Federal Aviation Administration

DOT/FAA/AM-12/2
Office of Aerospace Medicine
Washington, DC 20591

Analysis of En Route Operational Errors: Probability of Resolution and Time-On-Position

Larry Bailey

Civil Aerospace Medical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

February 2012

Final Report

OK-12-0025-JAH

Technical Report Documentation Page

1. Report No. DOT/FAA/AM-12/ 2	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Analysis of En Route Operational Errors: Probability of Resolution and Time-On-Position		5. Report Date February 2012 6. Performing Organization Code
7. Author(s) Bailey L		8. Performing Organization Report No.
9. Performing Organization Name and Address FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125		10. Work Unit No. (TRAIS) 11. Contract or Grant No.
12. Sponsoring Agency name and Address Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave., S.W. Washington, DC 20591		13. Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplemental Notes

Work was accomplished under approved task AM-AT09 09 Safety Risk Assessment Analysis

16. Abstract

The Federal Aviation Administration's Air Traffic Control Organization Safety Management System (SMS) is designed to prevent the introduction of unacceptable safety risk into the National Airspace System. One of the most important safety metrics used in the Air Traffic Organization's SMS is the rate and severity of air traffic control operational errors (OEs). While OE rates tell us about the frequency of occurrence, the rates in and of themselves do not provide a direct assessment of safety risk. Two additional metrics are proposed for inclusion in the Air Traffic Organization's SMS. These include the probability of resolution (POR) index and the time-on-position probability (TOPP) index. Whereas the POR is a measure of OE containment (i.e., resolving a loss of separation before the situation worsens), the TOPP is a measure of the occupational risk of an OE occurring due to traffic exposure. In this report, each metric is mathematically developed and empirically evaluated using archival en route data.

In Study 1, the utility of the POR is evaluated based on 1293 OEs extracted from an en route OE research database for the period May 1, 2001 to May 31, 2003.

In Study 2, the utility of the TOPP is evaluated based on 1,397,206 time-on-position entries from six en route centers for the 2006 calendar year. The results of both studies are discussed within a SMS framework.

17. Key Words Air Traffic Control, Safety Management System		18. Distribution Statement Document is available to the public through the Defense Technical Information Center, Ft. Belvoir, VA 22060; and the National Technical Information Service, Springfield, VA 22161	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	22. Price

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

CONTENTS

Analysis of En Route Operational Errors: Probability of Resolution and Time-On-Position

On March 14 2005, the Federal Aviation Administration (FAA) Air Traffic Organization (ATO) began using its Safety Management System (SMS) to assess all changes to the National Airspace System (NAS). As reflected in FAA Order JO 1000.37, the ATO SMS process is designed to identify, assess, mitigate, and document the acceptance of acceptable risk associated with technological and procedural changes to the NAS (FAA, 2007). Effective use of the SMS prevents the introduction of unacceptable safety risk into the NAS. Of course, before future risks can be properly evaluated, it is first necessary to assess the current risks to safety. One component of the ATO's SMS is its safety assurance requirement, which, among other things, involves the monitoring and tracking of safety-related data.

Historically, the ATO has used the rate of air traffic control (ATC) operational errors (OEs) as one of its important safety metrics. FAA Order 7210-56C defines an OE as: "An occurrence attributable to an element of the air traffic system in which:

1. Less than the applicable separation minima results between two or more aircraft, or between an aircraft and terrain or obstacles (e.g., operations below minimum vectoring altitude (MVA); equipment / personnel on runways), as required by FAA Order 7110.65 or other national directive; or
2. An aircraft lands or departs on a runway closed to aircraft operations after receiving air traffic authorization; or
3. An aircraft lands or departs on a runway closed to aircraft operations, at an uncontrolled airport and it was determined that a NOTAM regarding the runway closure was not issued to the pilot as required (p. 5-1, FAA, 2009a)."

Although tracking OE rates over time is one way of assessing the affect of technological and procedural changes to the NAS, we argue that there are at least two other metrics that can enhance the understanding of safety risk: (a) OE containment (and its corresponding probability of resolution) and (b) the probability of an OE occurring based on how long controllers are on position. The remainder of this report describes the results of two studies that highlight the important contributions that both of these metrics make to the SMS process.

STUDY 1: OE CONTAINMENT

The ATO classifies OEs into one of four safety risk categories based on the percentage of the prescribed separation minima (called separation conformance) that exists between the two aircraft at the time of closest proximity. Four safety risk categories are used to describe the relative severity of an OE:

1. Proximity Events: An OE where 90% or greater separation is retained in either the horizontal or vertical plane and does not include any violation of wake turbulence separation minima. Although proximity events are technically OEs, they are not viewed as a threat to aviation safety.
2. Category C (low risk): A loss of airborne separation where the separation conformance is greater than or equal to 75%, but the horizontal and vertical separation retained is less than 90% of the required separation. In events with wake turbulence violations the lateral separation retained is greater than or equal to 85% but less than 100%.
3. Category B (moderate risk): A loss of airborne separation where the separation conformance is greater than or equal to 34% but less than 75%. In events with wake turbulence violations the lateral separation retained is greater than or equal to 70%, but less than 85%.
4. Category A (high risk): This is the most severe type of OE and involves a loss of airborne separation where the separation conformance is less than 34%. In events with wake turbulence violations, the lateral separation retained is less than 70%.

OE severity classification can be readily made using the charts provided in the appendices of FAA Order 7210.56C (FAA, 2009a). In our study, we used the Non-Wake Separation Conformance Categorization chart of Appendix 9 (shown as Figure 1) and two Conformance Categorization tables from Appendix 11 (shown as Tables 1 and 2).

Currently the ATO tracks the number of Categories A&B OEs as a measure of safety. The number of Category A&B OEs is divided by the number of aircraft operations expressed in millions. This rate is then used to establish and to monitor progress toward achieving safety goals.

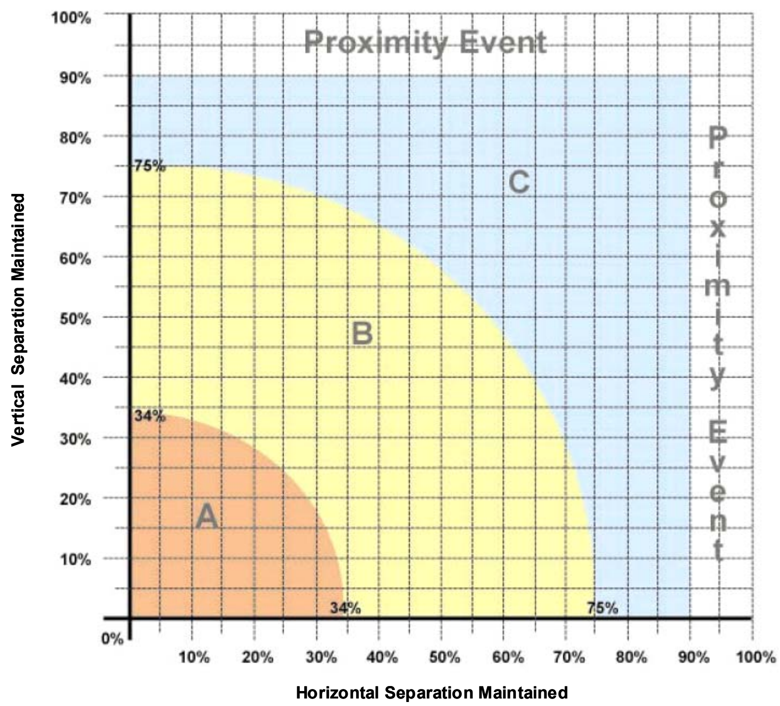

Figure 1. Non-Wake Separation Categorization (from Appendix 9, FAA Order 7210-56, FAA 2009b).

