefing is a prominent factor in their occurrence.

Training and Experience. Historically, controllers learned basic air traffic control procedures at the FAA Academy using a generic airspace. More recently, new facility trainees have taken other types of training such as that provided by military facilities or College Training Initiative (CTI) schools. When a new trainee arrived at a facility, they were called "developmentals" whose skills are further refined during each facility's developmental training program. Developmental training consisted of classroom activities, laboratory simulation problems, and on-the job training (OJT) in which the developmental developed his/her skills while under the supervision of a formal OJT instructor. Developmentals eventually learned to control traffic independently on multiple pieces of airspace (called "positions" in a TRACON and "sectors" in en route facilities). TRACON and en route developmental controllers also learned to perform increasingly difficult duties, starting with entering flight data through radar associate duties and ending with radar duties. Tower controller training was similar in that it started with the flight data/clearance delivery position but later split into two equally difficult positions, the ground and local controllers, that had to be learned separately. Upon the completion of field training, a developmental became a certified professional controller

(CPC) by becoming certified on each position required at the facility or area to which he/she was assigned. Because of the requirement to become certified, CPCs can only control traffic on sectors (in that airspace) on which they have been certified.

Two reports, separated by nearly two decades, presented similar findings about the relationship of controller training and experience to OEs. Spahn (1977) reported that controllers with five years or less experience (after certification) were more susceptible to OEs than more experienced controllers. Mayberry et al. (1995) qualified this susceptibility by stating that controllers with six or fewer years of experience were about 30% more likely to have an OE compared to more experienced controllers. Broach and Schroeder (2005), in their analysis of en route OE data from 1997 to 2003, found that younger controllers with less experience had the highest OE rates. However, Lowry et al. (2005) concluded that insufficient information was available to draw a conclusion about the relationship between experience and OEs.

Findings such as these suggest that greater attention should be spent monitoring the performance of less experienced controllers. Though not a research report, Boone's (2004) memo on OEs at Indianapolis Center (ZID) suggested that a) a significant percentage of ZID OEs were attributed to controllers either during OJT or within two years of certification, and b) when the interval between certification on all Radar Associate positions and the commencement of Radar training was increased, that percentage was reduced.

Although there is considerable literature that describes and tracks controller training across time, there is an absence of literature on controller performance. For example, all controllers certified to control traffic at a given sector are considered to be equivalent. Furthermore, there appear to be no studies that have reported how controller skills improve or degrade with the passage of time.

Broach and Schroeder (2005) assessed error occurrence across time for a group of en route controllers. In a follow-on analysis, the authors identified 5,559 controllers employed at an en route center throughout the seven-year time period. Of that group, 3,852 (about 69%) were OE-free, and 21% had a single OE. This means that 9% of the controllers had between two and six OEs in seven years. We do not know how these data extrapolate across the remaining years of a controller's career, except that the overall OE rate tends to decline across age. Additional information is needed to understand what helped 69% of the en route workforce to remain OE-free during this time period. What distinguishes their performances from those controllers who had one or more errors?

There are indications that controllers who made OEs may perceive the error process differently than those who did not. NARI (Conner & Corker, 2001) found some differences in the perceptions of interviewed controllers who previously had zero, one, or multiple OEs. For example, controllers with no OEs considered ATC procedure-following to be a significant OE causal factor, but those with multiple errors gave it the lowest weight. On the other hand, controllers with no OEs rated ATC conditions as noncontributory, while controllers with one or multiple errors rated it higher.

HMI and Equipment. Given the considerable expense associated with equipment acquisition, it is not surprising that the largest number of documents related to Contextual Conditions fell within this category. For the most part, the documents that addressed OEs from an HMI perspective were theory-based because the authors theorized about or described the impact that new and/or existing technologies have on controller performance (c.f., Hopkin, 1989). However, the effects of new technologies on OEs were not specifically studied. Instead, much of the focus was directed at problems controllers may have after the new technologies are implemented in the field. Thus, the focus was more on controller performance, in general, rather than on OEs.

Because most of the documents in this sub-category were associated with new technologies, it was disappointing not to find documents on field studies that tracked the impact that the technologies had on OEs. While it is known that during the early phase of field implementation, some controllers incur an OE due to HMI problems (typically, when this happens the equipment and not the controller is charged with the OE); once the problems are addressed, it appears that further evaluation is not conducted of the impact of the technologies on OEs. One exception was a concern raised by Corker (2004) about potentially negative effects resulting from changes in procedures and utilization of the new URET display.

If a new technology is expected to have a marked impact on OE reduction, then once implemented, there should be a discontinuity in the OE error rates between pre- and post- implementation. Despite the relatively simple analyses needed to conduct a pre- and post- implementation study, few studies have analyzed the impact that new technologies have had on the incidence of OEs. As the ATO continues with its modernization program, it is critical that that the appropriate baseline data are being collected to ensure a proper assessment of a technology's positive or negative effect on controller performance.

Non-Compliance Issues

Non-compliance is a purposeful disregard of rules or procedures, existing rules, regulations, instructions, or standard operating procedures by choosing not to respond or selecting an action not in compliance with rules or operating procedures. Factors related to non-compliance with ATC policies and procedures were not the focus of any of the OE literature that we reviewed, and consequently will not be discussed in this paper.

Task Descriptions

A task is an activity that a controller is primarily engaged in at a specific time. Controllers often multitask, i.e., perform several tasks at a time. The controller task being performed at the time of an OE was not the focus of any of the OE literature we reviewed, and consequently will not be discussed in this paper. However, the OE report forms categorize aspects of controller activities, for example, monitoring the radar display or observing traffic.

Response Execution

Response execution refers to the outputs or actions based on the earlier processes, that is, how choices and plans were enacted as actions (either verbally or manually). Response execution errors are often characterized by their timing (such as too soon, too late) or information quality (such as unclear or incorrect). They can also be classified as errors of omission (absent) or commission (performed).

Response execution appears closely associated with controller planning and decision making. That is, response execution is the result of either planned or unplanned actions resulting from controller decisions based on factors that affect those decisions, including perception and vigilance, memory, contextual conditions, and organizational, managerial, and supervisory influences. Consequently, instead of discussing reports about controller actions that resulted in OEs, in this section, we discussed those actions as they were relevant to the other JANUS categories.

Mental Processes

Thirty-two percent of the OE-related documents fell in the JANUS Mental Processes category. Figure 7 shows the distribution of documents classified into the JANUS sub-categories for Mental Processes. Two sub-categories accounted for over three-fourths of the reports: Perception and Vigilance (47%), and Memory (32%). The literature from these sub-categories will be discussed in some detail. For a list of the reports classified as belonging to the remaining JANUS mental processes subcategories, the reader is referred to Appendix B.

Figure 7 shows the distribution of the OE literature based on the mental processes addressed. Most of the mental processing OE literature focused on aspects of perception and vigilance, followed by controller memory, planning and decision-making, then response execution. Although executing a response is not typically thought of as a mental process, responses are included here as consequences of mental processes.

Perception and Vigilance. Perception involves acquiring and processing sensory information to hear, see, touch, taste, and smell objects in the environment. Vigilance is the maintenance of attention required to obtain information that may be presented infrequently or monitor a dynamic and ever-changing environment.

In the OE literature, perception and vigilance have often been studied under the name of controller attention, (Kinney, 1977b; Schroeder, 1983), controller awareness and attention (FAA, 1986a; Rodgers & Nye, 1993), and later SA (Endsley & Rodgers, 1994; Rodgers, Mogford, & Strauch, 2000; Kelly, Krantz & Spelman, 2001). Studies designed to determine the effectiveness of OE interventions tend to rely on surveys, interviews, and self-reports from controllers and are lacking in the use of variables that measure controller perception and vigilance.

Estimates of the percentage of OEs related to perception and vigilance vary from a low of 27% (Kelly et al., 2001) to a high of 72% (Rodgers, Mogford, & Strauch, 2000). The variation in statistics is due to the type of data studied (OE narratives vs. causal factors identified on the OE final report) and the time period over which the evaluation was conducted. Although controller perception and vigilance have been often studied, a coordinated effort over time to track OEs specifically related to a loss or lack of perception and vigilance has been impeded because the OE reporting form did not include these causal factors. To address this gap, Rodgers & Nye (1993) recommended the addition of three causal factors to the OE final report to track the amount of controller SA: a) failure to detect displayed information, b) failure to comprehend displayed information, and c) failure to project future status of displayed data. Similarly, in the tower

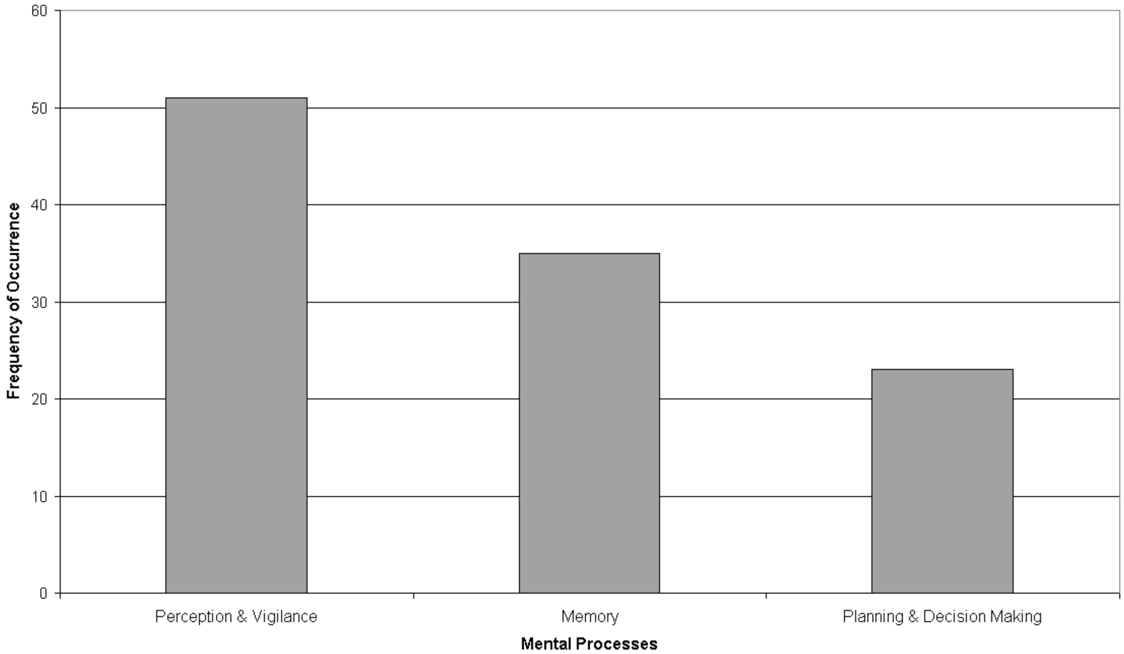

Figure 7. Distribution of OE-related reports by JANUS Mental Processes sub-categories.

environment, failure to observe aircraft might also be included as an indicator of lack of perception and vigilance (Kelly et al., 2001).

Memory. Memory consists of Working Memory (WM) and Long-term Memory (LTM). WM is a "blackboard" or "scratchpad" where one creates and maintains an understanding of a situation. WM is defined as a processing resource of limited capacity involved in the preservation of information while simultaneously processing the same or other information. LTM is the "library" of one's learned information and accumulated experiences. The LTM system is responsible for storing information on a relatively permanent basis.

Although memory failures have been associated with OEs in the en route, TRACON, and tower environments (for a review of the literature see Vingelis et al., 1990), much of the memory literature relevant to OEs has been in the context of runway incursions. In 1986, the NTSB published a special report on runway incursions that concluded that the primary controller-related factors associated with runway incursions were forgetting aircraft and absent or incomplete coordination between controllers. In 2001, Cardosi and Yost reviewed the literature and analyzed safety data involving controller errors in airport tower operations. Their review and analyses confirmed previous findings that identified memory failures as the most frequently cited causal factor of tower OEs. The second most common factor was communication errors, followed by coordination errors.

Memory aids are installed in all FAA facilities, although there appears to be no standardization in their use. Each facility is left to their own resources to design and implement effective memory aids. While the lack of standardization leaves room for error, the added flexibility enables facilities to create memory aids unique to their environment (e.g. addressing a particular runway configuration problem).

In 2003, the Department of Transportation OIG acknowledged that the FAA's numerous initiatives directed at reducing runway incursions, including the effective use of memory aids, have been successful. As the amount of traffic in the NAS is returning to pre- September 11, 2001 levels, the number of runway incursions has steadily been declining. However, it is unclear whether any of the many FAA initiatives have been responsible for the decline. Nevertheless, given the predominant role that memory failures have played in tower OEs, it is likely that memory-related OEs have also declined.

Planning and Decision Making. Planning and Decision Making consists of four types of mental processes: (1) Planning refers to the development of a stepwise process to reach an outcome. (2) Decision making occurs when more than one option is considered and then a choice between them is made. (3) When one solution emerges from one's understanding of the situation, this is called a judgment. (4) Problem solving occurs when a solution is needed to resolve a situation or reach a goal, but no ready options are available.

Earlier, when discussing the type of studies, we noted that the experiments reviewed did not use OEs as the criteria of interest. Instead, the intent of the studies was to investigate factors that affected OE precursors, such SA, memory, workload, and communications. As discussed, the problem with conducting experiments, in general, is that OE precursors do not operate in isolation. Instead, they interact in complex ways to increase the vulnerability of a controller to committing an OE. That very same complexity is also true with planning and decision-making, which is the result of the complex interaction of memory, perception, and vigilance (D'Arcy & Della Rocco, 2001).

The focus of the FAA's modernization efforts has been directed at providing controllers with improved decision-support tools; however, there appear to be no studies that examine the effectiveness of operational decisions. Herein lies the problem. Although various cognitive models have been proposed to elucidate controller decision-making (Wickens, Mavor, & McGee, 1997), these models have not been used to validate the effectiveness of any decision support tool. For example, in the model proposed by Wickens et al., controller memory serves as the foundation for SA, which in turn affects the quality of the controller's decision. If the underlying foundation is faulty (due to memory failure or incomplete SA), the decision must be faulty.

When assessing the effectiveness of a particular decision support tool, it is necessary to determine how the tool is integrated into the overall model of the controller's mental process. Moreover, once a decision support tool is developed, it is important to track its effect on reducing OEs that were the result of faulty decision-making.

FAA Initiatives to Reduce Operational Errors

The FAA has a history of implementing OE reduction initiatives developed at various levels within the legacy AAT and current ATO organizations. Ongoing analyses of OEs by the FAA revealed recurring causal factors, and initiatives were periodically fielded to address them. Topics have focused on communicating about OE trends to increase awareness of OE causal factors by all personnel in the organization, developing clear performance standards, ensuring compliance to standards, and developing long-term strategies.

Examination of initiatives helps to show where the ATO has focused its energies. This section is organized in a similar manner to the previous section that illustrated where the research community focused its energies. If there *is* a disconnect between the two groups, we can speculate about why it might have resulted; for example, because the organization was not aware of research activities, the researchers were not aware of operational needs, or perhaps the research results were not considered useful for operational application. Whatever the reasons, if there are gaps between the efforts of the research and operational communities, then steps should be taken to bridge them.

To examine OE-reduction initiatives, we used any available information that described a program intended to reduce OEs. Materials included such items as FAA orders and memoranda, briefing materials, and meeting notes. Because we were unable to locate a historical archive of these initiatives, most included here are fairly recent. Nevertheless, we feel confident that similar initiatives were previously undertaken, due to the consistent role of various factors in OE causation.

We identified 222 initiatives to classify. Because many of the documents were not dated, it was not always possible to place a given initiative within a historical context. Furthermore, it was not possible to trace the interconnections among source materials (i.e., whether one document was related to another); thus, some of the 222 initiatives probably represent duplicate activities. When a given document contained multiple initiatives, each initiative was classified into its respective JANUS category. Thus, the number of initiatives does not reflect the number of documents examined. Furthermore, when a given initiative addressed several JANUS categories, then the initiative was included in multiple categories. For example, one facility's "effective hearback" competition to highlight the frequency and significance of hearback/readback issues was classified in the following JANUS sub-categories: Perception and Vigilance, Pilot-Controller Communications, and Training and Experience. Finally, the classification of OE reduction initiatives was based on the topics addressed and not the quality of the implementation. Concerning the latter, in most cases, due to a lack of documentation, it was not possible to differentiate between an initiative that was only planned and one that was actually implemented. Thus, initiatives that were either planned and implemented or planned but not implemented are included in the JANUS classification.

