2013

Outcome-Based Risk Pathways: Utilizing Safety Reports to Understand Risks in Air Traffic Control

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Many accident investigation taxonomies have been developed over the years to assist in identifying and classifying causal factors and errors involved in near misses events and accidents. While these taxonomies are often used to better understand individual events, they also offer the potential for quantifying the relationships between causal factors and errors to better understand emerging systemic issues. In an effort to extend beyond traditional frequency-based accident analysis, this work details the relationships among causal factors by examining any differences among outcome types. An analysis of 417 Aviation Safety Reporting System (ASRS) reports yielded five key risk pathways present in air traffic control safety events involving actual or near losses of standard separation minima. These risk pathways allow mitigation strategies to be targeted directly at the key causal factors in order to produce the greatest positive impact on the system as a whole.

The ability to identify and understand human performance safety trends is necessary in complex industries, such as air traffic control (ATC). Furthermore, the development of a baseline of human performance for current day operations has the potential to impact the designs of future systems. Providing designers with knowledge of the current human performance trends in a system permits designers to incorporate mitigations aimed at those trends into the earliest stages of concept development (GAO, 2011). The human factors safety community of practice has long served as a key player in the enhancement of safety in the ATC domain. Human factors causal factors assessments are typically conducted using criteria, such as calendar year, domain type, geographic region, meteorological conditions, and many other conditions (Sawyer, Berry, & Austrian, 2012). Safety events, however, are seldom an outcome of one single causal factor, but are more commonly the culmination of multiple, related factors (Senders & Moray, 1991).

While many studies identify leading causal factors in frequency-based assessments, little has been completed to examine the relationships among the various causal factors within the air traffic domain. It is beneficial to the safety community to expand beyond traditional frequency-based assessments to incorporate causal factor relationship assessment. Furthermore, the examination of risk pathways that identify and quantify the statistically significant relationships among causal factors should be expanded to include event outcomes. The development and implementation of mitigations strategies based only on the most frequent error types has historically proven difficult due to the variability associated with human performance (Berry, Stringfellow, & Shappell, 2010). The associations determined by the risk pathways approach will assist in driving mitigations upstream. Since the higher-tier causal factors (e.g., agency influences) are associated with less variability, mitigation strategies targeted at these latent conditions may have the potential to produce "the greatest gains in safety benefits" (Li & Harris, 2006). Establishing risk pathways will aid in driving mitigation strategies targeted towards latent conditions while still incorporating active errors.

Purpose

This assessment presents the results of an analysis of safety event reports submitted by air traffic controllers describing safety events observed in live National Airspace System (NAS) operations. By analyzing reports of actual operations, the work presents a picture of the human factors safety issues associated with varying outcomes in NAS operations from an ATC perspective. In order to achieve this purpose, a customized air traffic safety taxonomy was developed based on an analysis and synthesis of existing taxonomies including Human Factors Analysis Classification System (HFACS) (Wiegmann & Shappell, 2003), JANUS (Isaac et al., 2003), and HERA (Isaac et al., 2003). The Air Traffic Analysis and Classification System (AirTracs) taxonomy was then applied to examine the underlying trends present in 417 ATC safety events resulting in a near or actual loss of standard separation minima (LoSS) with any significant differences between near and actual LoSS findings being examined. The prominent risk pathways among the AirTracs causal categories were identified. These identified human performance trends should serve as a foundation of current day human performance operational knowledge for human factors practitioners and NextGen system designers in the early stages of concept development.

Methodology

AirTracs provides a framework for systematically and thoroughly examining the impact of human performance on air traffic accidents and incidents. The framework of the AirTracs causal category model is based on the Department of Defense (DoD) HFACS model (DoD, 2005), while the detailed causal factors incorporate factors from HERA and JANUS (Isaac et al., 2003). The AirTracs framework promotes the identification of causal trends by allowing factors from the immediate operator context to agency-wide influences to be traced to individual events. The causal category model is displayed in Figure 1. For more information on the AirTracs causal factor categories see Sawyer, Berry, & Austrian, 2012.