Table 1. OE Severity categorization with 5 nautical miles (nm) lateral separation and 1000-foot vertical separation minima, non-wake condition

	Vertical									
Lateral	0 feet	100 ft	200 ft	300 ft	400 ft	500 ft	600 ft	700 ft	800 ft	900 ft
4.99-4.50 NM	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
4.49-3.75 NM	C	C	C	C	C	C	C	C	C	PE
3.74-3.72 NM	B	C	C	C	C	C	C	C	C	PE
3.71-3.62 NM	B	B	C	C	C	C	C	C	C	PE
3.61-3.44 NM	B	B	B	C	C	C	C	C	C	PE
3.43-3.18 NM	B	B	B	B	C	C	C	C	C	PE
3.17-2.80 NM	B	B	B	B	B	C	C	C	C	PE
2.79-2.25 NM	B	B	B	B	B	B	C	C	C	PE
2.24-1.70 NM	B	B	B	B	B	B	B	C	C	PE
1.69-1.63 NM	A	B	B	B	B	B	B	C	C	PE
1.62-1.38 NM	A	A	B	B	B	B	B	C	C	PE
1.37-1.35 NM	A	A	A	B	B	B	B	C	C	PE
1.34-0.80 NM	A	A	A	B	B	B	B	B	C	PE
0.79-0.00 NM	A	A	A	A	B	B	B	B	C	PE

From Appendix 11, FAA Order 7210-56, FAA 2009b.

Table 2. OE Severity categorization with 5 nautical mile (nm) lateral separation and 2000-foot vertical separation minima, non-wake condition

	Vertical									
Lateral	0 feet	100 ft	200 ft	300 ft	400 ft	500 ft	600 ft	700 ft	800 ft	900 ft
4.99- 4.50 NM	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
4.49- 3.75 NM	C	C	C	C	C	C	C	C	C	C
3.74- 3.72 NM	B	B	C	C	C	C	C	C	C	C
3.71- 3.68 NM	B	B	B	C	C	C	C	C	C	C
3.67- 3.62 NM	B	B	B	B	C	C	C	C	C	C
3.61- 3.54 NM	B	B	B	B	B	C	C	C	C	C
3.53- 3.44 NM	B	B	B	B	B	B	C	C	C	C
3.43- 3.32 NM	B	B	B	B	B	B	B	C	C	C
3.31- 3.18 NM	B	B	B	B	B	B	B	B	C	C
3.17- 3.00 NM	B	B	B	B	B	B	B	B	B	C
2.99- 1.70 NM	B	B	B	B	B	B	B	B	B	B
1.69 NM	A	B	B	B	B	B	B	B	B	B
1.68- 1.63 NM	A	A	B	B	B	B	B	B	B	B
1.62- 1.53 NM	A	A	A	B	B	B	B	B	B	B
1.52- 1.38 NM	A	A	A	A	B	B	B	B	B	B
1.37- 1.16 NM	A	A	A	A	A	B	B	B	B	B
1.15- 0.80 NM	A	A	A	A	A	A	B	B	B	B
0.79- 0.00 NM	A	A	A	A	A	A	A	B	B	B

	Vertical									
Lateral	1000 feet	1100 Feet	1200 feet	1300 feet	1400 feet	1500 feet	1600 feet	1700 feet	1800 feet	1900 feet
4.99- 4.50 NM	PE	PE	PE	PE	PE	PE	PE	PE	PE	PE
4.49- 2.80 NM	C	C	C	C	C	C	C	C	PE	PE
2.79- 2.55 NM	B	C	C	C	C	C	C	C	PE	PE
2.54- 2.25 NM	B	B	C	C	C	C	C	C	PE	PE
2.24- 1.88 NM	B	B	B	C	C	C	C	C	PE	PE
1.87- 1.35 NM	B	B	B	B	C	C	C	C	PE	PE
1.34- 0.00 NM	B	B	B	B	B	C	C	C	PE	PE

From Appendix 11, FAA Order 7210-56, FAA 2009b.

As of this writing, the FY2009 OE goal is to not exceed 2.10 Category A&B OEs/million aircraft operations (FAA, 2009b).

The emphasis on tracking category A&B OEs as indicators of NAS safety is consistent with the philosophy of tracking errors of consequence, rather than operator errors in general; a common theme that emerged at the Fifth Australian Aviation Psychology Symposium, Manly Beach, Sydney 2000. Representing this line of thinking, Maurino (2003) stated that:

"There is nothing inherently wrong or troublesome with error itself, as a manifestation of human behavior. The trouble with error in aviation lies with the negative consequences it may generate in operational contexts. This is a fundamental point: in aviation an error is inconsequential if the negative consequences of it are trapped before it produces damage. In operational contexts, errors that are caught in time do not produce damaging consequences and therefore, for practical purposes, do not exist. Countermeasures to error, including training interventions, should not be restricted to attempts to avoid errors, but rather to make them visible and trap them before they produce damaging consequences (pp. 11-12)."

Echoing Maurino's remarks, Toller (2003) challenged operators to think of error management as consisting of two components: (a) error prevention, which involves understanding why mistakes are made and taking steps to prevent them, and (b) error containment, which involves recognizing that errors are inevitable and taking steps to avoid the possibility of single-point failures.

Progress toward error prevention goals can be tracked through existing safety metrics; however, progress toward error containment goals requires additional metrics, such as the Probability of Resolution (POR) index that we propose. The POR is a measure of the efficiency with which the NAS is able to resolve separation losses (i.e., contain the errors through the actions of controllers and pilots) before they degrade into greater risks to safety.

We conceive of the four OE safety risk categories as representing zones through which point-in-time separation losses progress until they reach a minimum. Thus, each of the OE safety risk categories represents a potential containment field. As shown in Figure 2, all losses of separation begin with a point-in-time separation between two aircraft that is less that 100% of separation conformance. This point-in-time separation degrades until a situation is reached when the separation between two aircraft is at a minimum and no further degradation occurs. It is at the minimum that the amount of separation conformance is determined, and the event is classified into one of the four OE safety risk categories.

Using Figure 2 as a conceptual framework, we define the POR as the number of point-in-time losses of separation resolved (i.e., contained) within a given zone of separation conformance divided by all the point-in time losses of separation that were eligible to be resolved (that is, the point-in-time losses of separation that passed through a given zone of separation conformance) within that same zone of separation conformance. Using the OE classification system amounts to calculating the number of OEs within a given safety risk category

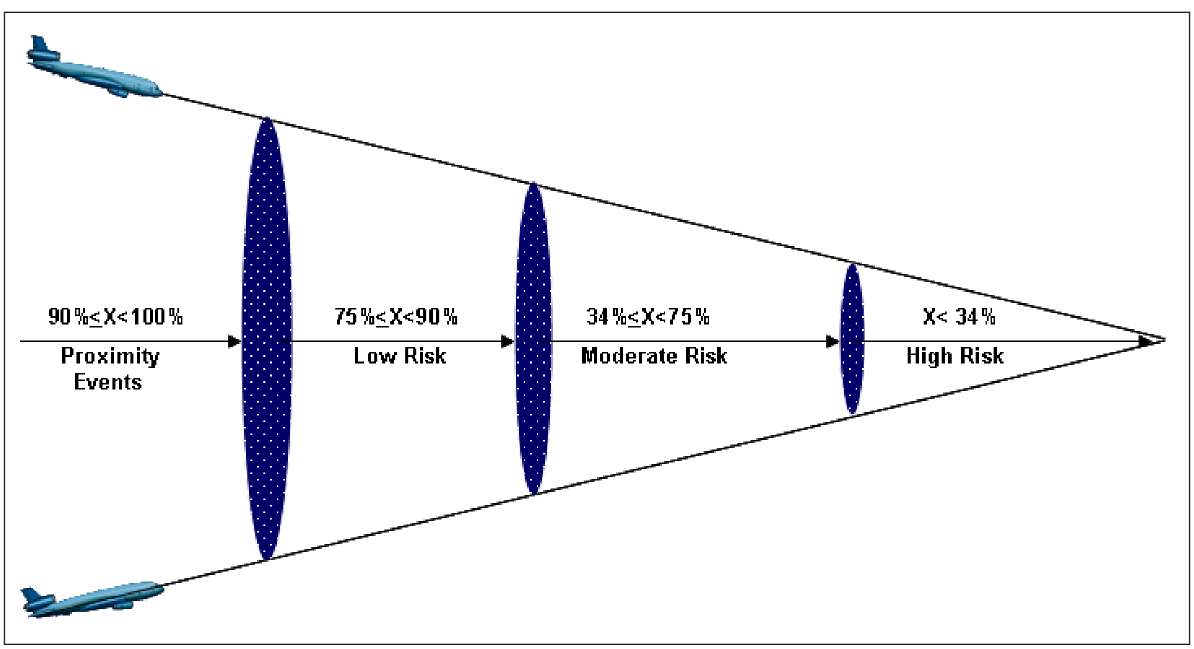

Figure 2. Operational error severity defined by the percentage of separation conformance remaining.