With the above caveats in mind, Figure 8 shows the frequencies of initiatives targeting each JANUS category.

Most initiatives in this sample targeted contextual conditions that contribute to human performance and result in OEs. This category was further broken down into its subcategories (see Figure 9). Initiatives classified in the Organization and Management categories reflect activities intended to be accomplished by headquarters or regional personnel, such as establishing a method for distributing information about OEs to facilities.

Figure 9 shows that most of the initiatives introduced by the Air Traffic Organization involved controller training, teamwork, and communications. Other initiatives not captured in these categories were related to Performance Management/ Performance Standards (n=12) and Controller-Ground Communications (n=1).

Figure 10 shows the number of initiatives targeting the JANUS Mental Processes subcategories. The highest percentage of initiatives targeted Perception and Vigilance (59%), and about half that many targeted Planning and Decision Making (29%). About 17% of the Mental Processes initiatives targeted Memory, and only about 7% targeted Response Execution.

Figure 11 compares the Contextual Conditions categorizations of both the research documents and initiatives. Given the possibility that some OE reduction initiatives are duplications, comparisons made between OE research and OE initiatives should focus on the trends and not the number of initiatives in a given JANUS category. It is apparent that the same six contextual conditions were emphasized by both the research and OE reduction initiatives (although not necessarily in the same order): a) training and experience, b) teamwork, c) pilot-ATC communications, d) HMI and equipment, e) airspace/surface, and f) traffic. Although the specific topics addressed by research and the OE reduction interventions may differ, the trend comparisons suggest that research and operations focused on the same general areas.

Figure 12 compares the distributions of initiatives and research articles targeting the OE Mental Processes subcategories. Again, when the trends are compared, we see that, with the exception of memory, both research and OE reduction initiatives had a similar focus on the mental processes. While research focused on memory more often than did the OE reduction initiatives, this should not be misconstrued as a lack of operational concern with regard to memory. On the contrary, addressing controller memory issues continues to be of major importance in ATC operations and is evident in the wide range of memory aids employed at ATC facilities.

A brief overview of the initiatives is given here. Appendix C contains more detailed descriptions of several of the initiatives, including air traffic re-creation tools, video briefing materials, the National Air Traffic Professionalism program, facility initiatives, activities detailed in the Air Traffic Quality Assurance Order, 7210.56 (FAA, 2002b), initiatives in the FAA/NATCA 3-Year Plan for OE Reduction (FAA, 2002c), and activities in the Short

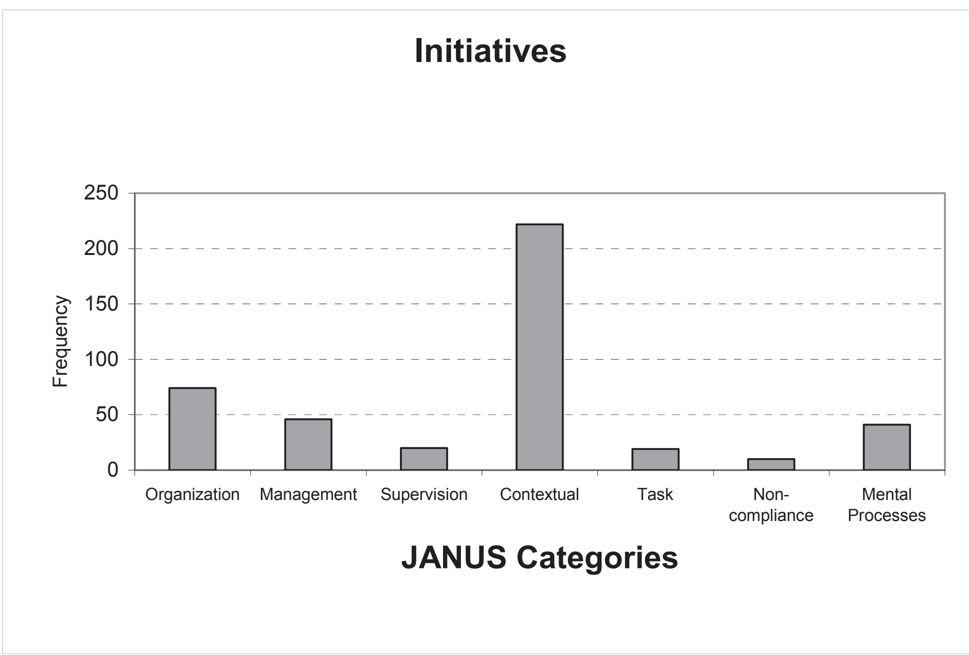

Figure 8. Distribution of OE-related initiatives by JANUS category.

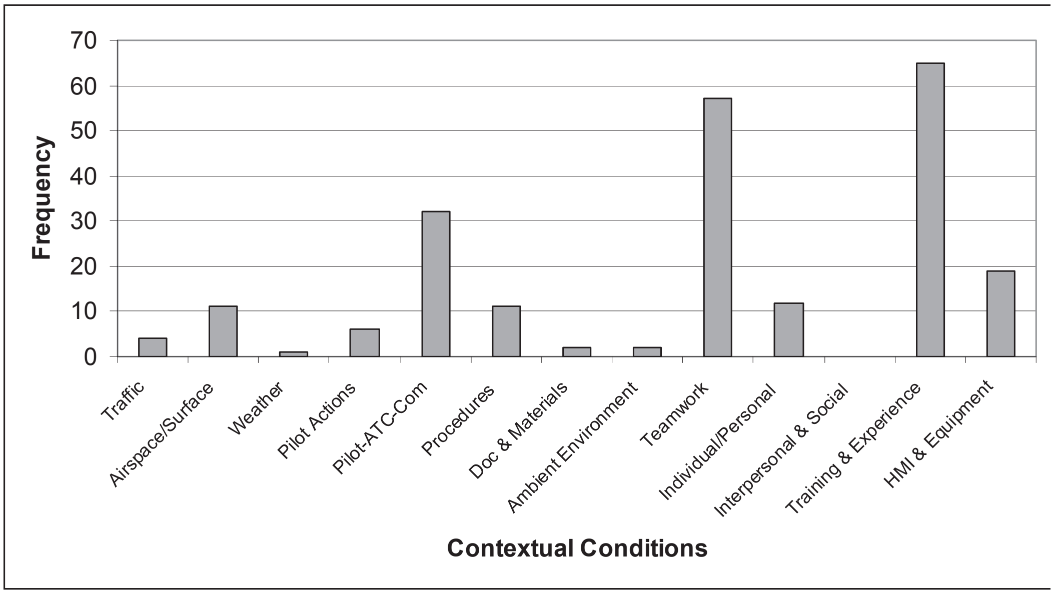

Figure 9. Initiatives targeting JANUS OE Contextual Conditions subcategories.

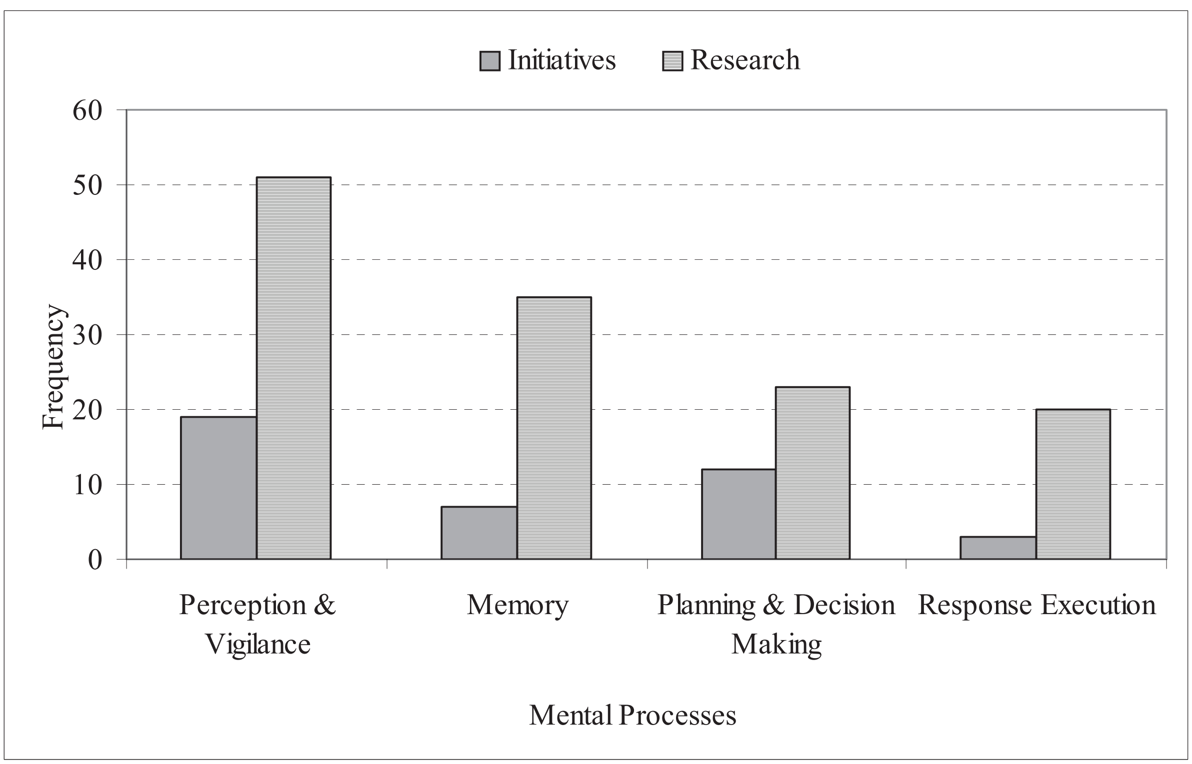

Figure 10. Initiatives targeting JANUS OE Mental Processes subcategories.

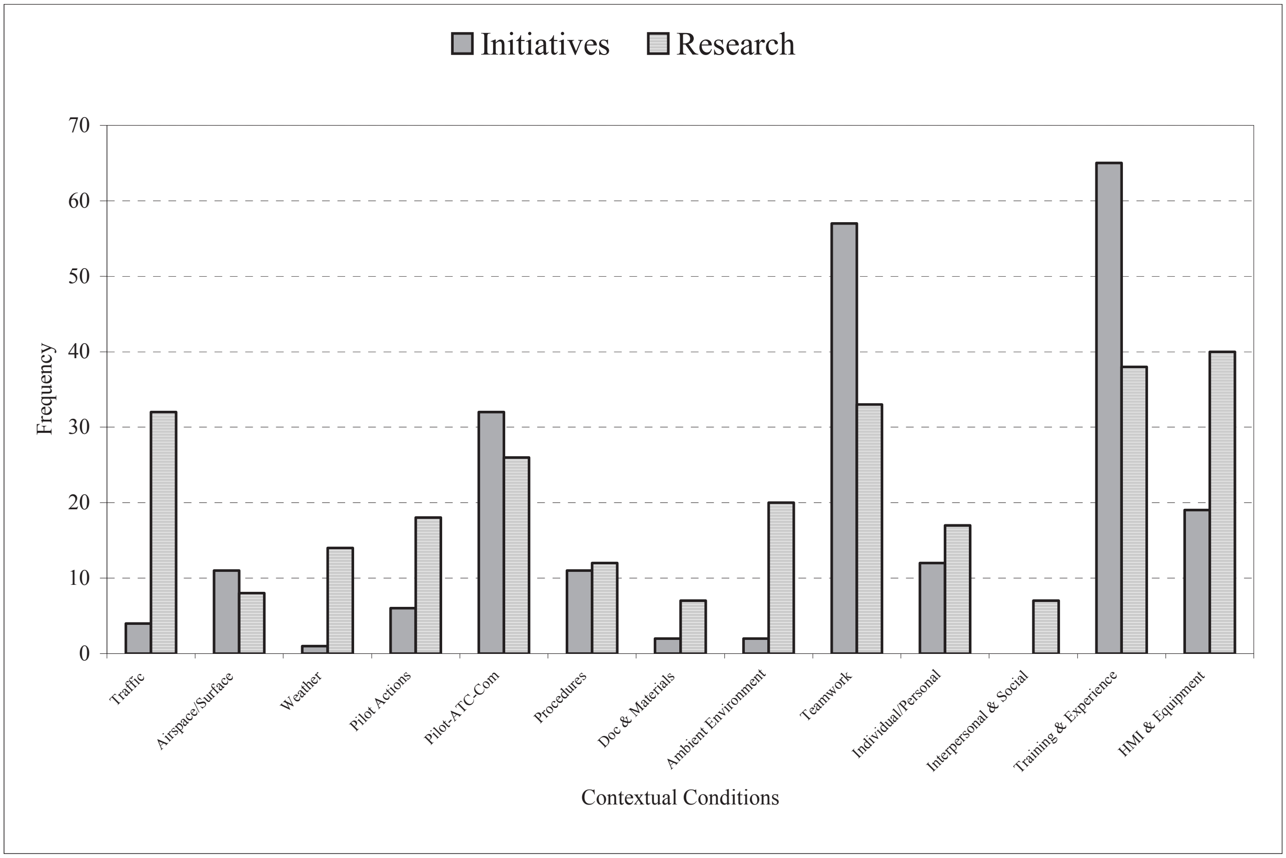

Figure 11. Comparison of results from the categorization of research articles and initiatives related to Contextual Conditions.

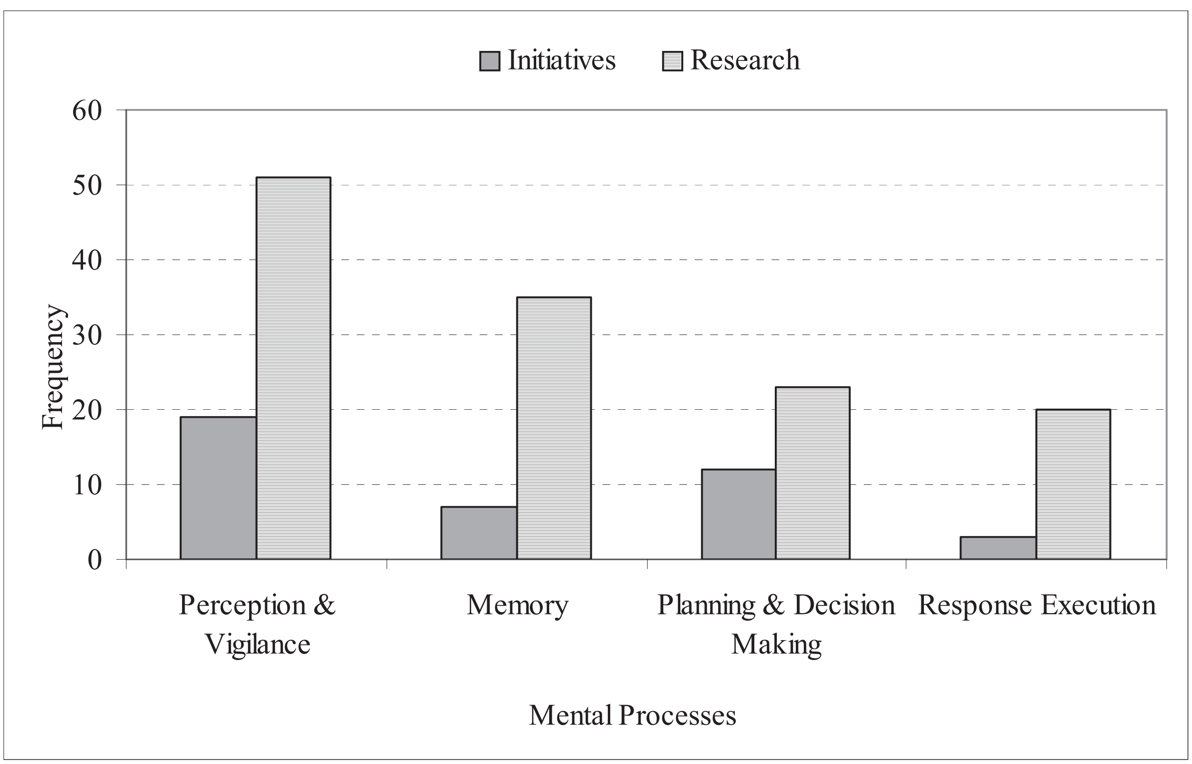

Figure 12. Initiatives and research articles targeting subcategories of mental processes.

