THE USE OF ODDS RATIOS AND RELATIVE RISK TO QUANTIFY SYSTEMIC RISK PATHWAYS IN AIR TRAFFIC CONTROL

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ABSTRACT

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 analysis of accident analysis, this work examines the relationships among causal factors by utilizing odds ratios and relative risk measures to establish risk pathways. An analysis of 253 ASRS reports yielded five key risk pathways present in air traffic control safety events involving actual or near losses of 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.

INTRODUCTION

In an effort to modernize the National Airspace System (NAS), the Federal Aviation Administration (FAA) is currently executing a considerable transformation of the NAS called Next Generation Air Transportation System (NextGen). NextGen aims to improve the convenience and dependability of air travel while increasing safety and reducing environmental impact. The introduction of new capabilities, decision-support tools, and automation through NextGen operational improvements offers the potential to change the daily activities and operations of air traffic controllers in the NextGen environment (FAA, 2012). While NextGen may produce many positive safety improvements, the introduction of each new system and capability also offers the possibility of increasing the human contribution to risk in the NAS (Sawyer, Berry, & Blanding, 2011). This is especially true when considering the system-wide impact and concurrent development of many of the systems (Berry & Sawyer, 2012). From a risk management perspective, research into these effects is needed to address the potential for both positive and negative impacts on the safety of the NAS (FAA, 2011).

The ability to identify and understand human performance safety trends is necessary in complex industries, such as aviation and air traffic control (ATC). Causal factors are typically analyzed using criteria such as calendar year, domain type, geographic region, meteorological conditions, and many other conditions. Safety events, however, are seldom an outcome of one single causal factor, but are more commonly the culminations 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.

RISK PATHWAYS

Typically, safety incidents and accidents are not the outcome of random events, but can be attributed to a combination of causal and contributing factors (Senders & Moray, 1991). Therefore, it is beneficial to the safety community to expand beyond traditional frequency-based assessments to incorporate causal factor relationship assessment. Several previous safety assessments have utilized a human factors framework to identify associations among key causal factors for flight deck safety (Li & Harris, 2006), mining, and field maintenance (Berry, Stringfellow, & Shappell, 2010). Within the air traffic domain, initial causal factor associations have been identified (Berry & Sawyer, 2011). This effort presented here builds on the initial associations by identifying prominent risk pathways and utilizing quantitative risk assessments. Risk pathways identify and quantify the statistically significant relationships between causal factors for a given set of data.

In addition to identifying the leading contributing factor, the risk pathways approach identifies the significantly associated causal factors linked to the leading contributing factor. 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 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

The work presented in this paper aims to show how narrative safety data can be utilized to quantify prominent risk pathways permitting for the development of targeted mitigation strategies. In order to achieve this purpose, a customized air traffic safety taxonomy was developed based on an analysis and synthesis of existing taxonomies including HFACS (Wiegmann & Shappell, 2003), JANUS (Isaac et al., 2003), and HERA (Isaac et al., 2003). The developed AirTracs taxonomy was then applied to examine the underlying trends present in 253 air traffic control safety events resulting in a near or actual loss of separation minima. The prominent risk pathways among the AirTracs causal factors were identified and potential mitigation strategies targeted towards those risk pathways were proposed.

DEVELOPMENT OF AN ATC HUMAN FACTORS SAFETY TAXONOMY

Long-serving as a key player in the enrichment of safety in the ATC domain, the human factors safety community of practice utilizes many safety tools and techniques to identify human performance trends. However, current tools and techniques are limited in the ability to identify and describe underlying safety patterns (GAO, 2011). Over the years, many human factors accident investigation taxonomies have been developed over the years to help identify and classify the causal factors and errors involved in near miss events, incidents, and accidents. These taxonomies exist at many levels of detail from generalized taxonomies to domain-specific taxonomies – each with their own benefits and limitations. Generalized taxonomies, such as the Human Factors Analysis and Classification System (HFACS), are easy to understand and allow for trend analysis of broad causal factors, but can be limited in identifying domain-specific mitigation strategies. Domain-specific taxonomies, such as JANUS and Human Error ATM (HERA), may more accurately describe individual ATC events, but can have too many causal factors to provide meaningful systemic analysis.

In order to examine and quantify risk pathways, a comprehensive taxonomy is needed to ensure that the operator actions and causal factors that contribute to safety events in the NAS can be identified. Such a taxonomy would allow a safety professional to identify prominent risk pathways and to extend beyond frequency-based, human error assessments. The Air Traffic Analysis and Classification System – AirTracs – was developed to systemically and thoroughly examine the impact of human performance on air traffic safety events. In the following sections, the taxonomies serving as the foundation for AirTracs will be discussed and the details of the AirTracs taxonomy will be examined.

THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

Fulfilling a need for a standardized accident investigation taxonomy, the HFACS taxonomy was modeled on Reason's (1990) Swiss cheese model of active failures and latent conditions (Wiegmann & Shappell, 2003). Initially designed for aviation, the HFACS taxonomy consists of one tier of active errors – unsafe acts – and three tiers of latent conditions – preconditions for unsafe acts, unsafe supervision, and organizational influence. The taxonomy provides a structured, systemic approach for investigating both accidents and near miss incidents.

Due to its origins, the HFACS taxonomy has been applied to the many facets of the aviation industry, including commercial (Wiegmann & Shappell, 2001), military (Li & Harris, 2006), and general aviation (Shappell & Wiegmann, 2004). Additionally, the application of the taxonomy has extended beyond the aviation industry to include maintenance (Berry, Stringfellow, & Shappell, 2010), mining (Patterson, 2009), and rail (Baysari et al., 2008). While the HFACS taxonomy has been applied to a wide range of industries, the level of detail needed to classify domain-specific causal factors is not present in the current HFACS taxonomy and similar generalized taxonomies. Without detailed information on the various causal factors, the mitigation strategies developed from generalized findings may lack the information needed for comprehensive and in-depth application (Pounds & Isaac, 2002).

HERA – JANUS

Developed jointly by the FAA and EUROCONTROL, the HERA-JANUS technique was created to comprehensively examine the human factors causal factors associated with safety events specifically in ATC. The HERA-JANUS taxonomy categorizes unsafe acts through detailing the error – in terms of error type, error detail, error mechanism, and information processing level – and the context of the error – in terms of task, information and equipment, and contextual conditions (Isaac et al., 2003). The taxonomy provides a thorough and meticulous approach for investigating ATC safety events. While the HERA-JANUS taxonomy has the level of detail necessary for an exhaustive understanding of a single safety event, the technique lacks in the ability to identify systemic safety patterns.

Without the ability to identify emerging trends in safety data, safety practitioners will lack the ability to develop mitigation strategies that address systemic issues (Wiegmann & Shappell, 2003).

AirTracs

The Air Traffic Analysis and Classification System (AirTracs) was developed by merging the HFACS and HERA-JANUS taxonomies to accommodate the strengths of each taxonomy while addressing their weaknesses (Berry, Sawyer, & Austrian, 2012). The framework of the AirTracs causal factor model is based on the Department of Defense (DoD) HFACS model (DoD, 2005), while the detailed causal factor categories incorporate factors from HERA-JANUS (Isaac et al., 2003). The AirTracs framework promotes the identification of human factors causal trends by allowing factors from the immediate operator context to agency-wide influences to be traced to individual events while still being able to identify human factors patterns and trends. The AirTracs causal factor model can be found in Figure 1, and the details of the causal factors can be found in Table 1.

Similar to the HFACS taxonomy, the AirTracs model follows a tiered approach. The first tier Operator Acts addresses those causal factors most closely linked to the actual safety event and describe the actions or inactions of the operator. Operator Acts causal factors are classified as Willful Violations or Errors with Errors being categorized as Sensory, Decision, or Execution. The second tier Operating Context describes the immediate environment associated with the operator and the safety event. Operating Context causal factors are classified as Controller Workspace, which is categorized as Physical Environment and Technological Environment, and Controller Readiness, which is categorized as Cognitive and Physiological Factors and Knowledge/Experience, and NAS Factors, which is categorized as Airport Conditions, Airspace Conditions, Aircraft Actions, and Coordination and Communication. The third tier Facility Influences describes the factors related to the actions or inactions of individuals at a ATC facility that have the ability to impact the whole facility or multiple individuals at a facility. Facility Influences causal factors are classified as Supervisory Planning, Supervisory Operations, and Traffic Management Unit. The fourth tier Agency Influence examines those factors related to the actions or inactions of the agency (in this case, the FAA) and is classified as Resource Management, Agency Climate, and Operational Process.

For safety events classified with the AirTracs framework, the presence or absence of each AirTracs causal factor at all four levels should be examined. The AirTracs causal factors are not mutually exclusive, and safety event classifications should include causal factors from all four tiers. For example, an individual safety event can include an execution error, a sensory error, cognitive and physiological factor, supervisory operations, and operational process.