divided by all the OEs that were equal to or more severe than the OE category in question. This is shown by the following equation:

$$POR_m = \frac{OE_m}{\sum_{i=m}^{4} OE_i} \qquad (Eq\ 1)$$

where:

POR= the Probability of Resolution for a given OE safety risk category m

OE = the number of OEs for a given OE safety risk category m

m = a given OE safety risk category in numerical order 1-4 corresponding, respectively, to Proximity Events, Category C OEs, Category B OEs, Category A OEs.

Notice that, as we calculate the POR for higher OE categories, we eliminate from the denominator the number of OEs from the lower risk categories. This is called computing probabilities without replacement. This means that previous events are removed (not replaced) on subsequent sampling. For example, the POR formula for category C OEs is as follows:

$$POR_{Cat\ C} = \frac{OE_{CatC}}{OE_{CatC} + OE_{CatB} + OE_{CatA}} \qquad (Eq.2)$$

All point-in-time losses of separation that were resolved within the region of proximity events were contained and, thus, were not eligible to be classified as category C or higher OE severity. Because of their ineligibility, those losses of separation were not included in the denominator while calculating the POR for the region of separation conformance defined by category C OEs.

In this study, we conceive of the OE severity categories as representing a series of OE containment fields complete with the various technologies and human support that are used to detect and resolve losses of separation. We calculated the POR for each OE severity category as a measure of the efficiency with which the point-in-time losses of separation are resolved before degrading to separation losses associated with higher safety risks. We then demonstrate how the POR provides additional information that should be included as a safety metric for the ATO's SMS.

METHOD

Data

A total of 1293 OEs were extracted from an en route OE research data base for the period May 1, 2001 to May 31, 2003. The extraction included the following variables: OE report number, the lateral and vertical distances recorded at the time of closest proximity, and the required lateral and vertical separation standards. Because an OE can be attributed to more than one controller, we extracted data for only the controller who was primarily responsible for the OE. This was to avoid having multiple cases associated with the same OE. We accomplished this by using a variable which was flagged to indicate the record of the primary controller. Thus, no specific individual was matched with a given OE.

The dataset chosen for this study was the same one used on a previous project, which evaluated the validity of the operational error severity index used at that time and reported in Bailey, Schroeder, & Pounds (2005). Because the dataset had previously been used, we understood its properties particularly with regard to missing data fields. OE reporting underwent a number of changes since 2002, each of which produced a different set of reporting procedures. This made it difficult to determine whether data were missing because of data entry errors or changes in procedures. Since our primary goal in this study was to demonstrate the utility of employing a measure of OE containment for SMS purposes, we were not as concerned about using current OE data as we were with having a dataset that we understood.

RESULTS

Table 3 shows the number of OEs and corresponding PORs associated with each of the OE severity categories.

Table 3. Probability of Resolution

OE Severity	OE_m	$\sum_{i=m}^{CatA} OEi$	POR_m
Proximity Event	333	1293	0.26
Category C	719	960	0.75
Category B	226	241	0.94
Category A	15	15	1.00

m = a given OE severity category

These data are presented graphically in Figures 3 and 4, respectively. When considering the en route centers as an aggregate, we see that the NAS was 26% (333/1293) effective at resolving losses of separation within the proximity event range, 75% (719/960) effective at the low risk range (Category C), 94% (226/241) effective at the moderate risk range (Category B), and 100% (15/15) effective at the high risk range (Category A). Notice that, in Figure 3, the number of OEs increased going from the Proximity Events to the Low-Risk Category C events, and then the number dropped off sharply as we progressed through Categories B and A. In contrast to Figure 3, the distribution of PORs in Figure 4 shows a continuous rise in efficiency as we progressed through the OE severity categories and ended with 100% resolution by the time we reached the Category A region.

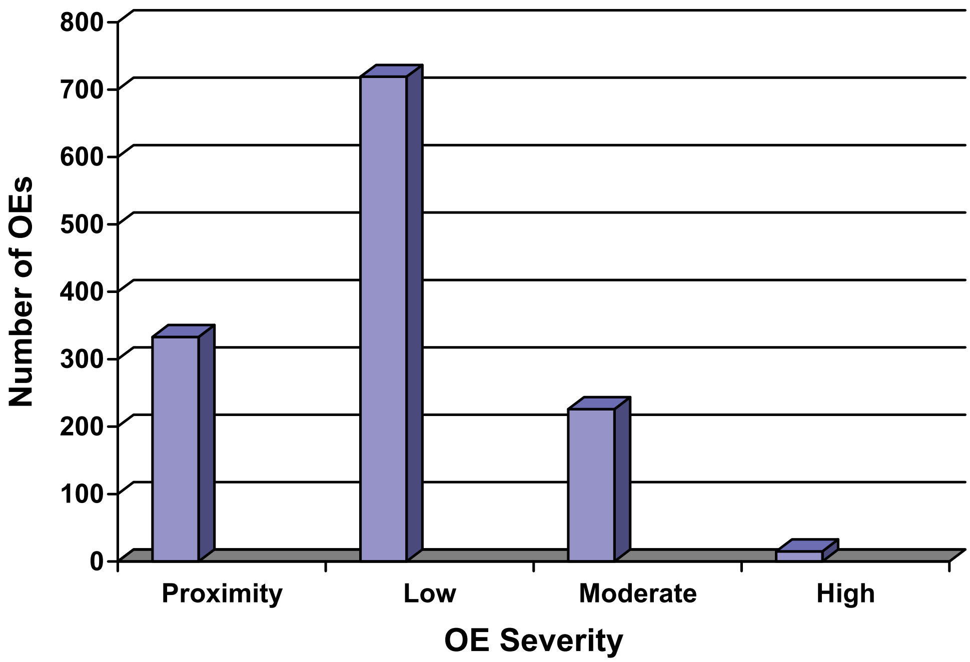

Figure 3. Distribution of OEs by OE Severity.

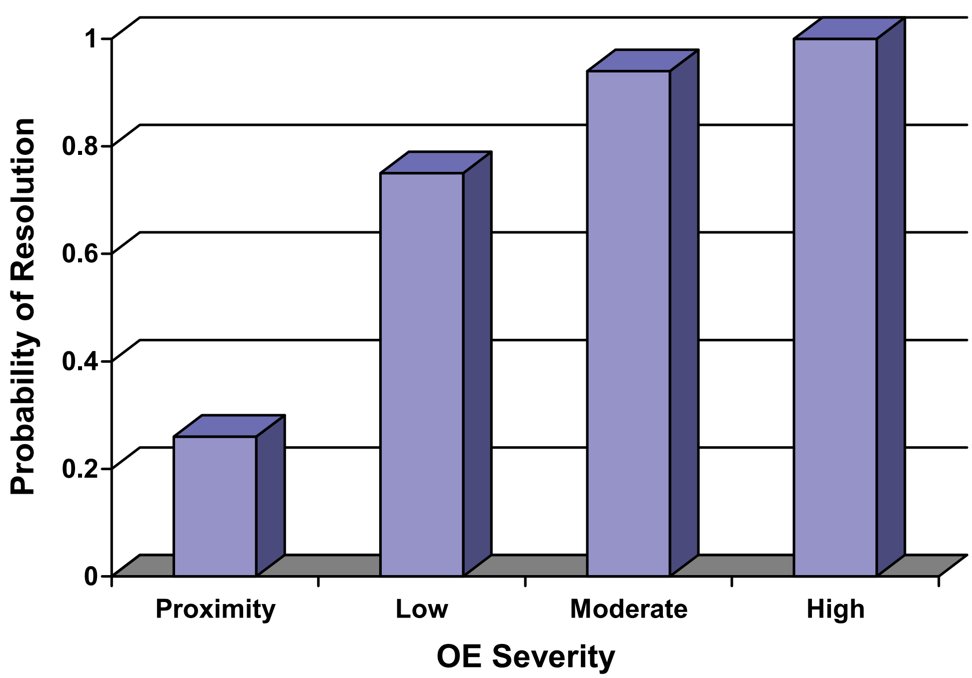

Figure 4. Probability of Resolution by OE Severity Category.