Term OE Reduction Initiative (FAA, 2002a). Examples of recommendations from workgroups are also included, such as those from the Operational Error Prevention and Reduction Workgroup, which met in 1996, and the Operational Errors in the U.S. Air Traffic System – A Task Group Review (FAA, 1987).

Initiatives Classified by JANUS Categories

Organization and Management

Recall that organizational and management initiatives should be incorporated into national/ facility level policies and procedures. However, the resources dedicated to the implementation of national/facility level policies and procedures are equally important. For example, the QA programs detailed in FAA Order 7210.56 (FAA, 2002b) correspond to initiatives that fall within the JANUS Organization and Management tiers.

At the national level, The Air Traffic Evaluations and Investigation Manager and Staff are expected to provide the necessary guidance to ensure that the QA program succeeds. Among other things, this guidance includes evaluating facilities' ATC QA programs and recognizing QA programs that have achieved significant accomplishments in OE reduction. For example, when a facility has achieved 1,000,000 error-free operations, it is awarded a national certificate of recognition as a member of the "None in the Million" Club.

At the regional level, Air Traffic Division (ATD) Managers are expected to develop a regional QA program, which includes a regional OE/OD prevention plan. The plan is included in a Regional QA Order that is then used to develop corresponding Facility QA programs and associated facility OE/OD prevention plans. Paralleling the national evaluation process, ATD Managers are required to conduct annual reviews of existing regional QA orders and programs. They also ensure that approved facility OE/OD prevention plans are in effect that emphasize the use of the basic ATC procedures to prevent and reduce OE/ODs and address the items pertinent to a particular facility's past deficiencies.

However, none of the documents we reviewed indicated whether adequate resources were provided to accomplish the initiatives. And, in spite of the existence of a mechanism that should provide a detailed assessment of OE/OD reduction initiatives, we were unable to find documentation about the success or failure of most regional or facility-level OE/OD reduction initiatives. This does not mean that the information was not collected. To the contrary, it is likely that the information resides somewhere within the ATO at the national, regional, and/or facility level. For example, Appendix C includes descriptions of Houston ARTCC's Quality Evaluation Program (QEP), Kansas City ARTCC's Performance Management Program, and the analysis of the Great Lakes Region's OE Reduction Efforts. Each of these initiatives included an evaluation. Overall, however, there appears to be no central repository for this kind of information, which makes it difficult to conduct a national audit to determine the success of the various OE reduction initiatives implemented at different sites.

Supervision

Operational supervisors (first-line supervisors) are important to the success of a facility's OE reduction program. Supervisors are tasked to conduct both primary operational duties and administrative duties. They monitor the operations and manage controller performance. However, few initiatives indicated whether there was organizational support for supervisors to accomplish these tasks. One task group that reviewed the air traffic system (FAA, 1987) raised a similar question. Noting that the quality of supervision varied both within and between facilities, the task group recommended that greater attention should be placed on supervisory training. Although first-line supervisors come from the ranks of controllers, this does not necessarily mean that their technical skills prepare them to manage controller performance and training. Good controller skills do not automatically translate into good supervisory skills.

Contextual Factors

Most OE reduction initiatives that addressed contextual factors focused on three areas: (1) training and experience, (2) teamwork, and (3) pilot-ATC communications.

Training and Experience. Skill development acquired through training and experience has been an ongoing focus of OE reduction initiatives. Initiatives include such things as designing suitable training platforms (e.g. computer-based instruction and ATC simulators), developing course content to address skill deficiencies associated with specific kinds of OEs (i.e., those associated with errors in data posting, radar display, aircraft observation, communication, coordination, and position relief briefings), and identifying the types of work experiences necessary to certify controllers and ensure that they maintain currency.

Although numerous types of ATC simulators have been developed, most have been used for the training of novice controllers. However, the need to use ATC simulators for proficiency training of experienced controllers was raised during the 1987 task group that reviewed the air traffic system (FAA, 1987), again in the Short Term OE Reduction Initiative (FAA, 2002a), and more recently in the FAA's 2005-2009 Flight plan. To date, few initiatives have been developed to address these issues for experienced controllers.

Teamwork. OE-reduction initiatives related to teamwork primarily focused on two topics: 1) the exchange of information among team members and 2) developing a positive approach to teamwork. Over a 14-year span, from the 1987 task group that reviewed the air traffic system (1987) to the 2002 Short Term OE Reduction Initiative (FAA, 2002a), the focus of information exchange initiatives was on the position relief briefing and the use of flight strips. Initiatives designed to improve the concept of teamwork among controllers followed the air traffic team enhancement model and its emphasis on professionalism and respect for each other (FAA, 1987; FAA, 2002a). It should be noted that, although components of teamwork (i.e., position relief briefing and coordination) have been identified as OE causal factors, deficiencies in teamwork have not. Thus, if the emphasis on teamwork as an OE mitigation strategy continues, greater attention needs to be placed on identifying the specific aspects of teamwork that affect OE occurrence, developing specific interventions, and tracking their effectiveness.

Pilot-ATC Communications. Initiatives designed to reduce hearback/readback errors are ever-present across time (Cardosi, 2001; FAA, 1987, 2002a and 2002b). Past initiatives have included developing training videos and materials based on OE case histories, auditing pilot-controller communications, and designing pilot-controller training. Given all the attention directed at reducing OEs related to hearback/readback errors, one wonders whether any of these initiatives reduced OEs in either the short-term (when awareness was high) or the long-term (when the topic faded into the background and another awareness program was fielded). Without clear evaluations of initiatives related to hearback/readback errors, it is unclear what can be done to further reduce this type of human error—except perhaps through technological advancement in digital communications. However, the inability to further reduce hearback/readback errors is merely an assumption until more information is known about these types of performance errors, including information about how they occur during normal operations and what circumstances contribute to some of these performance errors becoming OEs.

Task Descriptions

Some initiatives addressed the type of task the controller was performing if it was noted as being performed at the time of the OE. For example, improving processes associated with the transfer of position responsibility received repeated attention because of the increase in OEs reported within 20 minutes of a position relief briefing. Topics related to the task of communicating with pilots also received attention under topics such as improving phraseology and reducing readback/hearback errors.

Non-Compliance Issues

National, regional, and local SOPs were established and audits were conducted to ensure that facility directives were consistent with national Orders. Controller non-compliance with SOPs was not addressed by major initiatives, other than those that emphasized "back to basics."

Response Execution

No major OE reduction initiatives specifically targeted factors related to how responses were executed (e.g., the action taken was not timely or the wrong entry was made on the keyboard). Response execution errors were often left for specific training programs related to new systems (e.g., STARS, URET) to address.

Mental Processes

As was stated earlier in this report, the controller's job is primarily a mental one and, thus, one would expect a large number of initiatives to be developed to address controller mental processes such as perception and vigilance, memory, and planning and decision-making. However, this has not been the case. Instead, most of the mental processing initiatives we reviewed were associated with the training of novice controllers. When mental processes were addressed for experienced controllers, the initiatives tended to be more of the awareness-related refresher training. What appear to be lacking are initiatives that allow experienced controllers to test their mental processing skills and participate in activities designed to improve those skills. One initiative that best illustrates the latter approach is the National Air Traffic Professionalism (NATPRO) program.

NATPRO is a personal performance enhancement program intended to maintain skilled performance rather than provide remedial training for OE reduction. Instead of relying solely on knowledge-based awareness training, this approach integrates the concept of "performance coaching" by facility personnel certified as coaches. The program combines knowledge with practice so controllers can experience their own strengths and limitations and can gain insight into their mental-processing skills, especially those used in air traffic control. These skills include perception and vigilance, memory, and planning and decision-making, all of which are practiced in a dynamic environment.

NATPRO is designed as a series of installments that continue to challenge participants toward enhancement of skills associated with mental processing. Series 1 of the current NATPRO installment emphasizes perception and vigilance through the visual acquisition of information. The skills developed include multi-tasking, paying attention, scanning, detecting information, focusing on relevant information, and staying "in your zone." Although the skills are generic, it is expected that by improving these generic skills, individuals will demonstrate a corresponding improvement in job performance. By testing themselves against the computer and experiencing how their performance can vary in relation to such factors as distraction, fatigue, and boredom, participants gain increased understanding of their own performance and can develop personal improvement strategies. It will be necessary to investigate whether such personal improvement strategies will lead to improvements in controller performance under simulated and actual job conditions.

To the extent that we can measure differences in controller performance, we have a means of measuring the effectiveness of these types of skill enhancement programs. Developing controller performance measures would be a much better alternative than using the number and severity of OEs as a performance metric for individuals.

Discussion of Initiatives

Available information about past and current initiatives shows that the FAA has a history of deploying programs to reduce OEs that appear to revisit many of the same general causal factors. One reason that the FAA continues to implement the same strategies over and over may be that the factor of interest was not affected by previous initiatives (or was only temporarily affected until the initiative was concluded) and continues to be identified as an OE causal factor. Furthermore, air traffic control is a complex domain, and perhaps simplistic strategies for reducing OEs are not effective. A third reason why the FAA continues to repeat the same strategies might be that those who develop new initiatives "go with what they know" and hope it will work "this time." A fourth reason might be that personnel who develop new OE initiatives are new to the domain and have no institutional recollection of programs that have been tried previously. Naiveté and a lack of a historical record can lead one to select the "low hanging fruit." A fifth reason might be that personnel who develop OE initiatives think their program will be more effective at addressing the factor than previous programs. It is not productive to repeat the same action while expecting a different outcome.

Whatever the reason, the content and outcomes of OE reduction initiatives tend to be forgotten because they are not sufficiently documented. Repeating unsuccessful OE reduction initiatives should be avoided as a waste of resources. One way to decrease the likelihood of repeating previously unsuccessful initiatives would be to maintain an archive of all OE reduction initiatives (at the national, regional, and facility levels) and document their outcomes so that future developers would not implement unsuccessful programs. However, it is also unclear how to identify successful initiatives. Opinions about an initiative's effectiveness, for example, although relatively easy to obtain (e.g., surveys, anecdotes, focus groups) have all the disadvantages of subjective data. On the other hand, using OE counts or rates, which are infrequent outcomes describing very complex situations, may not be sensitive enough to evaluate whether the improvement in any one factor resulted in a decrease in OEs.

SUMMARY AND CONCLUSIONS

Our literature review was part of a larger effort to identify more immediate short-term strategies that could be undertaken to reduce the recent increase in OEs. We also anticipated that the effort would identify potential new intervention strategies as well as gaps in our OE knowledge base that require additional research. We gathered and reviewed documents that described previous OE reduction initiatives in an effort to identify strategies that may have been successful in the past and identify dimensions that could benefit from interventions, based on the research outcomes. To structure our approach to identifying gaps in the literature, we used the JANUS taxonomy to understand the extent to which HF issues typically associated with human errors had been addressed by research on OEs. This assessment revealed that a majority of the literature was focused on contextual conditions and mental processes. We then described the findings about contextual conditions and mental processes that figured most prominently in the literature.

As we begin our discussion of the gaps in the literature, it is important to emphasize that these gaps are based on the literature we reviewed and do not necessarily mean that the information is not known elsewhere within the ATO. However, if the information does exist, then it is also important to note that, in our search of internal documents via the FAA intranet and personal contacts within the ATO, we did not uncover it. Our discussion is organized around five central themes derived from the literature:

1. Consistency of OE data collected across time
2. Consistency of OE research
3. Evaluation of OE interventions
4. Multiple levels of OE analyses
5. Multifaceted nature of controller performance

Within each theme, we will describe what we know and don't know based on our review of the literature.

Consistency of OE Data Collected Across Time

What We Know

During the last two decades, the methods used to conduct OE investigations have been relatively consistent. FAA Order 7210.56 (2002b) describes a systematic approach to assessing factors contributing to an OE. The major causal factor categories in the OE reporting form have also remained relatively consistent. For example, the major categories in the Causal Factor section of Form 7210-3 (data posting, radar display, aircraft observation, communications, coordination, and position relief briefing) are the same as those referenced in Order 7210-47 (FAA, 1982). These categories do not describe HF issues such as controller mental processes but, instead, describe events that occurred at the same time as the OE.

This has led to a long history of conducting research and implementing initiatives that address the role of factors such as the amount of traffic, miscommunications (hearback/readback), coordination, and position relief briefings on OEs. Other variables of interest from a research perspective have typically not been collected or have only been collected on a superficial level: traffic complexity, situation awareness, and some temporal and demographic factors.

Efforts have been initiated over the years to improve the quality of some of the information obtained during the OE investigation process. For example, instead of using a subjective measure of traffic volume, the measure is now focused on the number of aircraft handled by the controller at the time of the error. Three questions about SA (failure to detect, comprehend, or project the future status of displayed data) were added to the form in the late 1990s. Other measures, such as complexity, remain subjective and difficult to define while others have not been addressed because insufficient data are collected during the investigations.

What We Don't Know

Because the same kinds of data have been collected over time, we tend to conduct many of the same analyses, get the same findings, and implement the same kinds of initiatives over and over. We know less about how other variables (such as organizational, managerial, and supervisory factors) that we have not historically collected may be related to OEs.

The kind of information that has historically been gathered during the OE investigation process tends to be descriptive and does not address many of the underlying causal dimensions typically associated with human error. For example, while job task analyses and personal reports emphasize the importance of memory and decision making in air traffic control, this factor has not been adequately addressed as part of the investigation process. This can be attributed, in part, to the fact that we cannot directly observe how memory influences the controller's decisions and overall performance.

Another problem with OE data collection involves the way OEs are identified. While potential OEs are systematically identified (and later confirmed) in en route facilities due to the presence of the "snitch patch" in the en route HOST software, the current approach to identifying OEs that occur at TRACONs and towers comes through verbal reports made by the involved controller, a supervisor, fellow controllers, or a pilot. As a result of differences in how OEs are identified, we do not know the extent to which OEs in TRACONs and towers are underreported. We are also unable to ensure that intervention strategies found to be effective in one area will be of equal benefit in others.

Consistency of OE Research

What We Know

Several variables have received repeated attention over the last 40 years; the three areas that have received most of the attention are: amount of traffic, time on position, and pilot/controller communications, specifically hearback/readback errors.

Amount of Traffic

The amount of traffic counted on a national basis is perhaps the single most important determinant of the frequency of OEs. As the overall volume of traffic increases, there has historically been a corresponding increase in OEs. No other single variable has accounted for more variance in OEs than traffic volume. However, the relationship becomes more complex when considered at the sector/position level. Despite the steady growth in air traffic during the 1970s and 1980s, the percentage of OEs that occurred under conditions of light and moderate traffic increased and was accompanied by a corresponding decline in the percentage of OEs attributed to heavy traffic. During the past seven years, our review of the OES database reveals that the number of aircraft handled by the controller at the time of an OE has remained relatively consistent, despite changes in the overall amount of traffic. In general, while the amount of traffic has increased at the level of the NAS, on a sector level, the amount of traffic associated with OEs has remained unchanged.

Time on Position

Research has consistently shown that a relatively high percentage of OEs occur during the first 20 minutes on position, and that relationship is consistent across options and during much of the day. While the tendency for OEs to occur early after taking over a position is often linked with position relief briefings, a summary of the NAIMS data from 1999 to 2003 revealed that only a small percentage of OEs were related to position relief briefings.

Communications

Miscommunication has historically been identified as a primary causal factor associated with OEs. Of all the miscommunication errors, hearback/readback errors were most commonly studied. Research has shown that, under normal operations, only a small percentage of all controller communications involve a hearback/readback error, and most of those errors are caught. Thus, few hearback/readback errors result in an OE. However, this does not negate the need to continue to conduct research on this issue because it still is an important factor related to OE occurrence.