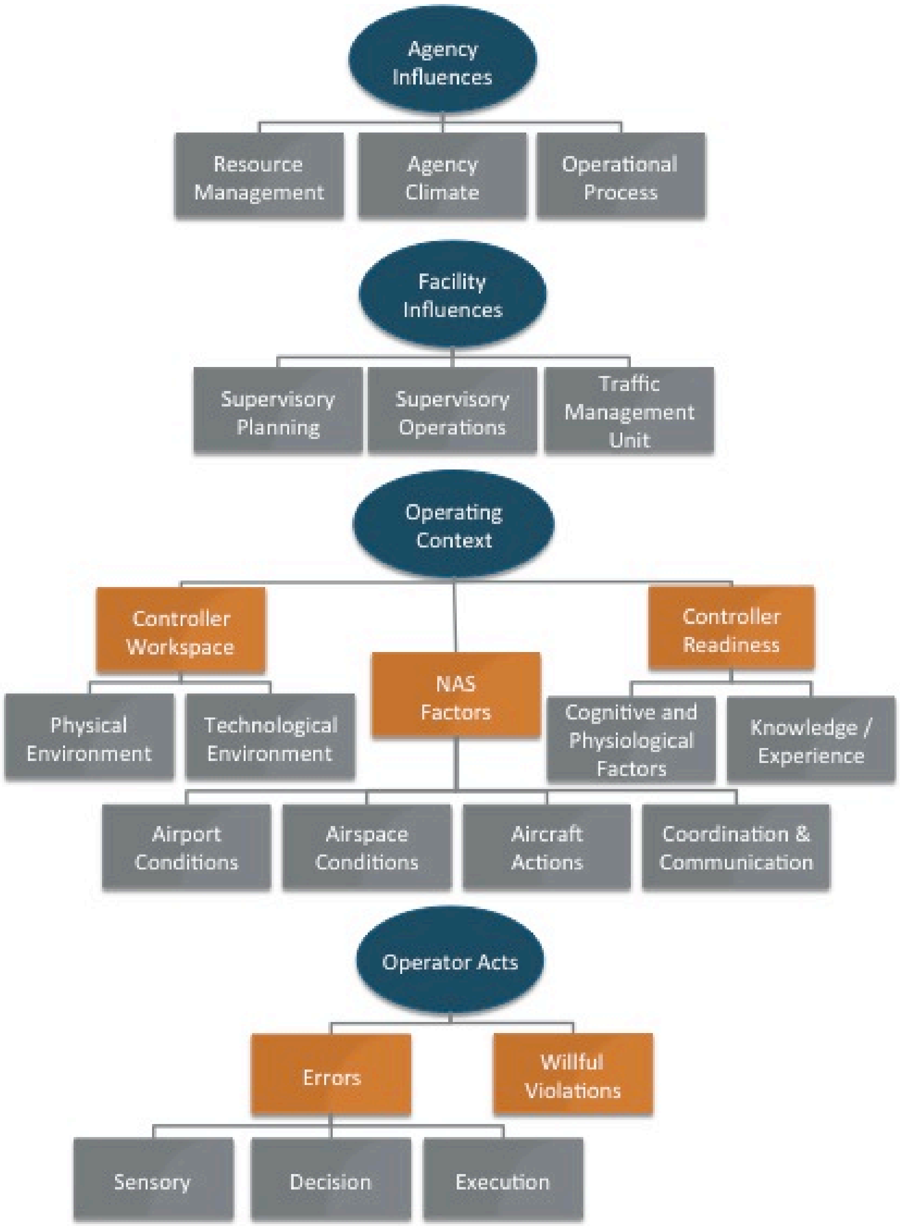

Figure 1: The Air Traffic Analysis and Classification System - AirTracs

APPLICATION OF AIRTRACS

The data utilized for this analysis was gathered from NASA's Aviation Safety Reporting System (ASRS). The ASRS is comprised of voluntarily submitted aviation safety reports filed by pilots, controllers, or other NAS actors (NASA, 2012). As with any voluntary reporting system, the ASRS combines the advantages of direct input on safety concerns from front-line personnel with the disadvantages of potentially biased points-of-view being described.

For this study all ASRS safety incidents reported by air traffic controllers during 2011 were queried. Additionally, only the safety reports that included either a near loss of separation minima or an actual loss of separation minima were analyzed. The resulting 253 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. For more information on the consensus method, please see Berry, Sawyer, & Austrian (2012).

Statistical Analysis

Each ASRS report was evaluated across all four tiers of the AirTracs framework. The presences or absence of each AirTracs causal factor present was recorded for each report. It is important to note that the AirTracs categories are not mutually exclusive. For example, an individual report can include both an execution error and a decision error. For each AirTracs causal factor, the percentage of ASRS reports including at least one instance of the causal factor was determined. In order to identify risk pathways, associations among causal factors were measured. Starting at the highest AirTracs tier Agency Influences, the relationship between each causal factor at the higher tier and the various causal factors 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 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 and relative risk values were 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 factors. The relative risk value further evaluates the association strength by examining the likelihood of a high tier causal factor being present or absent when a lower tier causal factor is present (Sheskin, 2011).