Table 4. Number of OEs associated with a given category of OE severity

OE Severity	Separation Conformance	Interval	Number OEs
Proximity Event	90%≤X<100%	11%	333
Category C	75%≤X<90%	15%	719
Category B	34%≤X<75%	40%	226
Category A	X<34%	34%	15

Table 5. Number of OEs associated with each 10% loss of separation conformance

Separation Interval	Separation Conformance	Interval	Number OEs	POR
1	90%≤X<100%	10%	333	0.26
2	80%≤X<90%	10%	540	0.56
3	70%≤X<80%	10%	252	0.60
4	60%≤X<70%	10%	84	0.50
5	50%≤X<60%	10%	41	0.49
6	40%≤X<50%	10%	19	0.44
7	30%≤X<40%	10%	18	0.75
8	20%≤X<30%	10%	6	1.00
9	10%≤X<20%	10%	0	NA
10	0%≤X<10%	10%	0	NA

Because the percentage of required airspace covered by the region of a given OE category did not represent equal intervals (see Table 4), we wondered if the trend of increasing POR efficiency would be replicated using equal separation conformance intervals. That is, we were curious about whether certain regions of inefficiency might become evident if equal separation conformance intervals were examined. Thus, we eliminated the OE severity categories (Figure 1) and instead divided the region of separation conformance into 10 equal percentage intervals. We then computed the number of OEs associated with each interval and calculated the corresponding PORs.

The number of OEs and corresponding POR for each separation conformance interval is presented in Table 5 and graphically represented in Figures 5 and 6, respectively.

Figure 5 shows the distribution of OEs across the regions of separation conformance. Notice that the pattern is similar to the one presented in Figure 3. In Figure 5, there was a sharp increase in the number of OEs going from the first to the second separation conformance interval, which corresponds to the transition between Proximity Events and Low Severity OEs shown in Figure 3. Following this increase in the number of OEs, in both figures there is a continuous decline throughout the remainder of the separation conformance regions.

In contrast to the similarities in the OE distributions, the corresponding POR distributions were different. Whereas in Figure 4 we saw a continuous rise in efficiency of OE containment as we progressed through the OE severity categories, in Figure 6, we see a drop in efficiency of OE containment occurring between the third and fourth interval. A zone of relatively lower OE containment efficiency (intervals 4-6) continues until reversing at the transition between the sixth and seventh interval. This zone is primarily in the Moderate OE severity (Category B) region depicted in Figure 4.

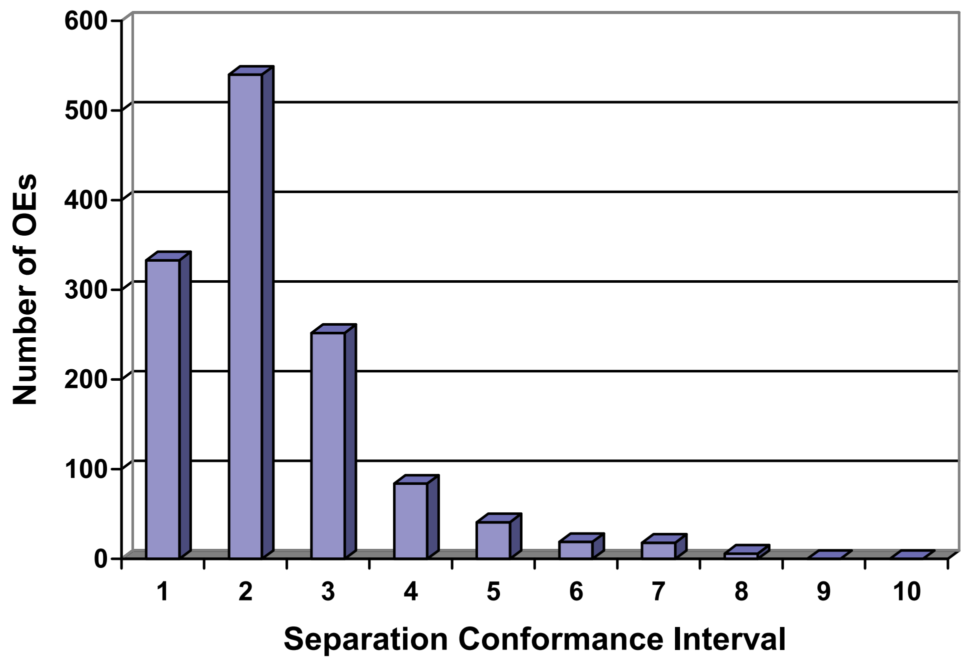

Figure 5. Number of OEs for Each Separation Conformance Interval.

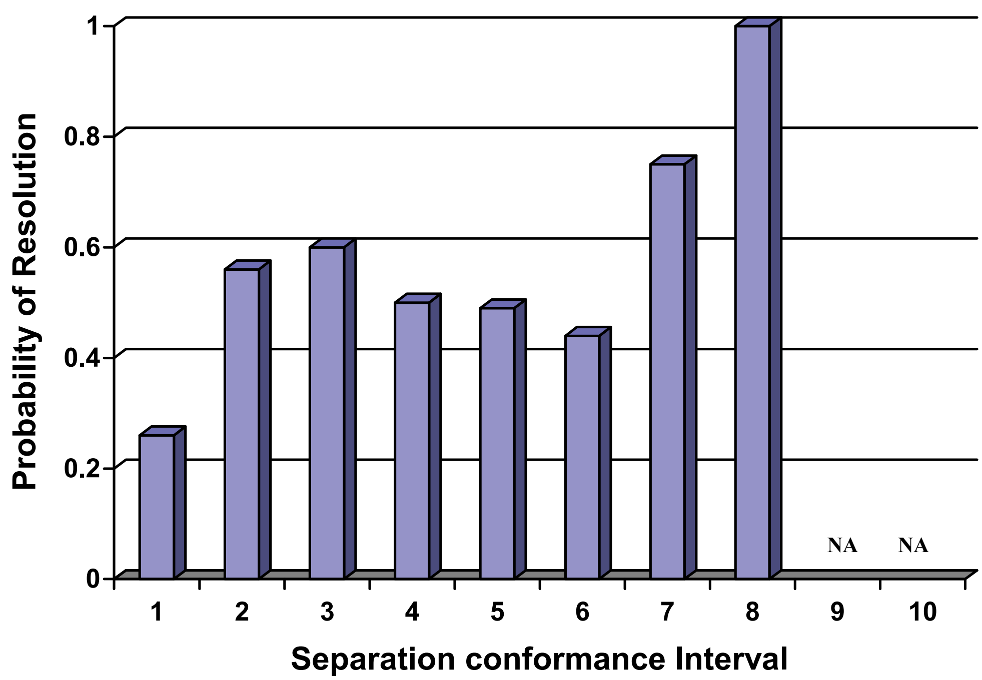

Figure 6. Probability of Resolution for each Separation Conformance Interval.