What We Don't Know

Amount of Traffic

We know little about the interaction between the amount of traffic and other factors such as airspace complexity. Most of the research on airspace complexity has addressed variables that predict sector congestion, not OEs. The limited amount of research that has related complexity to OEs has had inconsistent results. The exception is that we know that smaller sectors tend to have higher error rates. Thus, more research is needed that specifically relates airspace complexity to OEs. We also need to develop a better understanding of how much time controllers spend working traffic under various workload/complexity conditions.

Time on Position

Most research on the relationship between time on position and OEs has focused on position relief briefings, even though they were infrequently identified as a causal factor in OEs. Does the relatively higher number of OEs that occur soon after taking over a position occur because most controllers only work on a sector/position for short periods of time? Baseline information about how long controllers actually work a sector or position is necessary to understand this phenomenon. We also don't know how factors other than position relief briefings, such as readiness to perform, might contribute to OEs that occur soon after taking over a position.

Communications

Because most hearback/readback errors are caught, we don't know the conditions that make a controller vulnerable to failing to catch this kind of error during a communications exchange. For example, workload or traffic complexity might occasionally interfere with a controller's ability to catch a hearback/readback error. To identify these factors, research involving multiple variables is required.

Introduction of equipment that reduces the requirement to communicate verbally might reduce the incidence of some kinds of communications errors but might introduce other errors in cognitive processing, especially if the new equipment places a greater load on visual processes (e.g., transmission of text data link messages between the pilot and controller).

Evaluation of OE Interventions

What We Know

The two most common areas addressed by national, regional, and facility level interventions include communications (specifically hearback/readback errors) and position relief briefings.

What We Don't Know

Despite the continued interest in reducing OEs, we found little evidence of any systematic efforts to evaluate the effectiveness of OE reduction initiatives. While we received anecdotal reports about the success of certain individual facility interventions, we did not find any quantitative data to support those claims. This does not mean that facility-level data are unavailable; it merely means that these data were not included in any available OE data sources used for this study. Even at the national level where a number of OE reduction initiatives have been implemented, we could not find any documentation of the effectiveness of those initiatives. Without efforts to establish a method to record and track the effectiveness of OE mitigation initiatives, we will be unable to learn from past successes and failures. We were also unable to examine strategies that were claimed to be effective at one facility to determine if they could be effective at another.

Multiple Levels of OE Analyses

What We Know

Analysis of OEs is done by many parts of the organization at many levels for many purposes. For example, senior management has often focused their attention on national OE rates and reduced the percentage of OEs that fall in the highest severity category. Data analyses and initiatives focused at this level on information averaged over individual controllers and sectors or positions. On the other hand, facility management generally focused their efforts on particular controllers and sectors that had more OEs than others and on techniques and procedures often thought to be closely associated with OEs. Thus, national initiatives are often directed towards a more generic approach to reducing OEs while facility initiatives may address problems associated with a local issue, such as airspace.

A number of tools are available that allow us to conduct OE analyses to support questions asked at different levels of the organization. For example, the JANUS technique illustrates the many levels of analysis that are possible if sufficient information is available from the OE investigation. OE re-creation tools (e.g., SATORI and RAPTOR) provide an excellent opportunity to gain additional understanding about observable conditions surrounding OEs.

What We Don't Know

We need to understand how various factors interact to produce OE conditions by recognizing that multiple individual, situational, and organizational factors both contribute to OEs and serve as a deterrent to them. We should follow recommendations first made three decades ago to expand the gathering of human factors information during the OE investigation process. Once this is accomplished, we can develop analytic strategies to identify how various factors interact to contribute to the OE process.

To date, most analyses have focused on one or two variables. The future lies in efforts to fully address the dynamic multi-factor and multi-level conditions associated with controller performance. For example, we know from some studies that supervisors can play an important role in reducing the likelihood of OEs. However, research has not addressed several relevant questions: What aspects of their roles and responsibilities are most critical? To what extent can supervisors affect OEs by identifying poor performance, overseeing position relief briefings, providing support during high traffic loads, or taking other actions? Until we gain a better understanding of the dynamic nature of the OE process and the role of interactive factors, we are likely to continue to experience difficulties in developing truly effective intervention strategies. Finally, we have to consider broader organizational issues. Are initiatives designed to address conditions within an individual facility suitable for national deployment? We know little about these issues other than certain facilities have higher error rates than others. Further research is needed at higher organizational levels to understand which HF causes of OEs are common across facilities and which are specific to a given facility, area, sector, and/or individual or team.

The Multifaceted Nature of Controller Performance

What We Know

Over the course of their careers, many controllers will not have an OE, a small percentage will have one, and a still smaller percentage will have multiple OEs. All controllers are trained and certified to control traffic in a particular role (i.e., position) and on specific sections of airspace (e.g., sectors). Certification is required because each section of airspace is unique due to a variety of factors including size, airway configuration, traffic patterns, traffic mix, etc. These factors interact with the techniques controllers use to control traffic to create a unique environment. Despite the complex and dynamic nature of a controller's tasks, most investigations have focused on only one or two factors in the study of controller performance.

What We Don't Know

We do not understand the importance of the techniques and procedures some controllers adopt to remain relatively error-free. Additional information is needed to identify aspects of controller performance that allow some to remain "error free" or relatively error free throughout much of their careers. Are these skills developed during training, or are some individuals, because of their innate abilities, better controllers than others? We suggest that efforts to identify variables that affect controller performance should be based on a cognitive model of ATCS tasks such as that provided in Wickens et al. (1997, p. 93). Using a cognitive model to guide the choice of variables and data analysis should help us understand where breakdowns occur in relation to certain types of errors.

We have not adequately measured controller performance during training and certification. Such measures would allow us to evaluate the relative importance of identifiable weaknesses on the occurrence of future OEs. We also have limited knowledge about the extent to which OEs are influenced by airspace or traffic complexity beyond knowing that smaller sectors have higher error rates. Because errors in controller performance are likely to occur a number of times and not lead to an OE, what combination of factors or conditions prevents an OE from occurring? Is it related to attention, memory, decision-making, or other factors?

RECOMMENDATIONS

Based on our review of the OE research literature and the discussion above, we recommend the following:

Expand the OES database to better identify the human factors associated with OEs. There are two ways to improve the existing database. The first concerns the accuracy of the information. Continued efforts are needed to ensure that investigators' judgments about subjective categorizations, both within and across facilities, are made consistently. For example, criteria about the complexity of traffic conditions need to be clearly laid out so that judgments can be made consistently. Even on more objective measures (e.g., amount of traffic) we need to ensure that the time period during which traffic is counted is consistent across OEs. As part of this effort, there is a need to ensure that individuals responsible for gathering information during the OE investigative process have been adequately trained. Unless data are gathered consistently, we will be unable to adequately evaluate differences across facilities. Another element about the accuracy of the OE database concerns data entry. During our analyses of the database, we encountered numerous instances where data were incomplete or inaccurate. Additional safeguards are needed to ensure that values for variables in the database do not exceed specified limits. This is one way of improving data quality.

The second way to improve the database involves adopting the repeated recommendations made over the past 20 years to include additional categories that address HF dimensions traditionally linked to controller performance and human error. This information would more adequately describe the individual, situational, and organizational events that contributed to each OE. We feel that the current effort to utilize JANUS to analyze OEs at selected facilities is a step in the right direction. By improving the investigation process, we will have a richer database to assess the human factors most closely associated with OEs, one that will facilitate our understanding of potential linkages between factors and will provide greater support for efforts to assess the effectiveness of OE intervention strategies. Another way to improve OE investigations would be to adopt the DOT Inspector General's recommendation (DOT, 2003) to develop a method to better detect and re-create OEs in terminal facilities.

Obtain baseline information about air traffic operations to better understand conditions surrounding OEs. Baseline information about normal AT operations is needed to differentiate between conditions in which OEs occur and those in which OEs do not occur. For example, how does the level of traffic typically associated with OEs compare with the amount of traffic controllers typically experience? It would also be useful to obtain baseline information about the frequency with which supervisors monitor controller performance and the traffic situation.

We must also be able to identify and track the introduction of new NAS procedures/ technologies and assess their short- and long-term effects on controller performance and OE occurrence. Questions have been raised regarding the effects of URET (Corker, 2004), as well as efforts to use color to differentiate "own" from "other" aircraft with the introduction of STARS at the Philadelphia

TRACON. We also need to ensure that the information collected during OE investigations is sufficiently sensitive to allow us to determine how a new technology or procedure affected the incidence of OEs. For example, if shifting entries on URET's Aircraft List (ACL) distracted the controller so that he/she committed an OE, under today's system the error might be linked to the result of the distraction, rather than its cause. Continued efforts are needed to document these and other NAS procedural and technological changes so that scientists can adequately assess their potential influence on the OE process.

Some of these changes may dictate different ways in which we should aggregate and analyze the OE data. For example, increases in direct routing of aircraft may have shifted conflict points and required controllers to adjust some of their procedures and practices. When OE data are only aggregated by facility, we may miss subtle changes in the OE process. Greater recognition should be given to the dynamic nature of air traffic control and adjust the baseline and OE data analysis processes to more adequately address the new conditions.

Conduct analyses that account for the interactive nature of variables associated with OEs. Given that there have been few systematic attempts to understand the interaction of the multiple factors involved in the OE process, future research should be directed toward investigating their interaction. Without this emphasis, we are not likely to benefit from more sophisticated data collection and analysis strategies such as those suggested by JANUS.

Develop method of tracking and evaluating OE intervention strategies. Few facilities have tracked the effects of their OE reduction initiatives using measurable outcomes. Furthermore, there are few reliable indications that these initiatives have caused OE rates to decline. While some information about OE reduction initiatives may be available to the ATO, we were unable to document any systematic efforts to identify or assess the effectiveness of initiatives undertaken to reduce OEs. This may be partly because there is no central repository of information about the implementation of local or national initiatives or a record of their outcomes. To develop such an information repository, facilities must first provide a description of their OE reduction initiatives along with observed results, and national offices must compile information from the individual reports to track the success of different types of initiatives. Once identified, initiatives that are successful at one facility may be adapted to others.

Develop measures of controller performance. Even though controllers often feel that poor techniques and procedures on the part of their colleagues are causal factors in OEs, we could find little scientific literature that adequately described the role of techniques and procedures on OEs. We also did not find any literature that described the techniques and procedures used by controllers who have remained error-free over much of their careers. Efforts are needed to identify those "good" techniques and procedures that allow some controllers to remain error free. By developing a more complete understanding of the performance of controllers who do not commit OEs, we can design improved selection and training programs to ensure that those knowledge, skills, and abilities are present in certified controllers. An improved set of methods for periodically assessing operational performance will also allow supervisors to more readily identify aspects of controller performance that need improvement. Some of the initiatives have focused on these activities. However, to our knowledge, these efforts have not developed standardized procedures to assess controller performance.

Over the next decade, the number of retiring controllers will lead to a continuous flow of new trainees into AT facilities. Efforts are needed to establish a database about aspects of controller training performance that can be linked with the OE database. There should be sufficient granularity of performance assessments made during OJT to allow scientists to determine if specific weaknesses in training performance are associated with subsequent OEs. Without such a database, there will be no way of knowing whether training is effective and if adjustments in training would result in improved controller performance. Special attention needs to be focused on the first few years following certification because evidence suggests that younger, more inexperienced controllers have higher error rates.

Identify new approaches to reduce high impact causal factors. Our review identified several factors (e.g., hearback/readback, amount of traffic, time vulnerability) that have historically been associated with OEs. Although previous error mitigation strategies attempted to address these factors, there is no evidence that their influence has been significantly reduced. Thus, we continue to consider them to be fruitful areas of research. However, new approaches are needed to identify strategies that can reduce the role of miscommunication, time vulnerability, and other factors on OEs. New investigations should focus on the interplay of several factors in OE causation.

Given the current emphasis on OE severity, we need to more clearly understand the relationship between OE severity and various causal factors. Do the events that lead up to more severe OEs differ from those where severity remains relatively low? If so, can interventions be developed to interrupt the chain of events that lead up to the more severe OEs and thereby ensure that either severity remains low or that the OE likelihood is reduced?

From our review of the literature, it is clear that if the human factors research community continues to address issues concerning OEs in isolation of one another and of operations, it is unlikely that we will discover more than what we already know. Instead, this review suggests that it is time for a more comprehensive and coordinated approach to conducting research about HF causes of OEs. A national plan coordinated by the ATO's Safety Service Office is needed to identify the respective roles of members of the research community in investigating these issues and work with the operational community to translate the results into a set of operational OE reduction initiatives.

Examine OEs as a part of a safety culture. It would be useful to consider how OEs could be examined from the perspective of a "safety culture." By this, we mean the social norms and expectations present in an air traffic facility that influence the behavior of operational personnel. For example, a perceived punitive approach (norm or expectation) for dealing with OEs can result in underreporting (behavior) at facilities where OEs are not automatically identified. No data are available about how safety-related norms are developed in ATC facilities or how they affect behavior.

Other characteristics of a safety culture include a demonstration in all levels of the organization of values that support the goal of continually identifying and resolving safety-related problems, proactivity (rather than reactivity) in searching for and resolving safety hazards (especially through open discussion of problems), and development of metrics and data collection methods to assess safety levels and identify causal factors associated with errors.

It is not possible to study a safety culture unless you can measure safety. Currently, the FAA Flight Plan (FAA, 2005b) uses OEs as the primary measure of ATC safety. However, OEs may be inappropriate indicators of safety, if used alone, because they only occur infrequently and do not describe safety conditions in normal operations. Other, more appropriate measures might be better indicators of air traffic safety, such as the number of miscommunications between pilots and controllers or the number of data entry errors that occur at a sector when it gets busy. However, such measures are often difficult to gather and may be influenced by factors other than safety. There is also the problem of whether to measure the process or the outcome, or both.

If the goal of a safety culture is to collect all available information related to the safety of an operation, it is necessary to collect information relevant to all aspects of safety, not just those related to when a safety criterion is violated. It is necessary to be aware of what happens during normal operations and how other safety-related measures change before and after a criterion is violated. It is also necessary to obtain as much information as possible about a safety violation, which requires providing positive reinforcement to individuals to encourage them to provide information to help the organization increase the safety of its operations.

We believe that the investigation of OEs from the perspective of a safety culture must be based on a systematic collection and analysis of all data that could be relevant to identifying meaningful causal factors. JANUS is an example of a taxonomy that provides a structure for collecting OE causal factors data from a different perspective than has been used before. Instead of looking at only event-related errors such as those associated with communications, data posting, or radar displays, it might also be useful to obtain information about contextual conditions, mental processing errors, and supervision issues present at the time of the OE. If that kind of information were analyzed in the context of normative data about length of shifts, time on position, communications, amount and complexity of traffic typically present in the airspace, and so on, it might be possible to better understand how and why OEs occurred. If information from an expanded OE investigation database were used to develop OE reduction initiatives, then organizational tracking of their effectiveness could lead to an understanding of which initiatives would be useful in addressing particular or combinations of causal factors associated with OEs. This approach would support a "safety culture" concept because the organization could learn from the data how to continue to improve.

The research community can help the AT operational community by identifying data that would be useful to include in expanded, safety-related OE databases and by conducting analyses using those data. The operational community must collect the data, develop OE reduction initiatives, and track their effectiveness. The two communities can work together to interpret the data and decide how to identify initiatives that might be useful to reduce OEs. We know that the amount of traffic will increase over time. If OEs are not examined in a different way, then OEs will continue to increase along with the traffic. Only by working together can the two communities build a safety culture, better understand the causes of OEs, and work to reduce them and the processes leading to them.

In summary, this review points to the following recommendations:

1) Expand the OES database to better identify the human factors associated with OEs,
2) Obtain baseline information about air traffic operations to better understand conditions surrounding OEs,
3) Conduct analyses that account for the interactive nature of variables associated with OEs,
4) Develop a method for tracking and evaluating OE intervention strategies,
5) Develop measures of controller performance,
6) Identify new approaches to reduce high-impact causal factors, and
7) Examine OEs as a part of a safety culture.