Results and Discussion

The findings from the AirTracs analysis of 253 ASRS reports can be viewed in Table 1. The percentages in Table 1 do not sum to 100% since reports typically are associated with more than one causal factor. Along with the percentage of reports containing a particular causal factor, the leading sub-category for each causal factor is identified. For example, 51% of reports contain an execution error with the leading execution error being a procedural/technique error.

Table 1: AirTracs Findings

Operator Actions	Percentage of Reports	Leading Category
Sensory Error: Occurs when a controller's sensory input is degraded or sensory information is misinterpreted resulting in an inadequate plan of action Categories: Auditory Error, Temporal Error, Visual Error	8%	Visual Error
Decision Error: Occurs when a controller's behaviors or actions proceed as intended yet the chosen plan proves inadequate to achieve the desired end-state and results in an unsafe situation. Categories: Alert Error, Knowledge-Based Error, Prioritization Error, Rule-Based Error, Tool/Equipment Error	41%	Knowledge-Based Error
Execution Error: Occurs when a controller's execution of a routine, highly practiced task relating to procedure, training or proficiency result in an unsafe a situation. Categories: Attention Error, Communication Error, Inadvertent Operation, Memory Error, Procedural/Technique Error	51%	Procedural/ Technique Error
Willful Violation: The actions of controllers that represent a willful and knowing disregard for the rules and regulations. Willful Violations are deliberate actions. Categories: Willful Violation	2%	Willful Violation
Operator Context		
Physical Environment: The operational and ambient environment of the controller's immediate workspace. Categories: Ergonomic Issues, Lighting, Noise Interference, Vision Restricted, Workspace Clutter	6%	Vision Restriction
Technological Environment: The automation and technological systems used by controllers including the influence of equipment design, display/interface characteristics, checklist layouts, task factors and automation levels. Categories: Procedure, Communication Equipment, Display/Interface, Software/Automation, Warnings/Alarms	26%	Display/ Interface
Airport Conditions: The environmental and design conditions of the airport involved in the event. Categories: Ground Vehicle Traffic, Aircraft Traffic, Combined Positions, Airport Weather, Signage/Lighting, Construction, Layout/Design	6%	Airport Weather
Airspace Conditions: The environmental and design conditions of the airspace involved in the event. Categories: Sector Overload/Traffic, Sector Weather, Turbulence, Sector Design, Combined Sectors, Combined Positions	20%	Sector Weather
Aircraft Actions: The actions or inactions of the aircraft involved in the event that lead to an unsafe situation. Categories: Deviation, Unexpected Aircraft Performance, Flight Planning, Responding to Abnormal Situation, Go Around	43%	Unexpected Aircraft Perf.
Coordination and Communication: The teamwork factors of coordination and communication involved with the preparation and execution of a plan that result in an unsafe situation. Categories: Controller-Controller Communication, Controller-Flight Deck Communication, Coordination	8%	Controller-Flight Deck Comm
Cognitive and Physiological Factors: Cognitive or mental conditions of a controller and the physiological state of the actors that contributed to an unsafe event. Categories: Attention, High Workload, Complacency/Boredom, Automation Reliance, Expectation Bias, Fatigue, Medical Illness/Medication	32%	High Workload
Knowledge/Experience: The experience or knowledge level a controller has for a task, procedure, or policy that result in an unsafe situation. Categories: On-the-Job Training/Developmental, Low Experience CPC, Unfamiliar Task/Procedure	19%	On-the-Job Training/ Develop.

Facility Influences	Percentage of Reports	Leading Category
Supervisory Planning: The planning and preparation of operations conducted by facility management that result in an unsafe situation. Categories: Procedures/Policy, Staffing, Equipment, Training, Planning Violation	8%	Procedure/ Policy
Supervisory Operations: The day-to-day operations and tasks conducted by facility management that result in an unsafe situation. Categories: Sector Combination, Position Combination, Sector/Airport Configuration, Controller Assignment, Operational Tempo, Supervisory Coordination, Operational Violation	12%	Controller Assignment
Traffic Management Unit: The operations of the traffic management unit and their impact on the controller that result in an unsafe situation. Categories: Weather Response, Special Use Airspace, Traffic Management Initiatives	1%	Weather Response
Agency Influences		
Resource Management: The organizational-level decision-making regarding the allocation and maintenance of organizational assets that result in an unsafe situation. Categories: Equipment/Facility Resources, Human Resources, Monetary/Budget	4%	Equipment/ Facility Resources
Agency Climate: The organizational variables including environment, structure, policies, and culture that result in an unsafe situation. Categories: Culture, Organizational Structure, Policy	4%	Policy
Operational Process: The organizational process including operations, procedures, operational risk management and oversight that result in an unsafe situation. Categories: Operations, Procedures, Oversight	6%	Procedures