Table 6. Operational Error Management

OE Severity	Error Prevention Number	Error Prevention Percent of Total	Error Containment Number	Error Containment POR*
Proximity	333	26%	1293	0.26
Low	719	56%	960	0.75
Moderate	226	17%	241	0.94
High	15	1%	15	1.00

*POR = Probability of Resolution

With the previous analyses offering a cautionary note, we returned to our original purpose and reformatted the information in Table 3 into a two-component table of error management, as shown in Table 6. Under the heading of Error Prevention, we show the number and percentage of OEs associated with a given category of OE severity. For Error Containment, we show the number of losses of separation that were eligible to be resolved within a given OE severity category and the corresponding POR.

DISCUSSION

When the POR is included as a safety metric, all the necessary ingredients are in place for a two-component Operational Error Management System. Looking just at the error prevention indicators, we see the number of separation losses that were resolved within each of the four OE severity categories. This information tells us how well the ATO is at preventing or reducing the number and severity of OEs. This is the kind of information that one needs when establishing safety goals. However, there is a risk associated with using just these kinds of numbers. The prevention numbers in and of themselves do not help us understand how well controllers' actions and the pilots' responses prevented (i.e., contained) an initial loss of separation from getting worse. This is what the POR captures; thus, we recommend that it be included as an additional metric for the ATO's Safety Management System. However, from a methodological perspective, there is an unresolved issue concerning the separation conformance intervals that needs to be addressed before the POR is used.

In the results section, we explained how the lack of equal separation conformance intervals masked a zone of relatively low OE containment within the Moderate OE severity region. In fact, within this region the efficiency of OE containment continued to decline before taking a dramatic increase at the last time interval (interval 7). At this time, one can only speculate as to the cause of this phenomenon. Perhaps OEs within this region were surprises. That is, the controller may have been unaware that an OE was occurring until the separation loss crossed the 75% separation conformance threshold. By the time the OE was discovered, the controller did not have sufficient time to restore separation before incurring a further loss.

Regardless of the reason for the above phenomenon, it is important for an SMS to collect data at the finest level of detail necessary to make informed decisions. While there may be valid reasons for defining the official categories of OE severity as they are, the advantages of doing so must be weighed against the possible obstruction of more detailed information. Methodologically speaking, equal interval measurements are preferred over categorical assignments and, thus, it may be advantageous for the ATO to adopt equal separation conformance intervals both for metrics of OE prevention and containment.

Another issue that was raised in our study concerns the region of airspace defined by Proximity Events. This region had the lowest efficiency rating for OE containment even when equal OE intervals were used. Some may argue that with sufficient technology, losses of separation should be predicted well in advance of their occurrence and, thus, should be readily contained within the Proximity Event region. One of the current advance warning systems is the conflict probe that is part of the User Request Evaluation Tool (URET), installed at en route centers (Brudnicki & MacFarland, 1997). URET's conflict probe software attempts to model the future state of a sector by using the current flight plan of aircraft and projecting their trajectories 10-20 minutes into the future. Given the dynamic nature of ATC, it is not surprising to find that URET's conflict probe produces a number of false alarms, making it problematic as an advance warning system. Thus, in practice, URET is more useful as strategic predictor of potential aircraft conflicts rather than an actual warning of an impending conflict. The FAA is currently developing an en route automation modernization (ERAM) system with an improved conflict detection system (Allendoerfer, Willems, Zingale, & Pai, 2006). The improved system will be basically like URET, only better integrated into the operational software, thus more sensitive to the dynamic changes of ATC.

Despite the desire to provide conflict warnings to alert controllers of potential losses of separation, it is ultimately the responsibility of each controller to keep aircraft properly separated according to the prescribed separation minima. Among other things, this requires that controllers use their professional judgment to maintain a safe and expeditious flow of traffic (FAA, 2009a). It is this professional judgment that comes into play whenever a controller detects that he or she has allowed an OE to occur. Depending on the circumstances, once a controller has discovered that an OE has occurred, he or she should use professional judgment to restore aircraft separation. Consequently, it is possible that a controller may choose a set of conflict resolution maneuvers (via speed, altitude, and heading adjustments) that allow the separation minima to be further compromised temporarily to prevent a disruption in the existing traffic flow or prevent involved aircraft from having to execute maneuvers that would alarm or injure the passengers. Of course, the greater the separation losses at the time of OE detection, the fewer degrees of freedom are available for controllers to execute actions based on their professional judgments. Nevertheless, it is likely that losses of separation involving 90% or more of separation conformance will remain a region in which controllers may choose to allow greater losses of separation to occur in a controlled environment to minimize the need for pilots to make radical changes in their flight paths while aircraft separation is being restored.

As a final thought, it should be noted the metrics used for error prevention and error containment are system measures and, thus, are appropriate for use in monitoring the safety of the NAS. However, the measures in and of themselves provide little insight about the human factors associated with error detection and error resolution. At this level of analysis, human error taxonomies are needed for classifying both the human factors associated with the causes of OEs and their resolution. A number of classification systems are suitable for analyzing OE human factors causes. These include the Human Factors Analysis and Classification System, HFACS (Shappell & Weigmann. 2000; Scarborough, Bailey, & Pounds, 2005), JANUS (Pounds, & Isaac: (2003), and the Normal Operations Safety Survey, NOSS (Henry et al., 2008). None of the taxonomies, however, identify the types of judgment and decision-making strategies that are employed by controllers when resolving OEs. Thus, it remains for future research to determine whether existing taxonomies can be adapted to capture error resolution strategies or whether a completely different set of ATC judgment and decision-making measurements should be developed. In the study that follows, we return to the concept of error prevention by examining the impact that time on position has on the probability of an OE occurring. Time on position refers to the amount of time a controller was actively controlling aircraft before experiencing an OE.

STUDY 2: TIME ON POSITION

For an SMS to be effective, it must be able to identify anomalies or departures from normal operations. Although OEs are clearly departures from normal operations, there often exists insufficient information about what is "normal." Instead, it is assumed that for OEs to occur, the controller(s) involved must have done something different (i.e., non-normal); otherwise, OEs would be more frequent than they are. Although this line of reasoning has merit, it also creates a trap for error management. The trap is associated with jumping to a solution before properly understanding the problem.

Consider the ubiquitous finding that a higher percentage of OEs occur early on position and then taper off as the time on position (TOP) increases. This trend has been consistently observed across the tower, Terminal Radar Approach Control (TRACON), and en route options and times of day (Schroeder, Bailey, Pounds, & Manning, 2006). The trend is counterintuitive, given what is known about time on task and mental fatigue, in which lapses of attention become more likely as time-on-task increases (Trejo et al., 2007). From the time on task perspective, one would expect that the longer a controller is on position, the greater the chances that mental lapses in attention would occur. However, since a greater number of OEs occur earlier on position, as opposed to later, the assumption is made that controllers coming on position must not be fully prepared to manage the traffic situation due, in part, to a faulty position relief briefing. Although there is no doubt that managing the transfer of position process is safety-critical, it has been difficult to empirically link OEs that occur early on position with the transfer of position process.

In their study of en route OEs that occur early on position, Bailey, Pounds, & Scarborough (2008) found that the position relief briefing process was seldom reported as a contributing factor for OEs that occurred during the first 10 minutes following a position transfer. Although Bailey and his colleagues reported problems associated with the quality of data contained in the FAA's OE database, they also raised the possibility that the early on position OE may be the result of an exposure effect. They conjectured that a greater number of controllers in the NAS were on position for at least a 10-minute duration compared to any other time interval. That is, there were more opportunities (i.e., greater exposure) for OEs to occur earlier on position as opposed to later. However, at the time of their report, they, like other researchers (e.g. Lowry, MacWilliams, Still, & Walker, 2005), had been unable to obtain sufficient normal operations data to test the hypothesis of an exposure effect. Specifically, due to the labor-management agreements in place, TOP data describing operations during times when OEs were not occurring could not be released, even for research purposes.

Recently, we were able to obtain a limited amount of data describing the length of time controllers were on position when OEs were not occurring. We were able to match these data with the length of TOP at the onset of an OE. Together, the two datasets allowed us to calculate the probability that an OE would occur, based on the length of time a controller was on position, henceforth referred to as Time on Position Probability (TOPP). We then used the TOPP to determine whether an exposure effect was influencing the TOP distribution of OEs.