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Unknown. (1-9-2002). *Memphis ARTC center six area project historical summary and justification.* Unpublished manuscript.

Unknown. (n.d.). *Development of a methodology for identifying operational errors correctable through training.* Unpublished manuscript.

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Yesavage, J.A., Taylor, J.L., Mumenthaler, M.S., Noda, A., & O'Hara, R. (1999). Relationship of age and simulated flight performance. *Journal of the American geriatrics society*, Vol. 47:819-23.

APPENDIX A

LIST OF RESEARCH DOCUMENTS CLASSIFIED BY TYPE OF STUDY

DESCRIPTIVE STUDIES (DATABASE ANALYSIS; N=70)

Arjunan, M., Longstreet, E. J., & Woo, J. (1982)
ATC Operational Error Task Group (1987)
Atlanta Tower. (1988)
Aviation Safety - Air Traffic (1987)
Belanger, R. G. (1978, June)
Bellantoni, J. & Kodis, R. (1981)
Billings, C. E. & Cheaney, E. S. (1981)
Bowen, K. C. & Winokur, D. J. (2003)
Broach, D. (1999)
Broach, D. & Dollar, C. S. (2002)
Clough, D. L. (1986)
Conner, M. & Corker, K. (2001)
D'Arcy, J.-F. & Della Rocco, P. S. (2001)
De Valle, E. (2000, December)
Della Rocco, P. S. (1999)
Evans, A., Slamen, A., & Shorrock, S. T. (1999)
FAR Committee. (1987)
Federal Aviation Administration (1985)
Federal Aviation Administration (1985, September)
Federal Aviation Administration (1986a)
Federal Aviation Administration (1986b)
Federal Aviation Administration (1988)
Flight Safety Foundation (1976, November)
Fowler, F. D. (1980)
Gregory, K., Oyung, R., & Rosekind, M. (1999)
Histon, J. (2003)
DOT (2003)
Isaac, A., Shorrock, S. T., & Kirwan, B. (2002)
Jones, S. G. & Tesmer, B. (n.d.)
Kelly, D. R., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987).
Lowry, N., MacWilliams, K., & Still, R.J., and Walker, M.G. (2005)
Majumdar, A. & Ochieng, W. Y. (2000)
Mayberry, P. W., Kropp, K. V., Kirk, K. M., Breitler, A. L., & Wei, M. (1995)
McCoy, W. E. & Funk, K. H. (1991)
Memphis ARTC Center Six Area Project Historical Summary and Justification (2002)
MITRE. (2004)
Mogford, R.H. (2001)
Mogford, R. H., Allendoerfer, K. R., Snyder, M. D., & Hutton, R. (1996)
Mohleji, S. C. & MacWilliams, K. (2004)
Monan, W. P. (1980)
National Transportation Safety Board (1981)
National Transportation Safety Board (1983)
National Transportation Safety Board (1986a)
National Transportation Safety Board (1986b)
National Transportation Safety Board (1991a)
National Transportation Safety Board (1991b)
National Transportation Safety Board (1991c)
National Transportation Safety Board (1994)
Office of Air Traffic Evaluations & Analysis (1987)
Pape, A.M., Wiegmann, D.A., & Shappell, S. (2001)
Pounds, J. & Ferrante, A. S. (2003)
Pounds, J. & Isaac, A. (2002)
Pounds, J. (1999)
Press, J. (2004)
Prince, L.C. (1999)
Redding, R. E. (1992)
Rodgers, M. D., Mogford, R. H., & Mogford, L. S. (1998)
Scarborough, A. & Pounds, J. (2001)
Schroeder, D. J. & Nye, L. G. (1993)
Schroeder, D. J., Nye, L. G., & Dollar, C. S. (1991)
Sheridan, P. J. (1997)
Shorrock, S. T. & Kirwan, B. (1997)
Shorrock, S. T. & Kirwan, B. (2002)
Smoker, A. (10-15-2003)
Spahn, M. J. (1977)
The Office of Air Traffic Evaluations and Analysis (1987)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)
Wilson-Hill Associates, I. & McDonald, C. (1980)
Xing, J. & Bailey, L. (2005)

EXPERIMENTAL (N=15)

Castaño, D. & Parasuraman, R. (1999)
Endsley, M. R. & Rodgers, M. D. (1997)
Galster, S. M., Duley, J. A., Masalonis, A. J., & Parasuraman, R. (2001)
Hartman, B. & Fitts, P. M. (1950)
Jones, D. G. & Endsley, M. R. (2000)
Krol, J. P. (1971)
Lee, P.U. & Mercer, J. (2005)
Loftus, G. R. (1979)
Metzger, U., Galster, S.M., & Parasuraman, R (1999)
Murphy, L. L., & Smith, K. (2001, March)

Philipp, U., Reiche, D., & Kirchner, J. H. (1971)
Remington, R. W., Johnston, J. C., Ruthruff, E., Gold, M., & Romera, M. (2000)
Smolensky, M. W. (1992)
Whitfield, D. & Ord, G. (1980)
Willems, B. & Truitt, T. R. (1999)

FIELD STUDIES (N=16)

Burki-Cohen, J. (1995)
Cardosi, K. (1993)
Cardosi, K. (1994)
Cardosi, K., Brett, B., & Han, S. (1996)
Empson, J. (1987)
Endsley, M. R. & Rodgers, M. D. (1994)
Grossberg, M. (1989)
Hurst, M. W. & Rose, R. M. (1978a)
Hurst, M. W. & Rose, R. M. (1978b)
Jones, S. G. (1997)
Kanki, B. G. & Prinzo, O. V. (1996)
Langan-Fox, C. P. & Empson, J. A. C. (1985)
Masalonis, A. J. & Parasuraman, R. (2003)
Pounds, J. & Isaac, A. (2003)
Prinzo, O. V. (1996)
Sperandio, J. C. (1971)

THEORIZING (N=58)

Billings, C. E. & Reynard, W. D. (1981)
Cardosi, K. & Yost, A. (2001)
Cardosi, K. (n.d.)
Cardosi, K., Falzarano, P., & Han, S. (1998)
Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Cox, M. (1992)
Danaher, J. W. (1980)
Dekker, S. W. A. (2001)
Della Rocco, P. S. (1999)
Development of a methodology for identifying operational errors correctable through training (n.d.)
Endsley, M. R., Sollenberger, R. L., Nakata, A., & Stein, E. S. (2000)
Federal Aviation Administration (1960)
Federal Aviation Administration. (1986)
Federal Aviation Administration (1987)
Finkelman, J. M. & Kirschner, C. (1980)
Flight Safety Foundation (1976, November)
Gosling, G. D. (n.d.)
Grayson, R. L. & Billings, C. E. (1981)
Grayson, R. L. (1981a)
Grayson, R. L. (1981b)
Grossberg, M. (1987)
Hansen, M. & Zhang, Y. (2005)
Hebert, H. J. (n.d.)
Hilburn, B. (2004)
Hopkin, V. D. (1971)
Hopkin, V. D. (1973)
Hopkin, V. D. (1989)
Hutton, R., Olszewski, R., Thordsen, M. L., & Kaempf, G. L. (n.d.)
Isaac, A., Shorrock, S. T., Kennedy, R., Kirwan, B., Andersen, H., & Bove, T. (2002)
Jones, S. G. (1996)
Kalsbeek, J. W. H. (1971)
Kaulia, S., Gonzalez, R., Conner, J., Klasinksi, K., & Rainey, H. (1987)
Kinney, G. C. (1977)
Kinney, G. C. (1986)
Kirchner, J. H. & Laurig, W. (1971)
Kirk, K., Mayberry, P., & Lesko, M. (1996)
Letters From Atlanta Tower on Readback Error Action Plan (1988)
Lyman, E. G. (1981)
Maynard, P.W. & Rantanen, E.M. (2005)
McFarland, A. & Maroney, D. (2001)
McKinley, J. B. & Jago, R. J. (1985)
Monan, W. P. (1983)
Murphy, T. P. & Levendoski, R. J. (1989)
O'Connor, W. F. & Pearson, R. G. (1965)
Office of Safety Analysis (1989)
Prinzo, O. V., Britton, T. W., & Hendrix, A. M. (1995)
Rodgers, M. D. & Manning, C. A. (1995)
Rodgers, M. D. & Nye, L. G. (1993)
Rodgers, M. D., Mogford, R. H., & Strauch, B. (2000)
Rohmert, W. (1971)
Schroeder, D. J. (1983)
Stager, P. & Hameluck, D. (1990)
Stager, P., Hameluck, D., & Jubis, R. (1989)
Stammers, R. B. (1978)
Stein, E. S. & Bailey, J. (1994)
Stein, E. S. (1989a)
Training Committee. (1987)
Vingelis, P. J., Schaeffer, E., Stringer, P., Gromelski, S., & Ahmed, B. (1990)

APPENDIX B

LIST OF RESEARCH DOCUMENTS CLASSIFIED BY JANUS CATEGORIES CONTRIBUTING FACTORS

Organization (N=19)

Arjunan, M., Longstreet, E. J., & Woo, J. (1982)
ATC Operational Error Task Group (1987)
Belanger, R. G. (1978, June)
Conner, M. & Corker, K. (2001)
FAR Committee. (1987)
Federal Aviation Administration (1987)
Fowler, F. D. (1980)
Hopkin, V. D. (1971)
Isaac, A., Shorrock, S. T., Kennedy, R., Kirwan, B., Andersen, H., & Bove, T. (2002)
Majumdar, A. & Ochieng, W. Y. (2000)
Memphis ARTC Center Six Area Project Historical Summary and Justification (2002)
Murphy, T. P. & Levendoski, R. J. (1989)
National Transportation Safety Board (1983)
National Transportation Safety Board (1991a)
Office of Safety Analysis (1989)
Pape, A.M., Wiegmann, D.A., & Shappell, S. (2001)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Smoker, A. (10-15-2003)

Management (N=11)

Atlanta Tower. (1988)
Belanger, R. G. (1978, June)
Conner, M. & Corker, K. (2001)
Federal Aviation Administration (1960)
DOT (2003)
Kinney, G. C. (1986)
Lancaster, F.R. (1987)
National Transportation Safety Board (1981)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)

Supervision (N=16)

Broach, D. & Dollar, C. S. (2002)
Federal Aviation Administration (1960)
Federal Aviation Administration (1987)
Kaulia, S., Gonzalez, R., Conner, J., Klasinksi, K., & Rainey, H. (1987)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Kinney, G. C. (1986)
Kirk, K., Mayberry, P., & Lesko, M. (1996)
Lancaster, F.R. (1987)
Mayberry, P. W., Kropp, K. V., Kirk, K. M., Breitler, A. L., & Wei, M. (1995)
National Transportation Safety Board (1986a)
National Transportation Safety Board (1986b)
National Transportation Safety Board (1991c)
Pape, A.M., Wiegmann, D.A., & Shappell, S. (2001)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Shorrock, S. T. & Kirwan, B. (2002)

Contextual Conditions

Traffic/Airspace (N=40)

Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Castaño, D. & Parasuraman, R. (1999)
Conner, M. & Corker, K. (2001)
Danaher, J. W. (1980)
Empson, J. (1987)
Federal Aviation Administration (1988)
Federal Aviation Administration (1986a)
Galster, S. M., Duley, J. A., Masalonis, A. J., & Parasuraman, R. (2001)
Gosling, G. D. (n.d.)
Grossberg, M. (1989)
Hansen, M. & Zhang, Y. (2005)
Histon, J. (2003)
Hurst, M. W. & Rose, R. M. (1978a)
Hurst, M. W. & Rose, R. M. (1978b)
Jones, S. G. (1996)
Kelly, D. R., Krantz, J. W., & Spelman, J. (2001)
Kinney, G. C. (1977)
Lancaster, F. R. (1987)
Lee, P.U. & Mercer, J. (2005)
Lowry, N., MacWilliams, K., & Still, R.J., and Walker, M.G. (2005)
Mayberry, P. W., Kropp, K. V., Kirk, K. M., Breitler, A. L., & Wei, M. (1995)
McFarland, A. & Maroney, D. (2001)
Memphis ARTC Center Six Area Project Historical Summary and Justification (2002)
Metzger, U., Galster, S.M., & Parasuraman, R (1999)
Mogford, R.H. (2001)

Murphy, L. L., & Smith, K. (2001, March)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Rodgers, M. D. & Manning, C. A. (1995)
Rodgers, M. D. & Nye, L. G. (1993)
Rodgers, M. D., Mogford, R. H., & Mogford, L. S. (1998)
Scarborough, A. & Pounds, J. (2001)
Schroeder, D. J. & Nye, L. G. (1993)
Schroeder, D. J., Nye, L. G., & Dollar, C. S. (1991)
Sheridan, P. J. (1997)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)
Stager, P. & Hameluck, D. (1990)
Stammers, R. B. (1978)

Weather (N=14)

Bowen, K. C. & Winokur, D. J. (2003)
Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
D'Arcy, J.-F. & Della Rocco, P. S. (2001)
Hansen, M. & Zhang, Y. (2005)
Histon, J. (2003)
Jones, S. G. (1996)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987)
National Transportation Safety Board (1991a)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)

Pilot Actions (N=18)

Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Cardosi, K. & Yost, A. (2001)
Castaño, D. & Parasuraman, R. (1999)
FAR Committee. (1987)
Histon, J. (2003)
Jones, S. G. & Tesmer, B. (n.d.)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987)
McIntyre, H. (1988)
National Transportation Safety Board (1994)
National Transportation Safety Board (1986b)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Ferrante, A. S. (2003)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)
Stager, P. & Hameluck, D. (1990)

Pilot/ATC Communications (N=26)

Burki-Cohen, J. (1995)
Cardosi, K. (1993)
Cardosi, K. (1994)
Cardosi, K., Brett, B., & Han, S. (1996)
Cardosi, K., & DiFiore, A. (2004)
Cardosi, K., Falzarano, P., & Han, S. (1998)
Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Cardosi, K. & Yost, A. (2001)
Histon, J. (2003)
Kanki, B. G. & Prinzo, O. V. (1996)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987)
National Transportation Safety Board (1991a)
O'Connor, W. F. & Pearson, R. G. (1965)
Office of Safety Analysis (1989)
Pounds, J. & Ferrante, A. S. (2003)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Prinzo, O. V. (1996)
Prinzo, O. V., Britton, T. W., & Hendrix, A. M. (1995)
Rodgers, M. D. & Nye, L. G. (1993)
Scarborough, A. & Pounds, J. (2001)
Schroeder, D. J., Nye, L. G., & Dollar, C. S. (1991)
Shorrock, S. T. & Kirwan, B. (1997)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)

Procedures (N=12)

Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Kinney, G. C. (1977)
Lancaster, F. R. (1987)
Memphis ARTC Center Six Area Project Historical Summary and Justification (2002)
National Transportation Safety Board (1991b)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Rodgers, M. D., Mogford, R. H., & Strauch, B. (2000)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)

Documents & Materials (N=7)

Controller Error Working Group. (n.d.)
Lancaster, F. R. (1987)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)

Ambient Environment & Distractions (N=20)

Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Conner, M. & Corker, K. (2001)
Della Rocco, P. S. (1999)
Federal Aviation Administration (1985)
Federal Aviation Administration (1985, September)
Gregory, K., Oyung, R., & Rosekind, M. (1999)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987)
McIntyre, H. (1988)
National Transportation Safety Board (1981)
National Transportation Safety Board (1991a)
National Transportation Safety Board (1991b)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Scarborough, A. & Pounds, J. (2001)
Schroeder, D. J., Nye, L. G., & Dollar, C. S. (1991)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)

Teamwork (N=33)

Aviation Safety - Air Traffic (1987)
Cardosi, K. & Yost, A. (2001)
Cardosi, K. (n.d.)
Cox, M. (1992)
FAR Committee. (1987)
Federal Aviation Administration (1986c)
Federal Aviation Administration (1987)
Grayson, R. L. (1981)
Grayson, R. L. (1981)
Hebert, H. J. (n.d.)
Histon, J. (2003)
Jones, S. G. (1996)
Jones, S. G. (1997)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987)
Maynard, P.W. & Rantanen, E.M. (2005)
McCoy, W. E. & Funk, K. H. (1991)
McIntyre, H. (1988)
Mohleji, S. C. & MacWilliams, K. (2004)
National Transportation Safety Board (1981)
National Transportation Safety Board (1986b)
O'Connor, W. F. & Pearson, R. G. (1965)
Office of Air Traffic Evaluations & Analysis (1987)
Pounds, J. & Ferrante, A. S. (2003)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Pounds, J. (1999)
Rodgers, M. D. & Nye, L. G. (1993)
Smoker, A. (10-15-2003)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)
Stager, P., Hameluck, D., & Jubis, R. (1989)
Training Committee (1987)