Operator Acts were cited in 79% of the reports examined. The leading causal factor within Operator Acts was execution error which was cited at least once in 51% of the reports. In these reports the controller adequately identified the issue present, developed a plan to rectify the issue, but failed to adequately execute the plan to correct the issue. The leading category within execution errors was procedural/technique error indicating the technique or the procedure utilized by the controller was not accurately completed. In addition to execution errors, decision errors were present in 41% of the reports with knowledge-based error being the leading category. This finding indicates controllers are developing plans based on faulty information. The high percentage of reports with both execution and decision errors is consistent with previously completed studies of ATC (Berry & Sawyer, 2011; Berry, Sawyer, & Austrian, 2012), aviation (Wiegmann & Shappell, 2003), and other industries (Berry, Stringfellow, & Shappell, 2010). However, these findings present more questions than answers, and the development of meaningful mitigation strategies for these findings is difficult. Therefore, it is important to extend the analysis to develop a more comprehensive view of risks present in the NAS.

RISK PATHWAYS

The AirTracs risk pathways where statistically significant associations between causal factors were found are shown in Table 2. Only those causal factor pairings that were found significant from the Chi-Square analysis (p<0.05) were reported. The relative risk values indicate the likelihood of a high tier causal factor being present or absent in a report when a lower tier causal factor is present. For example, the findings for the resource management – supervisory planning pairing can be interpreted to show that a report citing a resource management causal factor is 4.784 times more likely to also have a supervisory planning causal factor than a report without a resource management causal factor.

Table 2: AirTracs Risk Pathways

	Pearson's Chi-Square		**Odd's**	**Relative**
AirTracs Causal Categories	Value	Significance	**Ratio**	**Risk**
AirTracs Tier 4 - Agency Influences				
Resource Management X Supervisory Planning	8.288	**	6.676	4.784
Resource Management X Technological Environment	4.360	*	3.833	2.259
Resource Management X Airport Conditions	11.491	***	8.885	6.256
Agency Climate X Knowledge/Experience	5.011	*	3.750	2.500
Operational Process X Airspace Conditions	4.118	*	2.939	2.164
AirTracs Tier 3 - Facility Influences				
Supervisory Planning X Technological Environment	9.771	**	4.051	2.373
Supervisory Operations X Airspace Conditions	7.998	**	3.058	2.261
Traffic Management X Airspace Conditions	4.212	*	8.417	3.472
AirTracs Tier 2 - Operating Context				
Physical Environment X Sensory Error	16.973	***	8.929	6.097
Physical Environment X Decision Error	4.288	*	4.391	0.338
Technological Environment X Sensory Error	11.159	***	4.583	3.977
Cognitive and Physiological X Execution Error	6.395	*	2.001	1.371
Knowledge/Experience X Decision Error	5.214	*	2.067	1.479
Airport Condition X Willful Violation	13.087	***	16.786	14.813
Aircraft Action X Sensory Error	6.409	*	4.493	0.244
Aircraft Action X Decision Error	5.140	*	1.812	0.699
Aircraft Action X Execution Error	4.676	*	1.736	0.761

** $p < 0.05$ ** $p<0.01$ *** $p<0.001$*

From the assessment, seventeen significant causal factor relationships emerged. Of note are the relationships between the Aircraft Actions factor and each of the three error causal factors. All three relationships produced significant results with relative risk values less than one (e.g. A report with an Aircraft Action causal factor was 0.244 times as likely to have a Sensory Error as a report without an Aircraft Action.). These reports represent situations where the controller was able to successfully manage and respond to aircraft actions with unsafe consequences. For these reports, the successful actions of the controller should be more thoroughly examined to determine if best practice guidelines could be created for handling aircraft actions. Linking together these relationships based on common factors allows for prominent risk pathways to be identified and to show the system wide impacts of causal factors. Five of the most prominent Risk Pathways along with their implications and potential mitigation strategies are discussed below.

Agency Climate Pathway

The Agency Climate Pathway demonstrates how agency-wide issues can be connected to specific operator actions. Agency Climate refers to the environment, policy, and culture throughout the agency that contribute to adverse events. Sample categories within Agency Climate include safety culture, labor relations, and agency policies. In this pathway, shown below in Figure 2, Agency Climate shows a significant association with the Knowledge/Experience factor which in turn is associated with Decision Errors.