The data utilized for this analysis was gathered from NASA's Aviation Safety Reporting System (ASRS), which is comprised of voluntarily submitted aviation safety reports filed by pilots, controllers, or other NAS actors (NASA, 2013). As with any voluntary reporting system, ASRS combines the advantages of direct input on safety concerns from front-line personnel with the disadvantages of potentially biased points-of-view. For this study, ASRS safety incidents resulting in a near or actual LoSS event were queried for reports filed by an air traffic controller and occurring in the calendar year 2011. The resulting 417 ASRS reports were classified with AirTracs utilizing the consensus method, which required a consensus or agreement on the causal factors contributing to the report by a panel. The panel members included human factors experts, retired air traffic controllers, and flight deck experts. Each report was evaluated across all levels of the AirTracs framework, and the presence or absence of each AirTracs causal category was recorded. It is important to note that the AirTracs categories are not mutually exclusive. For example, an individual report can include both an execution act and a decision act.

A Person's chi-square test or Fisher's exact test were utilized to identify any statistical differences among AirTracs causal categories when comparing near LoSS and LoSS events. If any statistical differences were identified between the two outcomes, the relative risk value for the significant causal category was calculated. For those causal categories that did not result in any significant differences between near LoSS and LoSS events, the risk pathways or associations among causal categories were examined. Starting at the highest AirTracs tier Agency Influences, the relationship between each causal category at the higher tier and the various causal categories at lower tiers was examined using a Pearson's chi-square test to measure the statistical strength of the association. In the instances where the assumptions of the Pearson's chi-square test were not met, a Fisher's exact test was conducted (Sheskin, 2011). If the AirTracs category resulted in a significant association being identified through the Pearson's chi-square test or Fisher's exact test ($p<0.05$), the odd's ratio was calculated for that particular association. The odd's ratio is a measure of the degree of the association strength that compares the odds of the presence of causal category (Sheskin, 2011).

Results

The findings from the AirTracs analysis of 417 near LoSS or LoSS ASRS reports can be viewed in Figure 1. The percentages in Figure 1 do not sum to 100% since reports typically are associated with more than one causal factor. When examining the differences between the findings for LoSS reports and near LoSS reports, only the Cognitive/Physiological causal category produces significant differences between LoSS and near LoSS reports (X^2 = 5.8212, p<0.05, Relative Risk=1.4600). Since only one significant difference was found between LoSS and near LoSS reports, the risk pathways were examined in the aggregate for all causal categories except for Cognitive/Physiological pairings.