Personal Factors (N=17)

Broach, D. (1999)
D'Arcy, J. F. & Della Rocco, P. S. (2001)
Della Rocco, P. S. (1999)
Finkelman, J. M. & Kirschner, C. (1980)
Gregory, K., Oyung, R., & Rosekind, M. (1999)
Hopkin, V. D. (1971)
Kinney, G. C. (1986)
Lancaster, F. R. (1987)
National Transportation Safety Board (1983)
National Transportation Safety Board (1991b)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Press, J. (2004)
Schroeder, D. J., Nye, L. G., & Dollar, C. S. (1991)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)

Interpersonal & Social Relations (N=7)

Jones, S. G. (1996)
Lancaster, F. R. (1987)
O'Connor, W. F. & Pearson, R. G. (1965)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)

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ATC Operational Error Task Group (1987)
Broach, D. (1999)
Clough, D. L. (1986)

Conner, M. & Corker, K. (2001)
Controller Error Working Group. (n.d.)
Cox, M. (1992)
Development of a methodology for identifying operational errors correctable through training (unknown)
FAR Committee. (1987)
Federal Aviation Administration (1960)
Federal Aviation Administration (1985)
Federal Aviation Administration (1985, September)
Federal Aviation Administration (1986a)
Federal Aviation Administration (1987)
DOT (2003)
Isaac, A., Shorrock, S. T., Kennedy, R., Kirwan, B., Andersen, H., & Bove, T. (2002)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Lancaster, F. R. (1987)
Mayberry, P. W., Kropp, K. V., Kirk, K. M., Breitler, A. L., & Wei, M. (1995)
Mogford, R.H. (2001)
Monan, W. P. (1980)
National Transportation Safety Board (1981)
National Transportation Safety Board (1983)
National Transportation Safety Board (1986b)
O'Connor, W. F. & Pearson, R. G. (1965)
Office of Safety Analysis (1989)
Pape, A.M., Wiegmann, D.A., & Shappell, S. (2001)
Pounds, J. & Ferrante, A. S. (2003)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Prince, L.C. (1999)
Redding, R. E. (1992)
Rodgers, M. D., Mogford, R. H., & Strauch, B. (2000)
Scarborough, A. & Pounds, J. (2001)
Schroeder, D. J., Nye, L. G., & Dollar, C. S. (1991)
Spahn, M. J. (1977)
Sperandio, J. C. (1971)
Training Committee. (1987)
Wilson-Hill Associates, I. & McDonald, C. (1980)

Human-Machine Interface (N=40)

ATC Operational Error Task Group (1987)
Bellantoni, J. & Kodis, R. (1981)
Cox, M. (1992)
De Valle, E. (2000, December)
Dekker, S. W. A. (2001)
Endsley, M. R., Sollenberger, R. L., Nakata, A., & Stein, E. S. (2000)
Evans, A., Slamen, A., & Shorrock, S. T. (1999)
FAR Committee (1987)
Federal Aviation Administration (1986b)
Federal Aviation Administration (1986c)
Federal Aviation Administration (1987)
Federal Aviation Administration (1988)
Fowler, F. D. (1980)
Hilburn, B. (2004)
Histon, J. (2003)
Hopkin, V. D. (1971)
Hopkin, V. D. (1989)
Isaac, A., Shorrock, S. T., Kennedy, R., Kirwan, B., Andersen, H., & Bove, T. (2002)
Kinney, G. C. (1986)
Kirchner, J. H. & Laurig, W. (1971)
Lancaster, F. R. (1987)
Langan-Fox, C. P. & Empson, J. A. C. (1985)
Maynard, P.W. & Rantanen, E.M. (2005)
MITRE. (2004)
Monan, W. P. (1980)
National Transportation Safety Board (1991b)
O'Connor, W. F. & Pearson, R. G. (1965)
Philipp, U., Reiche, D., & Kirchner, J. H. (1971)
Pounds, J. & Ferrante, A. S. (2003)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Rodgers, M. D. & Nye, L. G. (1993)
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Spahn, M. J. (1977)
Sperandio, J. C. (1971)
Stager, P. & Hameluck, D. (1990)
Stammers, R. B. (1978)
Training Committee. (1987)
Whitfield, D. & Ord, G. (1980)
Wilson-Hill Associates, I. & McDonald, C. (1980)

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Task Descriptions (N=2)

Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)

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Federal Aviation Administration (1988)
Kaulia, S., Gonzalez, R., Conner, J., Klasinksi, K., & Rainey, H. (1987)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)

Mental Processes

Perception & Vigilance (N=51)

Cox, M. (1992)
Danaher, J. W. (1980)
D'Arcy, J. F. & Della Rocco, P. S. (2001)
Della Rocco, P. S. (1999)
Development of a methodology for identifying operational errors correctable through training (unknown)
Endsley, M. R. & Rodgers, M. D. (1994)
Endsley, M. R. & Rodgers, M. D. (1997)
Endsley, M. R., Sollenberger, R. L., Nakata, A., & Stein, E. S. (2000)
Evans, A., Slamen, A., & Shorrock, S. T. (1999)
Federal Aviation Administration (1986a)
Flight Safety Foundation (1976a)
Flight Safety Foundation (1976b)
Galster, S. M., Duley, J. A., Masalonis, A. J., & Parasuraman, R. (2001)
Hartman, B. & Fitts, P. M. (1950)
Hebert, H. J. (n.d.)
Hopkin, V. D. (1973)
Isaac, A., Shorrock, S. T., & Kirwan, B. (2002)
Jones, D. G. & Endsley, M. R. (2000)
Jones, S. G. (1997)
Kalsbeek, J. W. H. (1971)
Kelly, D. R., Krantz, J. W., & Spelman, J. (2001)
Krol, J. P. (1971)
Langan-Fox, C. P. & Empson, J. A. C. (1985)
Lyman, E. G. (1981)
Masalonis, A. J. & Parasuraman, R. (2003)
Maynard, P.W. & Rantanen, E.M. (2005)
McCoy, W. E. & Funk, K. H. (1991)
McKinley, J. B. & Jago, R. J. (1985)
Mogford, R.H. (2001)
National Transportation Safety Board (1986a)
Office of Air Traffic Evaluations & Analysis (1987)
Office of Safety Analysis (1989)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Prince, L.C. (1999)
Redding, R. E. (1992)
Remington, R. W., Johnston, J. C., Ruthruff, E., Gold, M., & Romera, M. (2000)
Rodgers, M. D. & Nye, L. G. (1993)
Rodgers, M. D., Mogford, R. H., & Strauch, B. (2000)
Rohmert, W. (1971)
Scarborough, A. & Pounds, J. (2001)
Schroeder, D. J. (1983)
Shorrock, S. T. & Kirwan, B. (1997)
Shorrock, S. T. & Kirwan, B. (2002)
Spahn, M. J. (1977)
Stager, P. & Hameluck, D. (1990)
Stager, P., Hameluck, D., & Jubis, R. (1989)
Stein, E. S. (1989a)
The Office of Air Traffic Evaluations and Analysis (1987)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)
Willems, B. & Truitt, T. R. (1999)

Memory (N=35)

Cardosi, K., Hannon, D., & Sheridan, T., & Davis, W. (2005)
Cardosi, K. & Yost, A. (2001)
Cox, M. (1992)
D'Arcy, J. F. & Della Rocco, P. S. (2001)
DOT (2003)
Federal Aviation Administration (1987)
Finkelman, J. M. & Kirschner, C. (1980)
Flight Safety Foundation (1976b)
Grossberg, M. (1987)
Isaac, A., Shorrock, S. T., & Kirwan, B. (2002)
Jones, S. G. (1996)
Kaulia, S., Gonzalez, R., Conner, J., Klasinksi, K., & Rainey, H. (1987)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Kinney, G. C. (1986)
Langan-Fox, C. P. & Empson, J. A. C. (1985)
Loftus, G. R. (1979)
McCoy, W. E. & Funk, K. H. (1991)
McKinley, J. B. & Jago, R. J. (1985)
Memphis ARTC Center Six Area Project Historical Summary and Justification (2002)
Mogford, R.H. (2001)
National Transportation Safety Board (1986a)
Office of Safety Analysis (1989)
Pape, A.M., Wiegmann, D.A., & Shappell, S. (2001)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Pounds, J. (1999)
Shorrock, S. T. & Kirwan, B. (2002)
Spahn, M. J. (1977)
Stager, P. & Hameluck, D. (1990)
Stein, E. S. & Bailey, J. (1994)
Training Committee (1987)
Vingelis, P. J., Schaeffer, E., Stringer, P., Gromelski, S., & Ahmed, B. (1990)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)
Willems, B. & Truitt, T. R. (1999)
Xing, J. & Bailey, L. (2005)

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Conner, M. & Corker, K. (2001)
D'Arcy, J. F. & Della Rocco, P. S. (2001)
Development of a methodology for identifying operational errors correctable through training (1990)
Flight Safety Foundation (1976, November)
Hutton, R., Olszewski, R., Thordsen, M. L., & Kaempf, G. L. (n.d.)
Isaac, A., Shorrock, S. T., & Kirwan, B. (2002)
Kelly, D., Krantz, J. W., & Spelman, J. (2001)
Kinney, G. C. (1986)
Lyman, E. G. (1981)
McKinley, J. B. & Jago, R. J. (1985)
Mogford, R. H., Allendoerfer, K. R., Snyder, M. D., & Hutton, R. (1996)
Mohleji, S. C. & MacWilliams, K. (2004)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Prince, L.C. (1999)
Schroeder, D. J. (1983)
Shorrock, S. T. & Kirwan, B. (1997)
Shorrock, S. T. & Kirwan, B. (2002)
Spahn, M. J. (1977)
Stager, P. & Hameluck, D. (1990)
Stager, P., Hameluck, D., & Jubis, R. (1989)
Training Committee. (1987)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)

Response Execution/ACT Description (N=20)

Belanger, R. G. (1978, June)
Billings, C. E. & Cheaney, E. S. (1981)
Billings, C. E. & Reynard, W. D. (1981)
Development of a methodology for identifying operational errors correctable through training (1990)
Federal Aviation Administration (1986a)
Flight Safety Foundation (1976, November)
Grayson, R. L. & Billings, C. E. (1981)
Isaac, A., Shorrock, S. T., & Kirwan, B. (2002)
Kelly, D. R., Krantz, J. W., & Spelman, J. (2001)
Kinney, G. C. (1986)
McCoy, W. E. & Funk, K. H. (1991)
McKinley, J. B. & Jago, R. J. (1985)
MITRE. (2004)
Monan, W. P. (1983)
Pounds, J. & Isaac, A. (2002)
Pounds, J. & Isaac, A. (2003)
Smolensky, M. W. (1992)
Spahn, M. J. (1977)
Stager, P. & Hameluck, D. (1990)
Wiegmann, D. A., Rich, A. M., & Shappell, S. A. (2000)

APPENDIX C

REVIEW OF OE INTERVENTIONS

The legacy ATS organization conducted several broad activities over a number of years that focused on multiple areas of OE causal factors. The discussion below illustrates the ongoing effort to identify strategies designed to reduce OEs. Note that attention kept returning to particular causal factors as these factors were repeatedly identified in OEs. Although the formal activities overlapped in some ways based on this recurring interest, we treat them separately in this document for the purpose of discussing the programs. Following these descriptions, several other initiatives are described; some were national initiatives, some were facility-specific. Some are ongoing, while others have been concluded. The initiatives are not necessarily presented in chronological order.

OE Working Groups

1986 Task Group Review. In 1986 the FAA Administrator directed the Federal Air Surgeon to form a working group to address issues associated with ATC OEs. The group, comprised of representatives from the Air Traffic Service, the Office of Aviation Medicine, the FAA Technical Center, the Office of Aviation Safety, and MITRE focused their investigation on the human factors associated with OEs. Following their review of historical information and the existing OE database, they made several recommendations. These included support for the recently implemented Operational Position Standards program, an emphasis on the use of "positive air traffic control techniques," implementation of a nationwide flow control program, the addition of HF data fields to accident/incident reports, improved approaches to using simulation to evaluate ATCS proficiency, and a recommendation to periodically sample ATCSs' operational proficiencies. In addition to several other factors associated with advanced displays, the study group identified areas in which additional research was needed. Scientists at the FAA Technical Center were given responsibility for addressing issues involving memory and visual scanning. As a result of this effort, three reports were prepared (Stein, 1989a; Stein, 1989b; and Stein and Bailey, 1994). Stein (1989a) reviewed issues related to controller scanning. Stein (1989b) and Stein and Bailey (1994) were developed as memory guides for controllers.

Operational Errors in the U.S. Air Traffic System – A Task Group Review FAA. (1987). In 1987, the FAA Administrator initiated a study of OEs following a sudden increase after a two-year declining trend. A task group was directed to study system deficiencies related to OEs as well as other factors that impacted safe movement of aircraft in the system, such as pilot–controller communications, procedures, and human performance. The group was also tasked to make recommendations for corrective measures. The group consisted of management personnel from FAA Headquarters, operational personnel from ATC towers, TRACONs, and ARTCCs, as well as representatives from the U.S. Air Force, Navy, and Army, NASA, and CAMI. The topics covered were: Procedures and Regulations; Operations, Communications, and Equipment; Human Performance and Training; and HF Special Emphasis Items.

Problems identified included: existing procedures were not being followed, ARTCC separation standards were restrictive, Federal Aviation Regulations (FARs) placed inadequate responsibility on the pilot, lack of precision of ATC equipment (i.e., the J-ring), introduction of automated aids reduced controllers' memory skills, lack of organizational coordination before implementing new procedures, non-standardized and non-aligned procedures and QA practices across facilities, high rates of OEs for aircraft in transition (climbing/descending), the OE report did not have information necessary to pinpoint causal factors, lack of opportunity for developmentals to acquire experience on the position, lack of experienced OJT instructors, ineffective supervision, controllers didn't recognize when they begin to exceed their capabilities, lack of teamwork, lack of knowledge of aircraft performance in different conditions, inadequate position relief briefings, poor controller memory and decision making, failures in controllers' memory and decision making, and failure in information exchanges.

Recommendations were developed to address each problem identified under these topics. These included:

- increase adherence to procedures by instilling pride and motivation,
- use the performance management rating system to establish accountability for OEs,
- use a monetary award program for OE-free performance,
- test feasibility of visual separation for the ARTCC environment,
- further study reduced separation above FL290 and in oceanic environments,

- examine diverging course separation minimums,
- revise FAR requirements to specify pilot's responsibilities in communications with ATC,
- improve coordination processes between controllers and use of flight strips,
- improve organizational coordination prior to implementing procedural changes,
- improve QA staffing at facilities,
- improve controller training and instruction by better screening of instructors,
- use the FAA Headquarters' Quality Assurance program to assess the Academy's training program,
- provide error identification and tracking capabilities for terminals,
- increase continuity and standardization of facility procedures with national orders,
- track new procedures to identify which contribute to OEs versus reducing them,
- make the OE report meaningful in determining causal factors,
- streamline the FAA incident reporting system,
- make proficiency training mandatory,
- improve status indicators for equipment systems,
- use simulators for controller training,
- train supervisors,
- ensure that any disciplinary actions related to OEs are taken based on FAA policy,
- establish national training for operational supervisors,
- establish an HF newsletter for controllers,
- train all employees in teamwork,
- validate use of position relief checklists,
- conduct training for controllers on decision making and positive control,
- develop training for controllers on task organization and prioritization,
- develop memory aids and memory training for controllers,
- make changes to phraseology and readback procedures,
- institute an educational program for pilots on various elements of pilot-controller communications contributing to OEs,
- provide training for controllers emphasizing recognition of reduced alertness and mitigation strategies,
- ensure uniform application of accepted human performance principles in designing future systems, and
- develop a method to assess decrements in human performance resulting from operational demands.