METHOD

Sample

TOP data were available only for calendar year 2006. Because the total number of records exceeded the capacity of some of the software used for our analyses, we restricted the sample to include only data from the six en route facilities having the highest number of OEs in 2006 (hereafter called the "Big 6"). This decision was made to ensure that we had an adequate number of OEs to include in the numerator of our probability calculations, while at the same time not exceeding the limits of our software. The Big 6 facilities were the Chicago, Washington, Indianapolis, New York, Cleveland, and Atlanta air route traffic control centers (ARTCCs). Because the Big 6 also had the highest number of aircraft operations, their individual OE rates were sometimes lower than facilities not included in this study (FAA, 2006). Thus, the centers included in the Big 6 should not be misconstrued as reflecting "error prone" centers.

Data Extraction

We extracted the amount of time the radar controller was on position when each OE occurred. We focused our attention on the radar controller position because the controller in this position is primarily responsible for the separation of aircraft. For TOP data when OEs did not occur, we extracted the time when the controller signed-on to position and the time when the controller signed-off. The difference between the two times is the number of minutes a controller was on position.

We extracted 1,397,206 TOP records and 290 OE records. It should be noted that no attempt was made to extract OE severity information. This decision was made for two reasons. First, the formula used to calculate OE severity in 2006 was different from that used in subsequent years. Thus, we wished to avoid any confusion resulting from this change. Second, previous work failed to identify any statistically meaningful differences in OE severity based on the amount of time a controller was on position (Bailey et al., 2008). Thus, there was no empirical evidence that OE severity was related to the amount of time a controller was on position.

Calculations

TOPPs were calculated by dividing the number of OEs that occurred during a particular 10-minute time interval by the total number of controllers who were signed-on (i.e., exposed to the possibility of having an OE) during that time interval. Ten-minute intervals were chosen so that direct comparisons could be made to previous research conducted by Bailey, Pounds, and Scarborough, 2008.

$$TOPP_m = \frac{OE_m}{\sum_{i=m}^{13} TOP_i} \qquad (Eq\ 3)$$

where:

$TOPP_m$ = The probability an OE would occur within a given TOP interval n

OE_m = the number of OEs for a given TOP interval n

TOP_i = the number of controllers within a given TOP interval n

m = a given 10 minute TOP interval (i.e. "signed-on" time) in the sequence {1,2,3,4,5,6,7,8,9,10,11,12,13} corresponding to the following time intervals {0-10, 11-20, 21-30, 31-40, 41-50, 51-60, 61-70, 71-80, 81-90, 91-100, 101-110, 111-120, 121 and above}.

Notice that the denominator in Equation 3 decreased in size as we progressed through the OE time intervals. This is because the controllers who were eligible to commit the OEs within a given time interval were still signed-on at that time. Controllers who signed-off before a given time interval were not working traffic and, thus, were not eligible to commit an OE.

Table 7. Number of Controllers who signed off within a given time on position interval

Time Interval (min.)	Interval Range (min.)	Number of OEs	Number of Controllers
10	0-10	52	133,261
20	10.1-20	43	105,675
30	20.1-30	50	123,056
40	30.1-40	36	160,631
50	40.1 50	25	193,271
60	50.1-60	24	170,684
70	60.1-70	26	138,113
80	70.1-80	15	115,063
90	80.1-90	6	96,739
100	90.1-100	4	60,521
110	100.1-110	3	33,988
120	110.1-120	4	19,332
120.1+	120.1+	2	46,872
Total		290	1,397,206

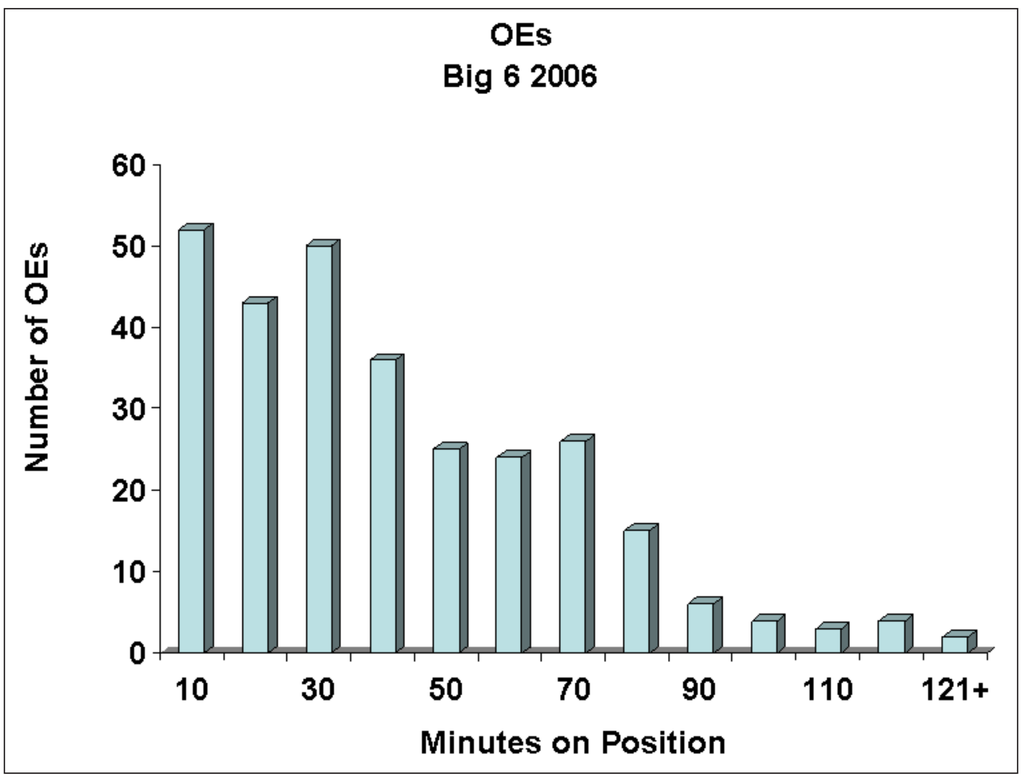

Figure 7. Annual number of OEs distributed by the amount of time on position that had lapsed before the OE occurred.

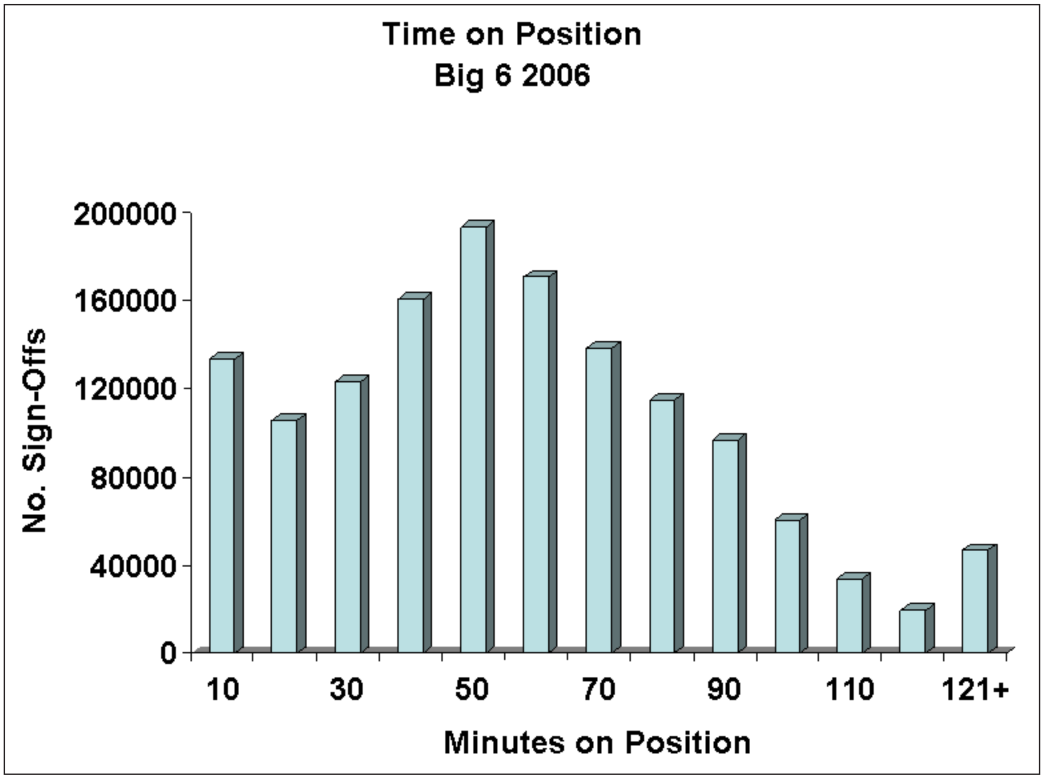

Figure 8. Annual number of sign-offs distributed by the amount of time on position. Sign-off refers to the amount of time that lapsed since signing on to position.