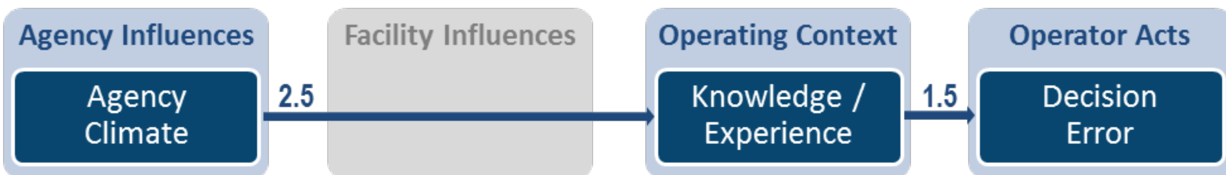

Figure 2: Agency Climate Pathway With Relative Risk Values

Reports citing Agency Climate as a causal factor were 2.5 times more likely to have a Knowledge/Experience causal factor than reports that did not identify an Agency Climate causal factor. Knowledge/Experience as a causal factor refers to situations when controllers lack the knowledge or experience to successfully execute a task, policy, or procedure. Sample categories within Knowledge/Experience include developmental controller, low experience controller, or unfamiliar task or procedure. The association between Agency Climate and Knowledge/Experience suggests that agency climate factors, such as inadequate training or staffing policies, are creating an environment where some controllers do not have adequate training or experience necessary to prevent losses of minimum separation standards.

The effect of this Knowledge/Experience gap is associated with Decision Errors. Reports citing Knowledge/Experience as a factor were 1.48 times more likely to also identify a Decision Error than reports without a Knowledge/Experience causal factor. Decision Errors occur when the controller has the adequate sensory information, but determines an inadequate or inappropriate plan of action to handle the situation at hand. This Knowledge/Experience –Decision Error relationship suggests that the knowledge or experience level of a controller is potential related to the development an inadequate plan or making an insufficient choice leading to a near or actual loss of separation minima.

Several key implications can be drawn from this pathway. First, it shows a distinct and quantified pathway from Agency Influences to Operator Acts. The policies and training resources being made available to controllers impact the abilities of controllers to make correct and safe decisions regarding the traffic in their sector. Second, by establishing this pathway, further investigation can be focused directly on this relationship in order to develop targeted mitigation strategies. The top identified category within Knowledge/Experience was On-the-Job-Training (OJTI), suggesting OJTI as the primary issue present. ATC relies heavily on OJTI, which allows a trainee controller to actively control traffic while being supervised by a certified professional controller (CPC). The OJTI experience allows for trainee controllers to learn the nuances of the job and in some instances, to learn from their mistakes (Wickens, Mavor, &McGee, 1997). While all actions are supervised by a CPC, who has the capability to take over control from the trainee, the actions of the trainee controller do occasionally lead to negative outcomes, such as a near or actual loss of separation minima (Berry & Sawyer, 2011).

The identification of causal factor pathways then allow for directed mitigations to be targeted specifically the causal factors that are associated with the operator acts and in turn the adverse outcomes. In this case, the role that Agency Climate plays in providing controllers the information needed to make decisions suggests that perhaps policies regarding OJTI should be investigated. Further investigation into this issue could be utilized to identify the specific types of information and scenarios that controllers are not currently receiving. This would allow training to be focused on the specific issues being seen in NAS operations.

Resource Management Pathway

The Resource Management Pathway in Figure 3 shows how the effects of poor resource management propagate through the NAS and ultimately contribute to safety events. Resource Management describes the agency-level apportionment and maintenance of equipment, facilities, human resources, and budget resources. The Resource Management Pathway is composed of two branches, one leading to Sensory Errors and the other leading Willful Violations.

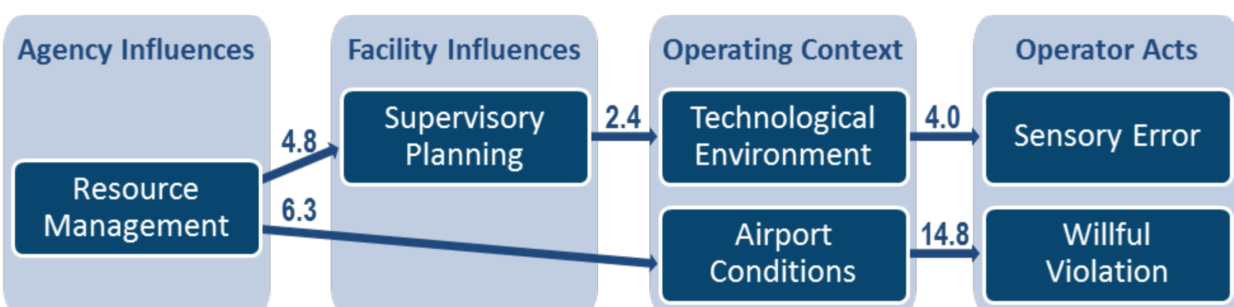

Figure 2: Resource Management Pathway with Relative Risk Values

Sensory Error Branch

The first branch of the Resource Management Pathway shows a significant association between Resource Management and Supervisory Planning. A report involving Resource Management was 4.784 times more likely to cite Supervisory Planning than a report without a Resource Management causal factor. Sample categories within Supervisory Planning include planned staffing levels, facility equipment maintenance, and training of controllers, suggesting that agency decisions have a direct impact on a supervisor's ability to manage an area.