Although several themes emerged across the group's recommendations (e.g., improve the incident reporting system, and develop training programs for both controllers and pilots to mitigate certain factors), no information is available about what actions, if any, were taken as a result of this activity.

Operational Error Prevention and Reduction Workgroup (September, 1996). A joint NATCA/FAA OE prevention workgroup met at the Center for Management Development (CMD) to review former OE mitigation strategies/research and to recommend changes to related FAA Orders. Their recommendations included: Discontinue mandatory decertification of controllers subsequent to OEs, focus on the system rather than the individual when reviewing OE causal factors, create mandatory readback/hearback training, engage the first-level supervisor to a higher degree when reviewing OEs, and develop a new method to remove subjectivity from the OE identification process, e.g., find a better technique than using a "rubber ruler" method that allowed marked variability in the assessment of whether an OE had occurred.

Short-Term Operational Error Reduction Initiative

The Short-Term OE Reduction Initiative focused on programs to "improve personnel readiness, awareness, and communications skills that should lead to a reduction in operational errors and deviations caused by incomplete position relief briefings, hearback/readback factors, as well as other misunderstandings and miscommunications" (FAA, 2002a). Emphasis was placed on maintaining good operating practices. This included ensuring that facilities had an OE prevention plan that incorporated a "back to basics" program. Three focal areas were included in this initiative: communications, position relief, and distractions. No archival data are available at this time that assessed the effects of these programs on OE reduction.

Communications. Errors in communications between controllers and pilots consistently rank within the top five causal factors identified in all operational errors. This initiative focused on developing good communication skills to reduce hearback/readback errors as well as other misunderstandings in communications. Awareness programs targeting readback/hearback errors were developed by headquarters staff as well as by regional and facility groups.

Air traffic facilities initiated a regular emphasis on good communication skills using random tape reviews that highlighted readback/hearback errors and examples of correct phraseology. During "tape talks," the supervisor and/or facility staff specialists reviewed voice recordings of a controller on a position to assess communication performance. Personnel were encouraged to assist others to improve their communications skills through positive coaching.

A thirty-seven minute training video titled *"Preventing Read Back Errors"* presented strategies to reduce the complexity of each communication to facilitate understanding. The video was a mandatory briefing item shown to all controllers.

Under this initiative, the first National Hearback-Readback Awareness Month (January, 2002) was established to focus on catching and mitigating this type of communication error. Based on its perceived success, this awareness program became an annual event with January inaugurated as Hearback – Readback Awareness Month, which included an ongoing emphasis on good communications skills, random tape monitoring to highlight examples of correct phraseology, and positive coaching. Anecdotal evidence suggests that some facilities may still occasionally conduct a program focusing on hearback/readback awareness. However, because no tracking mechanism exists, it is unclear which facilities are doing this or what the impact is on OE reduction.

Position Relief. The position relief briefing is a standard operating procedure designed to optimize transfer of position responsibility while at the same time minimizing the additional workload associated with the task of transferring the position. Many times, the relieving controller will accept position responsibility before being fully ready to do so. In some cases, the controller will have been uncomfortable with current or planned actions but will still accept the position instead of asking the controller being relieved to help work out the situation. The goal of the position relief initiative was to reduce operational errors caused by incomplete position relief briefings by improving personnel readiness and awareness in taking position responsibilities. "Most errors occur early in a shift or after a break. Take time with your relief briefing. Use the checklist. Make sure that the relieving controller has data he/she needs in working memory. This means that they are actively aware of it" (Stein, & Bailey, 1994).

As part of their facility OE reduction plan, all managers were required to emphasize the use of checklists during position relief briefing as part of their "back to basics" program. They also had to validate their facility's position relief briefing checklist, ensuring that it conformed to requirements of FAA Orders 7110.65R (FAA, 2006) and 7210.3 (FAA, 2005a), as well as provide for a capability to record the briefing and take necessary actions to ensure that audio recording of position relief briefings occurred. Operations supervisors/CICs were required to ensure that position relief procedures were followed, that the checklist was used, and where available, ensure that position relief briefings were recorded.

All personnel received mandatory training on use of the position relief briefing checklist and the audio recording requirement. They were trained and encouraged to "have the picture" before taking over a position and to accept position responsibility only after they were fully aware of the traffic. Both the relieving and relieved controllers were to ensure that a complete transfer of responsibilities was conducted. The relieved controller should ensure that the relieving controller had "the picture" before leaving the position. In the past, mandatory overlap periods had been established i.e., 5 minute pre/post relief briefings. The relieving controller and the controller being relieved were to establish an appropriate overlap period as part of the position relief briefing that would ensure complete transfer of position responsibilities. Some facilities mandated a specific amount of time that the relieved controller would remain on position. Other facilities adopted this as a good practice and allowed the overlap period to vary, depending upon traffic demands. The intent of the latter practice was to base the overlap period on traffic demand, reducing the likelihood of potential distractions associated with multiple personnel unnecessarily remaining in operational areas.

Although not part of this particular initiative, local adaptations to the position relief briefing were sometimes made to meet system needs. For example, "each URET CCLD facility was asked to ensure that pertinent URET CCLD information was integrated into any position relief briefing list, whether manual or electronic" (FAA Order 7210.3; FAA, 2005a). Not all en route centers were "URET CCLD" facilities, so not all were required to alter their briefing procedures in this way, but anecdotal evidence suggests that some facilities made other local adaptations to their position relief processes.

Distractions. The goal of this initiative was to reduce control room distractions so that controllers could increase their focus on the operations. For example, during periods of light traffic, controllers can be distracted from their primary duties by conversations unrelated to the control room operations. Under this initiative, during light traffic, operational supervisors/CICs were to reduce distractions in the control room and assure control room focus on operations.

Control Room Management. Effective control room management requires operations supervisors and managers to ensure that combining and decombining of sectors and positions are appropriate for current and forecasted traffic conditions. The distractions initiative included an effort to encourage the appropriate combining/de-combining of sectors and positions. Air traffic managers were instructed to brief all operational personnel on their expectations that sectors and positions would be combined/de-combined based on current and forecasted traffic conditions. Operational Supervisors and CICs were instructed to actively ensure operational focus by exercising good judgment and ensuring that sector/ position openings and closings were appropriate to the current and forecasted level of traffic.

FAA/NATCA 3-Year Plan for OE Reduction

The FAA/NATCA Operational Error Reduction Plan was a three-year effort (2002-2004) to prevent and reduce OEs. It was collaboratively developed between the Agency and NATCA to reverse the upward trend in OEs and focus attention on those scenarios identified as having the potential for the greatest risk to safety. No archival data were available that assessed the effects of these programs on OE reduction.

The Plan was based on principles of continuous communication at all levels about performance expectations and feedback about performance so that OE reduction strategies could be proactive instead of reactive. Initiatives in the 3-year plan included:

a) Establishing an FAA/NATCA coordinating structure made up of a National Safety Board, Steering Committee, and local facility Safety Boards. These groups were to provide periodic communications to employees about the program. For example, the Steering Committee planned to publish an Annual QA Program Oversight Report. A review of the 3-year plan was to be conducted annually to ensure the program met its goals.
b) Cataloging national, regional and local initiatives, including those from areas/facilities that had low numbers of OEs, those that reduced the number and/or severity of OEs, and those that identified/corrected problems before an OE occurred.
c) Empowering local safety boards to develop more extensive in-depth training programs using tools such as URET, DYSIM, JANUS, ETG, and ATTE. Memory enhancement training and other programs of performance enhancement (e.g., the CLT training prototype) and self-development were also encouraged.
d) Publishing and distributing a weekly Quality Assurance Digest of OEs to all facilities as a mandatory read and initial binder item to heighten OE awareness.
e) Changing the Operational Error Final Report to develop a new format useful and practical for identifying the root cause(s) of OEs (possibly including JANUS, once development is completed).
f) Preparing recommendations for a comprehensive system to provide a realistic view of safety and performance of the NAS as an alternative to the current measures and separation standards.
g) Establishing a Professional Standards Program based on peer assessment and intervention.

Teamwork. This initiative facilitated teamwork by advocating adoption of methods to clearly communicate expectations, such as holding team meetings and all-hands meetings, having briefings on current trends and issues, and discussing OE trends, evaluations, and customer inputs.

A format to emphasize lessons learned was established. It included the "In The Zone" program, which distributed information about noteworthy air traffic sessions, e.g., excellence in individual/team/facility performance, and the "In The Ozone" program, which distributed tapes of operational errors and near-OEs for the purpose of refresher training and lessons learned. It was strongly recommended that training conducted using the "In The Zone" and "In the Ozone" should involve groups of controllers to promote teamwork.

The 3-Year Plan also specified that ATTE training would be included in the curriculum for new hires. It was recognized that the addition of new hires provided an opportunity to instill cultural change at the onset of training, to emphasize that team responsibility is highly valued. Training was to be developed jointly by both parties and instituted at the Academy and CTI schools. Some elements of ATTE were incorporated into the Academy's courses for the terminal options. Discussions between the Academy and NATCA regarding what elements to include in courses for the en route option have not been completed.

This initiative emphasized information that could be used as refresher training for all controllers and targeted to specific individuals. Use of both refresher and skill enhancement training was encouraged. Techniques included using previous OE scenarios and re-creations as part of training, sharing personal accounts by controllers as lessons learned, and increasing awareness of QA focus items (both errors and good examples) through facility and standup briefings, employee work groups, and bulletin board information.

The Year of Quality Assurance. To facilitate the 3-Year Plan's OE reduction goals, "The Year of Quality Assurance" was launched in 2003. Representatives from air traffic management, the National Air Traffic Supervisors' Committee (SUPCOM), and the National Air Traffic Controllers' Association (NATCA) embarked on the "National Road Show," sending small teams to air traffic facilities to conduct interactive sessions about the 3-Year Plan's goals, technical training discussions, and performance management – as an ongoing process of observation and feedback. This effort was designed to develop a shared understanding of the goal from both a national perspective and incorporating the viewpoints of all employees. The traveling team explained the objectives of the National Safety Board, the Steering Committee, and local facility Safety Boards. The team also illustrated how employees could support the OE reduction initiatives.

Identifying Causal Factors. As part of the 3-Year Plan, the FAA and NATCA proposed that the current OE Final Report Form was time-intensive, required significant resources, and did not adequately address a full range of causal factors. In support of data-driven decisions about OE intervention strategies, the FAA Air Traffic Office of Investigations determined that an improved method was needed to identify causal factors related to human performance. This effort was responsive to goals in the FAA's 1999 Strategic Plan and the 1999 National Aviation Research Plan. The result was a technique, JANUS, to identify OE factors related to human performance along with contextual and contributing conditions. JANUS was developed and tested by both the FAA and EUROCONTROL (Pounds & Isaac, 2001).

The JANUS structure was described earlier as part of the method for organizing this report. However, when the technique is used to analyze an OE, it can identify very specific factors for each JANUS category. For example, factors of mental processes (i.e., expectation bias) or of teamwork (i.e., the lack of inter-facility coordination) can be identified. These factors can then be targeted for interventions or used in more complex analyses to prioritize factors. The Steering Committee reviewed the current OE Form and JANUS beta test results to determine if a new format for the OE Form could be implemented that would be more useful and practical as an aid in determining the root cause(s) of operational errors. As part of this effort, the JANUS technique was programmed as a web-based tool (eJANUS) and began field-testing at en route centers.

Based on the findings from the JANUS beta test and a field survey of operational personnel commissioned by AAT-200 (Conner & Corker, 2001), several studies were initiated. One study, using data from Indianapolis ARTCC, is being conducted by CAMI to examine the relationship between both static and dynamic sector characteristics and OE occurrence. A series of studies is examining the role of Operational Supervisors in OE prevention to identify requirements, practice, and "best practices" so that strategies can be developed to bridge these if needed.

Traffic Re-creations

During the 1990s, the FAA Air Traffic Evaluations and Investigations staff and Atlanta air route traffic control center (ARTCC) collaborated with the CAMI to develop the Systematic Air Traffic Operations Research Initiative (SATORI; Rodgers & Duke, 1993). SATORI graphically re-creates radar data that are routinely recorded by en route air traffic control facilities. SATORI enables its users to re-create traffic samples in a format similar to what was displayed to the controller, for example, showing relative location and separation, speeds, and headings of aircraft involved in an OE. SATORI is a tool that can be used to expand proficiency training with the capability of reviewing significant traffic samples, such as emergency situations, distracting events, peak periods of traffic flow ("pushes"), the effects of weather on traffic flow, and situational distracters, to promote learning from them. The Radar Audio Playback Terminal Operations Recording (RAPTOR) was developed by Air Traffic Services in the New England Region and is a similar re-creation tool for terminal operations. SATORI, RAPTOR, and other re-creation tools are currently being used in diverse ways for training, e.g., OJT, skill enhancement, refresher training, and review of OEs during investigations.

Severity Index

Every violation of separation standards provides an important opportunity for lessons learned and system improvement, although not all operational errors share the same characteristics. Separation standards and procedures differ depending upon, for example, the type of airspace, weather conditions, type of aircraft, and altitude. The U.S. Department of Transportation, Office of Inspector General (DOT, 2000) recommended that the FAA Air Traffic Investigations Division tackle the problem of modeling and defining the severity of OEs that occurred above the runway surface to describe the extent to which applicable separation standards were violated. The purpose was to group airborne OEs and thus be able to both focus resources on the most severe events and identify factors related to specific categories of events. Data about systemic causes of OEs could then be used to more explicitly direct action towards the prevention of future occurrences.

In 2001, the FAA Air Traffic Evaluations and Investigations staff developed a classification system to distinguish between airborne OEs based on characteristics of the operational environment. The SI categories give the FAA a new method to distinguish high severity OEs from those less severe. This approach allows the FAA to focus energy on OEs having common characteristics. Targeting efforts towards the more severe OEs is a more effective use of available resources.

Training Initiatives

The FAA Air Traffic Evaluations and Investigations Staff initiated several programs that focused attention on proactive skill building through performance maintenance and enhancement activities rather than remedial training programs. It was anticipated that programs that provide regular ongoing support of skill sets routinely used by controllers to control traffic would sustain an already highly skilled workforce and would also decrease OEs when incorporated in the controller's day-to-day performance.

Video Briefing Materials. Analysis of OE data by the Air Traffic Investigations Division Staff revealed several complex system vulnerabilities. Consequently, they produced a series of videos to focus awareness on recurring factors found to occur during OEs. Periodically, videos were also produced to address factors related to incidents and accidents. Copies of these were sent to all FAA air traffic facilities for use as briefing materials.

The *"Break the Chain"* video illustrates how events, if uninterrupted, can culminate in an accident or incident and how attending to details can help break that chain of events. The video *"Collision Course: What are the Odds?"* depicts an actual incident, demonstrating how rare and improbable events can occur. *"Consequences of Simple Omissions"* is a compilation of actual events illustrating how small omitted actions, lack of attention, failure to follow operational practices, compounded by poor facility practices, and lack of self discipline or professionalism resulted in incidents ranging from operational errors to fatal accidents. *"Preventing Readback Errors,"* describes strategies to reduce the complexity of communications and chunk information in meaningful units to facilitate understanding.

Skills Training – Keeping the Mental Edge. The National Air Traffic Professionalism (NATPRO) program was a new training approach that was initially developed under the sponsorship of the FAA Air Traffic Investigations Division. The program is a personal performance enhancement program intended to maintain skilled performance, rather than provide remedial training for OE reduction. Instead of relying solely on knowledge-based training, this approach integrates the concept of "performance coaching" by facility personnel who are certified as coaches (NATPRO Cadre Instructor, Course No. 55095) to deliver the training (NATPRO, Course No. 55096) at their facility. The program combines knowledge with practice so that controllers can experience their own strengths and limitations and can gain insight into their mental processing skills, especially those used in air traffic control. These skills include perception and vigilance, memory, and planning and decision-making, all of which are practiced in a dynamic environment. In a pilot field study at an FAA en route center, this program was demonstrated to be a more cost-effective, personally rewarding method of delivering training than traditional proficiency testing or remedial training programs (Breedlove, 2004). NATPRO Series 1 was deployed at en route centers in 2004.