RESULTS

The results of the data extraction are shown in Table 7 in which the time-on-position and OE records were grouped into 13 ten-minute categories. The TOP distribution of OEs is presented in Figure 7, and the distribution of the amount of time controllers were on position is presented in Figure 8. Notice that the mode for the OE distribution in Figure 7 occurs during the first time interval; the mode for the TOP distribution of Figure 8 occurs during the fifth time interval. When the two figures are compared, it appears that something other than an exposure effect is causing the OE peak observed in Figure 7. However, when the TOPP is calculated, this proves not to be the case.

As shown in Table 8, the number of controllers eligible to commit an OE is the total number who were still signed-on to position (the column labeled as) within a given time interval and not the number of controllers who had signed-off . When the number of sign-ons is plotted against time (see Figure 9), we see that the mode and shape of the distribution more closely matches mode and shape of the OE distribution shown in Figure 7. This suggests that some sort of "exposure effect" may be operating to at least partly account for the distribution of OEs across time on position.

Table 8 further shows the TOPPs associated with each of the 13 TOP intervals. When considering the Big 6 facilities as an aggregate, the TOPPs ranged from a low of 0.002% (for the ninth and tenth intervals) to a high of 0.006% for the twelfth interval for an overall average TOPP of 0.004%, which is equivalent to four OEs out of every 100,000 sign-ons. At the level of the individual, this means that, on average, a controller has a four in 100,000 chance of having an OE each time he or she signs on to position. At the level of the Big 6, this means that for every 100,000 position changes, four OEs will likely occur. When plotted across time (see Figure 10), the TOPP distribution is bimodal with peaks at the seventh and twelfth 10-minute intervals. However, care must be taken in interpreting the results due to the small number of OEs that occurred in the later intervals. Due to the small number of OEs (i.e., OEs become more and more rare), the later probabilities are likely not to be as robust as those derived from the early, and mid-range time intervals.

Table 8. Time-on-position probabilities associated with 13 time intervals

m	Time Interval	OE_m	TOP_m	$\sum_{i=m}^{13} TOP_i$	$TOPP_m$
1	10	52	133261	1397206	0.004%
2	20	43	105675	1263945	0.003%
3	30	50	123056	1158270	0.004%
4	40	36	160631	1035214	0.003%
5	50	25	193271	874583	0.003%
6	60	24	170684	681312	0.004%
7	70	26	138113	510628	0.005%
8	80	15	115063	372515	0.004%
9	90	6	96739	257452	0.002%
10	100	4	60521	160713	0.002%
11	110	3	33988	100192	0.003%
12	120	4	19332	66204	0.006%
13	120.1+	2	46872	46872	0.004%

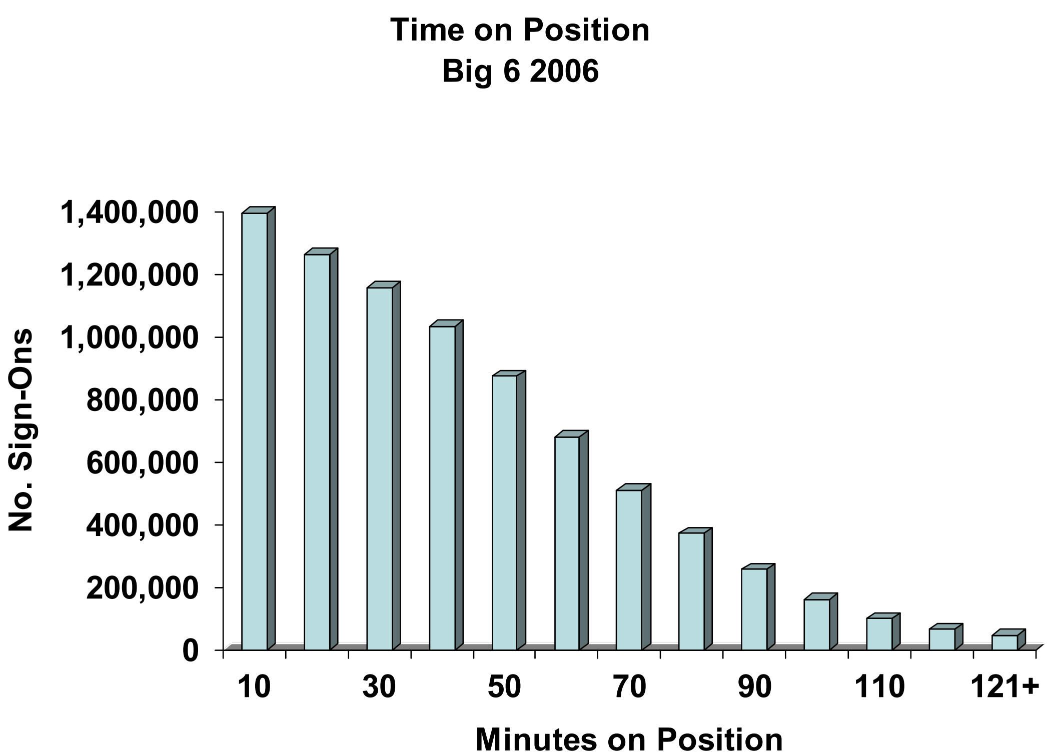

Figure 9. Annual number of sign-ons distributed by the amount of time on position. Sign-on refers to the number of controllers who were still signed on to their position after a given amount of time had lapsed.

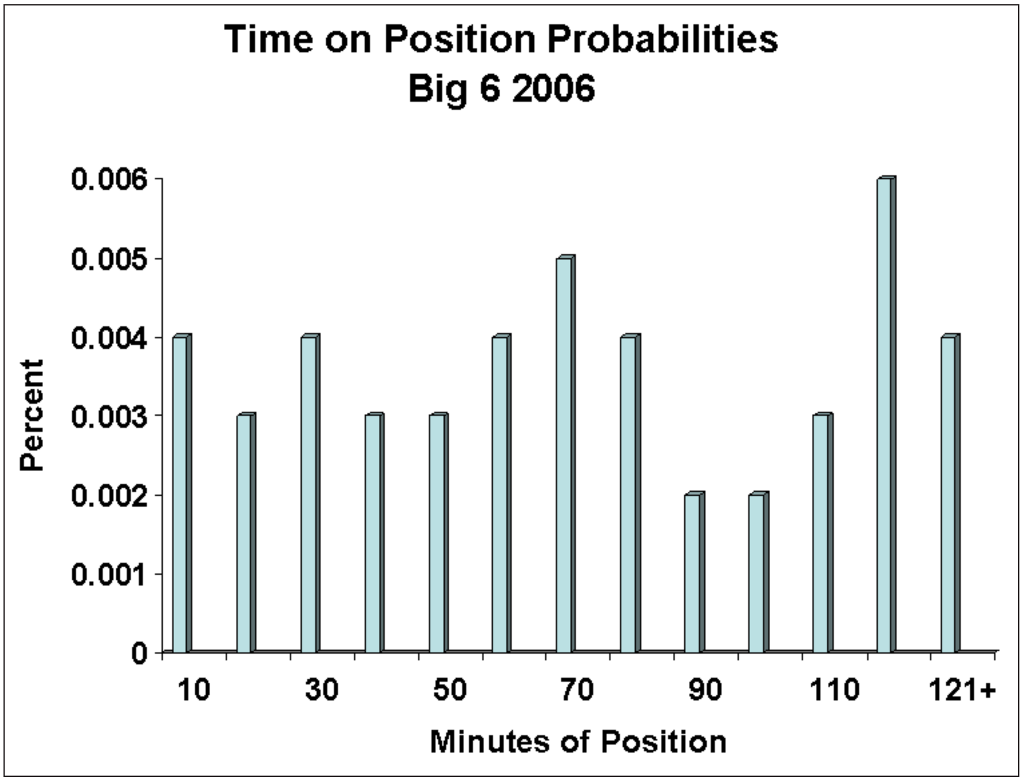

Figure 10. Time on position probabilities (TOPP) calculated for each 10-minute time on position interval.