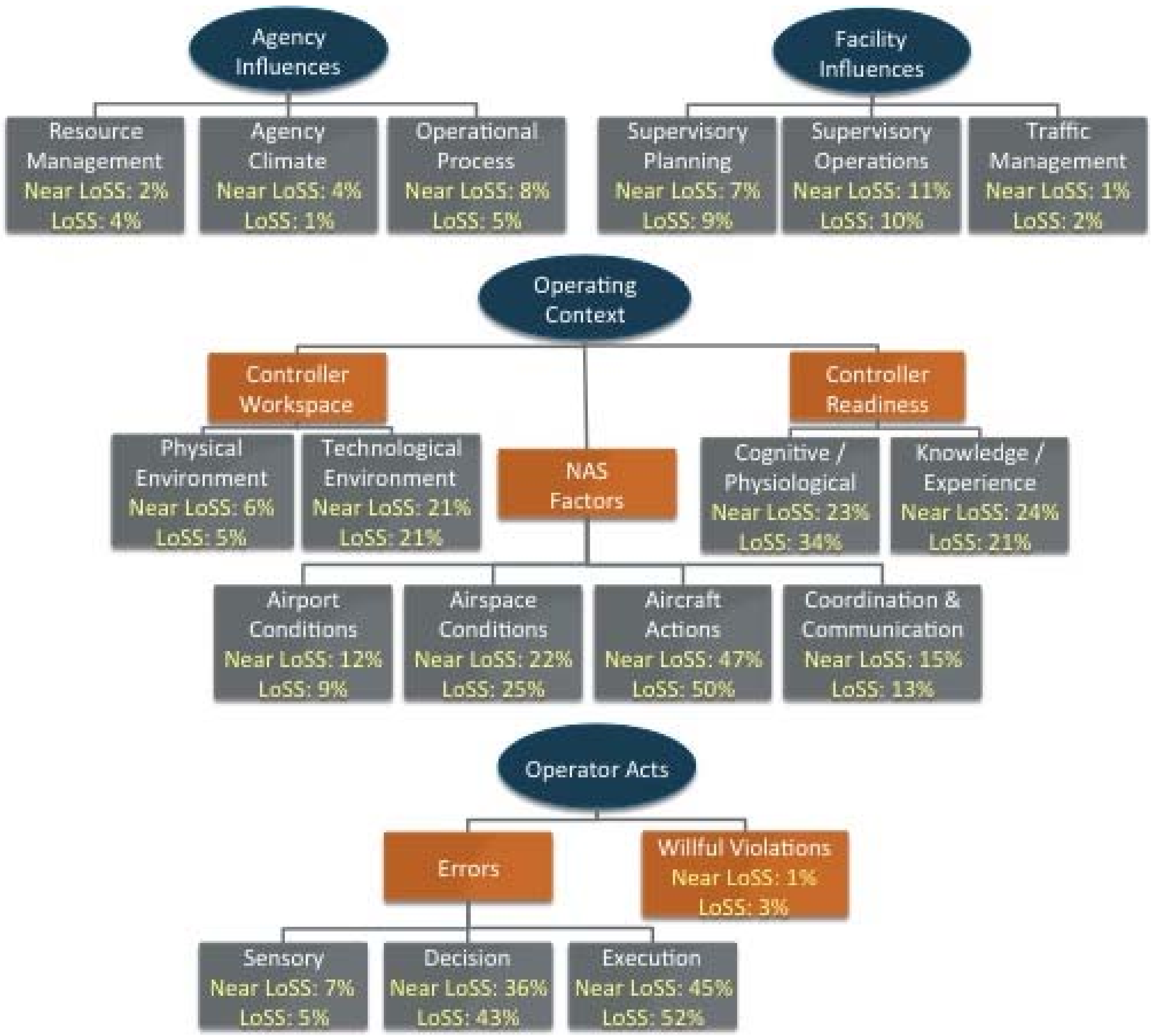

Figure 1. AirTracs Findings (Percentage of ASRS report with causal category presence indicated for each outcome)

The AirTracs risk pathways where statistically significant associations between causal categories were found are shown in Table 1. Only those causal category pairings that were found significant from the Pearson's Chi-Square analysis and odds ratio analysis (p<0.05) were reported. Five risk pathways were identified containing ten causal category associations. When the LoSS and near LoSS reports were compared, the Cognitive/Physiological causal category resulted in significant differences between the two outcomes. When examining Cognitive/Physiological pairings, one significant association emerged for each outcome. For LoSS outcome reports, the Cognitive/Physiological causal category was significantly associated with Execution Errors (X^2 = 5.5640, p<0.05, OR = 1.9542), and for near LoSS outcome reports, the Cognitive/Physiological causal category was also significantly associated with Execution Errors ($X^2 = 8.1969$, $p<0.05$, OR = 2.6600).

Table 1. LOS and Near LOS Risk Pathways

AirTracs Causal Categories	Pearson's Chi Square	Odds Ratio
Resource Management Pathway		
Resource Management X Supervisory Planning	5.8103	4.7000
Supervisory Planning X Technological Environment	9.4869	3.0358
Technological Environment X Sensory Error	13.7832	4.4911
Aircraft Actions Pathway		
Aircraft Actions X Decision Error	12.1495	2.0291
Aircraft Actions X Execution Error	20.0748	2.4438
Airport or Airspace Condition Pathways		
Supervisory Planning X Airport Condition	4.3151	2.5249
Supervisory Operations X Airspace Condition	12.3069	3.0154
Traffic Management X Airspace Condition	8.9855	13.5319
Knowledge/Experience Pathway		
Knowledge/Experience X Decision Error	4.2199	1.6212
Sensory Error Pathway		
Physical Environment X Sensory Error	22.5564	8.9176

Note. All Pearson's Chi Square values and Odds Ratios presented above are significant ($p<0.05$).

Discussion

When examining the LoSS reports versus the near LoSS reports, only the Cognitive/Physiological category resulted in significant differences between the two outcomes. The findings indicated that LoSS reports were 1.4600 times more likely to include a Cognitive/Physiological causal category than near LoSS reports. Sample causal factors within the Cognitive/Physiological causal category include high workload, attention, complacency/boredom, automation reliance, fatigue, expectation bias, and medical illness. In situations where separation could potentially be lost, this finding indicates that when a controller is under pressure from mental or physical conditions, a resulting outcome of an actual LoSS versus a near LoSS is more likely. These Cognitive/Physiological factors may either greatly contribute to the complexity of the event or may inhibit the controller from adequately detection and preventing the event.