The initial NATPRO program (Series 1) emphasized visual acquisition of information. The course content included multi-tasking, paying attention, scanning, detecting information, focusing on relevant information, being ready to take position, working "ahead of the traffic," and staying "in your zone." Although the skills are generic, it is expected that by improving general skills, individuals will demonstrate a corresponding improvement in job performance. By testing themselves against the computer and experiencing how their performance can vary in relation to factors such as distraction, fatigue, boredom, etc., participants gain increased understanding of their own performance and can develop personal improvement strategies. It will eventually be necessary to determine empirically whether those personal improvement strategies will lead to corresponding improvements in controller performance under simulated and actual job conditions.

Initiatives by Air Traffic Managers

In 2004, air traffic managers recommitted themselves to a program of immediate and long-term OE reduction through facility-level actions and consistent performance management at all organizational levels. The following are examples of initiatives designed by air traffic managers and their staffs to address facility-specific problems. No archival data are available to identify which of these were executed by what facilities or to assess the effects of these programs on OE reduction.

Communications. All operational personnel were briefed on performance management initiatives. Managers, OMs, and Operations Supervisors (OSs) held face-to-face briefings and focused on individual employees' performance management history, CIC/OJTI status, and disciplinary history. Facility air traffic management briefed their facilities on expectations about performance management and the link between FAA performance, facility performance, and supervisory performance. OMs and OSs were required to provide feedback to their employees.

Processes were examined to ensure that employees received the instruction and help they required when training needs were identified. These efforts guaranteed that special emphasis items would be assessed and/or addressed. Activities would be communicated and coordinated and appropriate follow-up actions would be initiated.

Operational Standards. Each facility was required to develop clear operational standards of conduct and performance. These standards were tailored to meet specific facility needs and management-ensured 100% compliance. In the operational areas, for example, supervisors actively engaged in directing the operation (e.g., observing position relief briefings, interacting with TMU, staffing to traffic, making position and break assignments), performance management (e.g., on-the-spot corrections, teamwork), and managing the operational environment (e.g., reducing noise levels, limiting distractions). OMs and OSs ensured 100% compliance with requirements for technical training discussions, operational error follow-up, timely response, and thorough documentation of all identified performance deficiencies. All performance or conduct deficiencies were discussed with affected employees and documented for follow-up.

Long-Term Strategies. Air traffic managers of en route and large TRACON facilities used the existing monthly telecon to discuss issues related to developmental training, performance management, refresher training, performance and conduct actions related to multiple OEs, and ongoing development and sharing of automation to support performance management.

Training strategies were implemented including a redesign of qualification training to include topics of traffic management, operational error prevention, teamwork, and changes to the air traffic environment (e.g., URET). Refresher training addressed causal factors trends related to operational errors. Developmental training was changed to include true simulation. The NATPRO program was deployed to all en route centers.

Teamwork. For a period of time, different incentive programs were popular. For example, "None in a Million" HQ awards were handed out to facilities having no OEs during a million facility operations. Competitions at the facility level also took place, with various incentives given for error-free performance, such as by one area of specialization within a center.

"Best Practices." In 2004, Air Traffic developed and distributed a list of "best practices" for towers, centers, and flight service stations to emphasize a focus on "back to basics" performance. The list was distributed as a "pocket card" reminder. For example, "best practices" included:

1) Give and receive a complete and thorough position relief briefing (record & overlap);
2) Listen to ensure that readbacks are correct;
3) Ensure that coordination and communication are clear, complete, and correct; and
4) Avoid distractions.

Performance Management Emphasis

The intent of this initiative was to make training proactive (i.e., administered before an OE occurs) and not reactive (i.e., administered only after an OE has occurred). All facility personnel were asked to plan and support performance management together. To accomplish this, a formal process was instituted for conducting Technical Training Discussions (TTDs).

Technical Training Discussions (TTDs) and an example of implementation. A TTD is a discussion between the employee and his/her first level supervisor about the employee's performance. To assess a controller's performance, the first-level supervisor is required to conduct a TTD for each employee certified on at least one operational position. These discussions are neither "pass/fail" nor "satisfactory/ unsatisfactory;" nor do they include discussions of conduct.

TTDs are not based on a single "snapshot" of performance but instead on a continuous assessment of the employee's technical performance using both direct and indirect methods and on the appropriate job functions and indicators as described in FAA Order 3120.4. Indirect methods may include remote monitoring, tape reviews, and SATORI re-creations of traffic samples that he/she controlled.

In a TTD, all training administered during an OE/D is reviewed to develop and direct individualized technical training that appropriately addresses identified technical performance issues. An employee may demonstrate overall acceptable technical performance, but might benefit from technical training on a particular skill or task. If no new issues are identified, this too is discussed and documented. Reports are designed to allow the facility to identify recurring and significant proficiency training needs so that effective training plans can be developed.

A TTD is not conducted only following an OE. They can be held whenever the first-level supervisor identifies an area in an employee's technical performance that might benefit from individualized technical training, no earlier than 6 months following the employee's previously documented technical training discussion, no later than 60 days after the first-level supervisor assumes responsibility for an employee who has not had a technical training discussion documented during the previous 6 months.

Houston Center's Quality Evaluation Program (QEP). In October 2003, Houston Center developed and implemented a Quality Evaluation Program (QEP) to improve the assessment of controller performance using Technical Training Assessments (TTAs) and TTDs. The QEP provides a number of different ways to look at performance. As a result of the program, most areas of specialization showed a significant improvement in performance proficiency. Facility QA staff expected that, since performance is directly tied to operational errors and deviations (OE/ODs), improvement in individual and team performance would help reduce the number of OE/ODs.

The cornerstone of this program was the establishment of two Quality Evaluation Supervisor (QES) positions in the facility. These supervisors are assigned to the Quality Assurance Office and conducted QEP assessments of controller performance independent of technical assessments conducted by the individual employee's Operations Supervisors. The QES adhere to a strict standard of evaluation for each assessment. Items assessed include altitude assignment and confirmation, monitoring of readbacks, traffic advisories, route clearances, speed control, vectoring, beacon assignments, and point outs. An evaluation of the process showed that the QES assessments were accurate, consistent, and objective.

All deficiencies are addressed as quickly as possible by the first-level supervisor. In the event that a supervisor was unable to address a particular assessment within 15 days, notification was given to the Quality Assurance Office so that tapes and/or SATORI re-creations could be made and retained for review.

An improved system for tracking technical performance trends was also developed. The QESs maintained a master schedule of TTAs and TTDs and an electronic folder for each employee. The master schedule ensured that each employee received a TTA every other month and a TTD every six months. Any necessary follow-up assessments were accomplished during the intervening months. In an "After Care" program, the QESs performed random TTAs for employees involved in recent operational errors/operational deviations/incidents.

Formal organizational recognition of good performance was also part of the program. If an employee performed without a deficiency during a TTA, formal recognition was awarded. The recognition program included certificates, monthly posters, and inclusion on a Regional Honor Roll. "Fantastic Feats" was the first program employed for this purpose; however, to maintain interest and spark involvement, the program changed periodically. The "Chain of Excellence" Program recognized all deficient free performance as a "Link in the Chain."

The QES supervisors and the Quality Assurance (QA) Manager met with the OMs on a regular basis to discuss all aspects of the program and make adjustments as needed. The QES assessments were tracked so that results could be examined at the level of the individual, specialty, and facility. All performance deficiency trends were incorporated into current and future training programs.

In addition to the finding that most specialties showed a significant improvement in controller performance, TTA data indicated that technical performance deficiencies decreased an average of 16.6% in the facility and that deficiency-free performance increased by an average of 50.8% over the same period.

These data can also be used to produce various types of facility information. For example, although the majority of specialties showed a significant improvement in performance during the time period reported, one specialty showed an increase in deficiencies. However, this was attributed to an increase in the number of items being assessed and the presence of heavy weather for the majority of one assessment period. The overall number of deficiency-free performances increased for the same time period. Also, individual performance found to be deficient during other assessment periods showed improvement in later assessments. In sum, the improved system for tracking technical performance trends permitted performance deficiencies to be addressed through quality training in a timely manner both for the individual and for the facility.

Kansas City Center's Performance Management Program. In late 2002, Kansas City ARTCC initiated a Performance Management Program (PMP). The PMP program was based on the belief that the best OE initiative is directed at the level of the individual rather than at groups. The program elements included a Quality Assurance Review (QAR), a direct observation module, and a TTD. The QAR is a process conducted for other types of system deficiencies unrelated to OEs. One element of a QAR is a review of the employee's performance, along with other factors, such as procedures or equipment, which may have contributed to a deficiency in the control of traffic. QAR activities may range from a discussion of the situation with the involved controllers to reviewing recorded radar and voice communications data.

All forms used for these processes are automated and linked to a reporting feature. For example, the QAR module and the direct observation module automatically feed the TTD program. This process resulted in very few TTDs being conducted without including individual, specific performance information in the review. This information is powerful when reviewed by the supervisor with the controller. For example, the controller and the supervisor can review a sample of voice tapes representing a controller's communications on position over a period of several weeks. They provide a means for the controller to review normal phraseology habits. It is an opportunity for the controller to determine whether good or poor habits have been developed. This assists the controller to enhance his/her communications skills.

After initiating the program in April of 2003, the center's OE/ODs declined for the next three years, resulting in a 2002 "commendable" rating from the national evaluation team. Table 1 (Truelove, Hatem, & VanDyne, 2005) shows the number of OEs by year of program implementation.

Computer-Based Instruction in Human Factors. Responding to the push to reduce OEs, personnel in the Great Lakes Region's Air Traffic QA office distributed a three-module program on human factors. FAA headquarters staff provided the program to interested facilities nationwide. The material covered topics such as attitude, cooperation, communication, organization, efficiency, perception, memory, and attention. Most of the material appeared to be based on generally accepted psychological and physiological theories.

Table 1. ZKC OEs by year of PMP implementation.

Program year	Date	# OEs
Prior year	1/1/01 – 12/31/01	29
First year	1/1/02 – 12/31/02	27
Second year	1/1/03 – 12/31/03	19
Third year	1/1/04 – 12/31/04	20
Fourth year	1/1/05 – 7/31/05	10

An individual knowledgeable in both human factors and ATC reviewed the material and expressed the opinion that controllers would find the lessons entertaining but that the material would have limited training value. Without supporting data we don't know whether the materials can be applied directly to controller performance. Take, for example, statements such as "controllers who recognize and maximize situational awareness skills automatically distance themselves from high-risk situations and errors." While this statement might be true, it is not clear whether this observation about automatic behaviors was based on any data and, if so, whether they were collected from operational controllers. Similarly, statements suggesting that controllers select, process and remember only those perceptions on which attention has been focused (i.e., in focal attention) ignores what is known about how people also process information that is not the focus of attention or information of which they are not fully aware. This emphasis on focal attention might lead controllers to discount other processes that can also lead to human error. Suggestions that controllers have a physiological structure that allows them to know the difference between important and unimportant information seem to be irrelevant or misleading. Examples given of important and unimportant information are of a fire versus a lawn mower. The authors suggest that somehow the physiological brain structure knows the difference between what is important and what is trivial information. Such broad statements risk giving controllers unwarranted confidence to rely on their physiological structure as a form of performance "backup" system. Finally, the statement that the complex tasks of air traffic control require faster processing speed to complete operations should also include a discussion of experience, skill, etc. and their effect on performance. Thus, there are a number of concerns associated with the development and use of this training module.

Sheridan's Analysis of OE Reduction Efforts. Sheridan, (1997) analyzed the effectiveness of OE reduction efforts conducted in the Great Lakes Region during fiscal year 1996 (FY96). At the beginning of FY96, several initiatives were initiated by regional headquarters' managers in an attempt to reduce OEs. These included assigning an OE quota to field managers, not to be exceeded within each air traffic manager's area of responsibility. Air traffic managers were held accountable through negative performance evaluation ratings. For his analysis, Sheridan used data from both OEs and operational deviations (which accounted for approximately ten percent of the total error rate). Results showed that intervention efforts had a mixed effect on OE rates.

- The en route OE rate exhibited a modest correlation with traffic volume ($r = .497$). Traffic explained only approximately one-quarter of the variance in the OE rate.
- The terminal OE rate also exhibited a modest correlation with traffic volume ($r = .460$). Traffic explained roughly 21% of the explained variance in the OE rate.

Error rates rose marginally in the en route environment while a modest improvement was realized in the terminal environment. Data revealed that en route OE rates rose from 8.50 per month to 9.83 per month. By contrast, tower OEs on average fell from 5.78 per month to 5.0 per month. One possibility for the differences lies in the changes in traffic volume experienced during the different reporting periods. However, analyses revealed that traffic volume explained a modest percentage of the explained variance in OE rates.

Runway Safety Initiatives

In October 2002, after an accident involving arriving and departing aircraft at a municipal airport, the FAA adopted NTSB recommendations (FAA, 2002b) and required air traffic control tower facility managers to include local procedures in their facility directives to assist the ground and local controllers in maintaining awareness of aircraft positions on the airport. Procedures were adjusted to address the needs of a specific facility or airport.

The Runway Safety Office identified several initiatives for controllers covering topics related to communications and teamwork. CBI Modules for ATC were developed by the Runway Safety Office on topics of awareness of conditions, procedures, rules, and tools. The Memory Enhancement Project convened a workgroup to review availability of off-the-shelf programs and to identify memory aids currently used at facilities. Originally, the results were intended to be distributed to other facilities for their consideration as potentially useful tools. However, distribution was not completed.

In 2001, a booklet entitled "Runway Safety: It's Everybody's Business" was distributed (Cardosi, 2001). Half of the material was directed at controllers to describe what they could do to improve surface safety. The other half of the material was directed at pilots and their role in surface safety. Topics included causes of OEs, memory strategies, how to improve pilot-controller communications, the importance of teamwork, and strategies to mitigate fatigue. Additional recommendations include the following. Only recommendations with an ATC focus are listed here.

Controller Communications. Three recommendations were made.

- Minimize controller-pilot voice communications, e.g., eliminate unnecessary elements of controller transmissions and explore expanded use of standard (classified) taxi routes.
- Develop operational protocols for ATC communications in airport operations, e.g., a requirement for pilots or ground personnel to use standard phraseology when communicating with ATC.
- Implement improved communication technology to reduce blocked or partially blocked transmissions.

AT Procedures. One recommendation was made.

- Improve procedures for taxiing aircraft into position, holding on the runway, and crossing intersecting runways.

Controller Training. Three recommendations were made.

- Promote training in communications and coordination, such as cross-operational training for pilots and controllers on the others' duties and concerns.
- Provide controllers with refresher training (e.g., phraseology, memory enhancement, scanning) for surface operations.
- Implement teamwork training to improve communications, cooperation, and operations planning between AT and airport users.

Regional Runway Safety Initiatives. Several regional air traffic and runway safety offices developed additional materials and programs to reduce OEs, including a number of initiatives implemented by the Regional Runway Safety Program Managers, such as pilot briefings, Runway Safety Action Team (RSAT) meetings with airport operators, tenants, and tower personnel, and initiatives with AOPA, such as issuance of publications on runway safety, videos, etc. All of these efforts were geared to minimize the possibility that pilot actions would result in incidents, including OEs.

A real-time, human-in-the-loop simulation study (called ACTIVE-1) was conducted at Anchorage Tower by the FAA Alaskan Region Runway Safety Office to determine whether a high fidelity tower simulator could be useful to enhance controller training (Racine & Sierra, 2004). In particular, the study investigated whether a high fidelity tower simulator would improve controller recognition and management of common factors leading to runway incursions (RI), and improve their skill in taking appropriate actions to mitigate unanticipated events. The study used a series of operationally challenging scenarios and a state-of-the-art tower simulator to determine if fully qualified and current tower controllers would benefit from simulator practice. Performance improvement from pretest to posttest was based on measures of efficiency and safety. Results showed significant improvements in detection of specific scripted errors as well as general trends of improvement in other system performance measures.