This pathway continues with the Supervisory Planning – Technological Environment connection. Reports citing Supervisory Planning were 2.38 times more likely to also cite Technological Environment than a report without Supervisory Planning causal factors. The Technological Environment causal factor describes the technical workstations, systems, and automation a controller must interact with. This relationship suggests that the technological issues that are present in these safety events are not isolated occurrences, but rather are connected to facility level influences, which are in turn associated with agency level decisions. This could either be the result of failing to fix malfunctioning or inoperable technological systems or of not providing effective and reliable technological systems to controllers.

The issues identified with the Technological Environment causal factor are also associated with weaknesses related to Sensory Errors. A report citing Technological Environment was 3.98 times more likely to have a Sensory Error than a report without a Technological Environment causal factor. Sensory Errors occur when the controller acts or fails to act based on a misinterpretation of auditory, visual, or other sensory information. This relationship suggests that Technological Environment issues present are related to the means in which information is visually displayed or aurally relayed to the controller, rather than related to the type of or quality of information being relayed.

This branch of the Resource Management Pathway emphasizes the importance of providing the various resources necessary to design, update, and maintain the automated systems that controllers use to control traffic. Further, when technological issues are identified there should be a mechanism in place to allow these technological issues to be communicated to facility and agency level stakeholders. Therefore, it is essential that the agency and the facility allocate resources for technical operations to maintain the systems.

Willful Violation Branch

The second branch of the Resource Management Pathway highlights the relationship between Resource Management, Airport Conditions, and Willful Violations. A report with a Resource Management causal factor was 6.256 times more likely to also have an Airport Conditions causal factor than a report without a Resource Management causal factor. An

Airport Conditions causal factor describes the environmental and design conditions of an airport, and sample causal categories include airport weather, airport configuration, and ground vehicle traffic. The relationship between Resource Management and Airport Conditions demonstrate that the agency-level decisions regarding equipment, human, and monetary resources has the ability to impact the adverse conditions at an airport.

This branch continues with Airport Conditions being associated with Willful Violations. A report with an Airport Conditions causal factor was 14.813 times more likely to have a Willful Violation causal factor than a report without an Airport Conditions causal factor. Willful Violations occur only when an operator willfully and knowingly disregards the rules, regulations, policies, and standard operating procedures. It is important to note that while only 2% of the reports contained a Willful Violation, those reports were overwhelmingly related to Airport Conditions. This relationship suggests that the violations that do occur are not the result of intentional neglect or recklessness, but rather happen as controllers push beyond the boundaries of normal operations in order to cope with degraded or inadequate airport conditions. Violations are still quite serious occurrences that warrant individual investigation to determine the true reasons for violating allowable procedures and to develop mitigations accordingly.

Airspace Conditions Pathway

The Airspace Conditions Pathway in Figure 4 shows the Agency and Facility issues significantly associated with the Airspace Conditions causal factor. The Airspace Condition causal factor refers to the environmental and design conditions of the airspace where the near or actual loss of separation minima occurred.

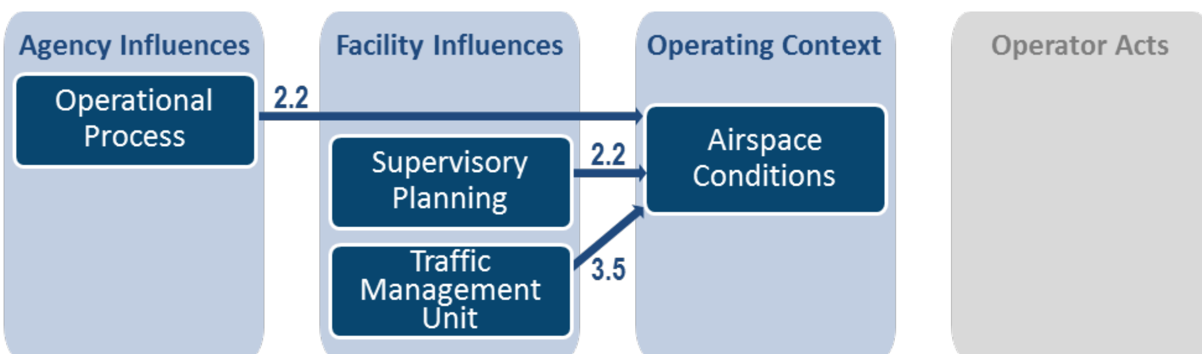

Figure 3: Airspace Conditions Pathway with Relative Risk Values

The Airspace Conditions causal factor includes the causal categories such as sector design, combined sectors, and sector overload/traffic. Three other causal factors were shown to be significantly associated with Airspace Conditions: Operational Process, Supervisory Planning, and Traffic Management Unit.