The lack of significant differences among the remaining causal categories indicates that contributing factors may be similar regardless of outcome when comparing LoSS versus near LoSS events. This finding may indicate that controller's errors and mistakes are similar regardless of the outcome (near or actual LoSS). A controller may make an incorrect decision or poorly execute a plan leading to either a near or actual LoSS. However, if a manager is attempting to reduce the number of LoSS events by transforming the LoSS events into near LoSS events, managers should not focus on those causal categories that lack significant differences (e.g., execution error) and should focus on the causal category that did result in a significant difference – Cognitive/Physiological factors.

Risk Pathways

From the assessment of the aggregated LoSS and near LoSS reports, five risk pathways were identified that included ten causal category associations. The five pathways will be discussed in the following sections.

Risk Management Pathways. The risk management pathway is initiated with an association between the Risk Management causal category and the Supervisory Planning causal category, followed by an association between the Supervisory Planning causal category and the Technological Environment causal category, and resolved with an association between the Technological Environment causal category and the Sensory Error causal category. This connection illustrates how agency-level decisions regarding resources, such as budget, personnel, or equipment, can create a ripple effect throughout the causal chain and among various levels of the organization. Furthermore, the association between Technological Environment and Sensory Errors indicates that LoSS or near LoSS events with a Sensory Error may be attributed to the controller's technology or workstation not being salient enough to alert the controller to a potential conflict.

Aircraft Actions Pathway. The aircraft actions pathway incorporates the Aircraft Actions causal category associations with both the Decision Error and Execution Error causal categories. This pathway suggests that weaknesses exist among the decision/response selection and response execution phases of information processing, rather than the perception phase. Therefore, mitigations should be targeted towards improving controller's decision-making and plan execution in response to unexpected aircraft actions, such as pilot deviations and go-arounds. In 2013, the FAA (Teixeira, 2013) identified the current fiscal year's top five hazards in the NAS with one of the top five hazards being recovery. The aircraft actions pathway coincides with the recovery top five hazard. Both the hazards and the pathway identify the manner in which controllers respond to adverse events as being a current shortcoming in the NAS. Mitigation strategies for the recovery hazard should aim to address both decision errors and execution errors.

Airport or Airspace Conditions Pathways. The airport or airspace conditions pathways incorporate either the Airport Conditions causal category or the Airspace Conditions causal category. Both of these causal categories describe the design and environmental conditions of either the airspace or airport the aircraft is operating in, such as weather or sector/airport layout. The airport or airspace conditions pathways also include the Supervisory Planning, Supervisory Operations, and Traffic Management causal categories. This pathway suggest that the plans and actions of facility management, such as front line managers and traffic management unit, impact the way aircraft operate in and controllers respond to the environment and conditions of the airspace or airport. For example, if a traffic manager does not issue a traffic management initiative to reroute aircraft around a weather system, the aircraft or a stream of aircraft may encounter a weather system causing the controller to respond to the adverse condition under a more time-sensitive situation. Further analysis and research should be conducted to identify the details of the errors and actions of those actors at the facility management level.

Knowledge/Experience Pathway. The knowledge/experience pathway includes the Knowledge/Experience causal category and the Decision Error causal category. This pathway suggests that if a controller lacks experience with a situation (e.g., an unfamiliar procedure) or knowledge of a certain task (e.g., a controller in training), the controller's decisions, choices, and plans may not be adequate for the situation. Mitigation strategies should incorporate improving the knowledge base of the controller, which may be achieved with the least adverse impact to the safety of the NAS by simulator-based training. Controllers should complete simulator scenarios and conditions that may be unfamiliar or precarious to improve the decision-making process.

Sensory Error Pathway. In addition to the Sensory Error – Technical Environment association, the Sensory Error causal category was also associated with the Physical Environment causal category. These two association pairing illustrate the importance of the workspace conditions on the controller's perception. For example, if the control room is too noisy or the radar screen not bright enough, the conditions can impact the controller's ability to detect a potential conflict.

Conclusions

In order to examine the dynamic relationships of causal factors, an expansive human factors taxonomy, AirTracs, was utilized to identify prominent risk pathways based on a particular outcome. The

AirTracs taxonomy was utilized in assessing 417 ASRS air traffic control reports that resulted in a near or actual LoSS. The percentage of reports linked to each causal category was identified for both outcomes. The AirTracs outcome findings were compared and only the Cognitive/Physiological causal category resulted in a significant difference. For both outcomes, the Cognitive/ Physiological causal category was associated with the Execution Error causal category. When combining the near and actual LoSS reports, five key risk pathways were identified, and potential mitigation strategies were discussed. Targeting systemic mitigation strategies offers the potential to proactively reduce risks associated with the causal factors within the pathway.

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