DISCUSSION

The TOPP results suggest a different interpretation from that which is commonly associated with the analyses of OE by TOP. The OE data suggest that the NAS is most vulnerable to OEs occurring early on position and that the vulnerability decreases with time. In contrast, the TOPP data suggest that a period of vulnerability may exist early on position, but that the vulnerability is greatest when a controller has worked longer on position. The latter interpretation is more consistent with the literature associated with time-on-task fatigue, in which the operator experiences greater mental fatigue the longer the time spent on task.

While it appears that some sort of exposure effect is responsible for the greater number of OEs occurring early on position, this by itself is not sufficient to explain the OE distribution. There is still the observed drop in the TOPP between the first and second 10-minute interval. One might argue that the difference between the two (0.00001) is based on something related to the transfer of position process. Using this line of reasoning, one out of every 100,000 position changes would produce an OE that was related to a faulty transfer of position. This would translate to 14 OEs during the first 10 minutes, as compared to the 52 OEs reported in Table 7. Another way of saying this would be 27% of the OEs occurring during the first 10 minutes may be associated with the position relief process. Of course, if one were to use these numbers, we would have to have an explanation, which we do not have, for a similar increase in OEs between the second and third 10-minute interval. Thus, there remains some ambiguity as to the meaning attached to the TOPP distribution.

Despite the above problem, it is interesting to speculate about the meaning of the TOPP anomaly observed within the 60 to 80-minute intervals. On average, an en route controller spends 55 minutes on position. Might it be possible that the anomaly is an indication of mental fatigue associated with time on task? If so, then how many OEs might be attributed to time-on-task fatigue? If we use a TOPP base rate of 0.000003, then anything above this might be attributed to something unique to that time interval. When this difference is multiplied by the number of people on position within that interval, the resulting number is the number of anomalous OEs. Using this process for the 60- to 80-minute intervals, 21 out of the reported 65 OEs (35%) appear to be associated with something unique to that time interval. Although we started with the assumption that time-on-task fatigue might be driving the anomaly, it is important to note that the available data are insufficient and that drawing any conclusions from these data needs to be substantiated through other lines of inquiry.

CONCLUSIONS

The probabilities associated with OE containment and TOP are two important measures to be considered for inclusion in the Air Traffic Organization's Safety Management System. The probability of OE containment (i.e., Probability of Resolution) provides a measure of effectiveness of the NAS through the actions of controllers and pilots at containing OEs at the lowest risk to safety. The Time-on-Position Probability provides a measure of the risk of an OE occurring based on how long a controller is working on position. Both measures represent enhancements, compared to just the reporting of the frequency of OE occurrences and OE rates; thus, both measures should be considered for inclusion in the Air Traffic Organization's system of safety metrics.

REFERENCES

Allendoerfer, K.R., Willems, B., Zingale, C., & Pai, S. (2006). Methods for examining possible effects of en route automation modernization (ERAM) on controller performance, (Report No. DOT/FAA/TC-TN06/14). Washington, DC: FAA Office of Aerospace Medicine.

Bailey, L., Pounds, J., & Scarborough, A. (2008). En route operational errors: transfer of position responsibility as a function of time on position. (Report No: DOT/FAA/AM-08/16). Washington, DC: FAA Office of Aerospace Medicine.

Bailey, L., Schroeder, D.J., & Pounds, J. (2005). The air traffic control operational errors severity index: An initial evaluation. (Report No. DOT/FAA/AM-05/5). Washington, DC: FAA Office of Aerospace Medicine.

Brudnicki, D.J., & MacFarland, A.L. (1997). User request evaluation tool (URET) conflict probe performance and benefits assessment, MP97W0000112, The MITRE Corporation, Center for Advanced Aviation System Development: McLean, VA.

Federal Aviation Administration (2006). Administrator's fact book. Retrieved January 12, 2010, from http://www.faa.gov/about/office_org/headquarters_offices/aba/admin_factbook/media/200612.pdf

Federal Aviation Administration (2007). Air Traffic Organization Safety Management System, FAA Order JO 1000.37. Retrieved January 12, 2010 from http://www.faa.gov/air_traffic/publications

Federal Aviation Administration (2009a). Air Traffic Quality Assurance, FAA Order 7210.56C, Retrieved January 12, 2010 from http://www.faa.gov/air_traffic/publications

Federal Aviation Administration. (2009b). FY 2009: Portfolio of goals. Retrieved January 12, 2010 from http://www.faa.gov/about/plans_reports/media/FY09_Portfolio_of_Goals.pdf

Federal Aviation Administration (2010). Office of Safety: Safety Management System. Retrieved July 30, 2010 from https://employees.faa.gov/org/linebusiness/ato/safety/sms/implementation

Henry, C., Berg, E., Down, G., Fallow, P., Knauer, M., Koivula, K., Krois, P. & Morley, .J, (2008). Turning data into change: Applications of Normal Operations Safety Survey (NOSS) findings. Retrieved January 4, 2010 from http://www.hf.faa.gov/Portal/techrptdetails.aspx?id=2093

Lowry, N.M., MacWilliams, K.J., Still, R.J., & Walker, M.G. (2005). Analysis of operational errors. (Report No. MP05W0000025 Rev. 1). McLean, VA: MITRE.

Maurino, D. (2003). Aviation safety and human factors: The years to come: In *Innovation and consolidation in aviation: Selected contributions to the Australian Aviation Psychology Symposium 2000*. Edkins, G. and Pfister, P. (Eds.) pp.7-14. Burlington, VT: Ashgate.

Pounds, J., & Isaac, A. (2003). *Validation of the JANUS technique: Causal factors of human error in operational incidents.* (Report No: DOT/FAA/AM-03/21). Washington, DC: FAA Office of Aerospace Medicine.

Scarborough, A., Bailey, L., & Pounds, J. (2005). *Examining ATC operational errors using the Human Factors Analysis and Classification System*. (Report No: DOT/FAA/AM-05/25). Washington, DC: FAA Office of Aerospace Medicine.

Schroeder, D., Bailey, L., Pounds, J., & Manning, C. (2006). *A human factors review of the operational error literature* (Report No: DOT/FAA/AM-06/21). Washington, DC: FAA Office of Aerospace Medicine.

Shappell, S.A. & Weigmann, D.A. (2000): *The Human Factors Analysis and Classification System* (Report No: DOT/FAA/AM-00/7). Washington, DC: FAA Office of Aerospace Medicine.

Toller, M. (2003). Legislating behavior: The regulators dilemma. In *Innovation and consolidation in aviation: Selected contributions to the Australian Aviation Psychology Symposium 2000*. Edkins, G. and Pfister, P. (Eds.) pp. 227-230. Burlington, VT.: Ashgate.

Trejo, L.J., Knuth, K., Prado, R., Rosipa, R., Kubitz, K., Kochavi, R., Matthews, B., & Zhang, Y. (2007). EEG-based estimation of mental fatigue: Convergent evidence for a three-state model. In Schmorrow D.D. and Reeves L.M. (Eds.), *Foundations of augmented cognition* (pp. 201-211). New York: Springer.