Of the three associated causal factors, Traffic Management Unit showed the highest relative risk rating as reports citing Traffic Management Unit were 3.47 times more likely to also identify Airspace Conditions than reports which did not cite Traffic Management Unit. The Traffic Management Unit causal factor described the actions and operations of the traffic management unit, such as issuance of traffic management initiatives and development of weather response plans. While the Traffic Management Unit does not directly interact with individual aircraft their actions are directly related to the airspace conditions that controllers must manage traffic. Inadequate traffic management plans have the potential to increase a controller's workload by too many aircraft being routed through a sector or by a controller having to issue multiple weather-related reroutes and amendments.

Furthermore, a report with an Operational Process causal factor was 2.164 times more likely to have an Airspace Condition causal factor than a report without an Operational Process causal factor. The Operational Process causal factor describes the various agency level operations, processes, and oversight. Many of the reports citing both of these causal factors represented situations where either the sector design or policies related to handoff procedures created the opportunity for adverse airspace conditions which later contributed to the adverse outcome of a near or actual loss of separation minima.

Additionally, a report with a Supervisory Operations causal factor was 2.261 times more likely to have an Airspace Condition causal factor than a report without a Supervisory Operations causal factor. The Supervisor Operations causal factor refers to the day-to-day operations and tasks conducted by facility management. This relationship infers that the daily actions of the supervisor or front line manager can potentially impact the airspace and traffic within the airspace. In particular, the front line manager determines when and how both sector and controller positions should be combined and decombined. If a front line manager waits too long to split apart combined sectors, the controller could inadvertently become overloaded, thereby increasing the potential of an adverse event and making the sector split more difficult.

The lack of any significant association between the Airspace Conditions causal factor and the causal factors at the Operator Act tier suggest the Airspace Conditions causal factor is linked to various stages of the decision-making process, rather than one particular stage. The Operator Act tier is modeled after the decision-making process where information must first be accurately perceived (Sensory Error), a decision or response must be developed (Decision Error), and the response must be properly executed (Execution Error). In other pathways, higher tier causal factors were associated to particular Operator Acts causal factors. However, this pathway lacks any direct association with these causal factors indicating that airspace conditions potentially impact all stages of the decision-making process. Mitigation strategies targeted towards this pathway should incorporate all the stages of the decision-making process and should not be limited to a singular stage or causal factor.

Cognitive and Physiological Factors Pathway

The Cognitive and Physiological Factors Pathway shown in Figure 5 is composed of a single, but important connection between Cognitive & Physiological factors and Execution Errors.

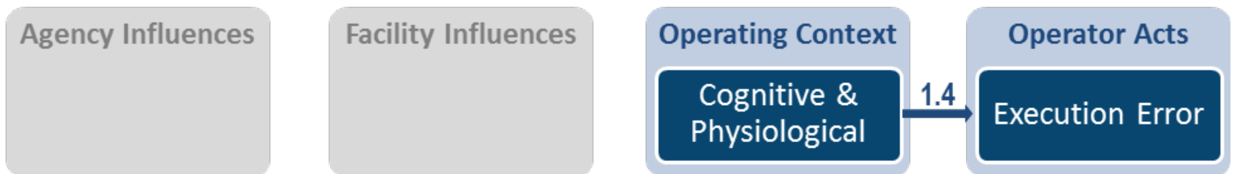

Figure 4: Cognitive and Physiological Pathway with Relative Risk Value

The Cognitive and Physiological factor refers to the mental and physical condition of the controller, and includes sample causal categories such as expectation bias, automation reliance, and fatigue. A report with a Cognitive and Physiological factor was 1.37 times more likely to have an Execution Error than a report without a Cognitive and Physiological Factor. Execution Errors describe situations where a controller has correctly perceived the situation and determined the proper course of action, but makes an error while executing the plan. Sample Execution Error categories include memory errors and inadvertent operations. The Cognitive and Physiological Factor – Execution Error relationship suggests that the mental and physical state of the controller primarily impacts a controller's ability to properly execute their plans. In many reports, controllers described how the impact of factors, such as fatigue or stress from high workload, inhibited their ability to complete a routine task. This relationship also provides a key insight into potentially reducing executions errors by focusing mitigations at reducing the prominent causes of the identified Cognitive and Physiological factors.

Physical Environment Pathway

The Physical Environment Pathway traces the effects that a controller's immediate workspace can have on their performance. Sample Physical Environment causal categories include restricted vision, lighting, and workspace clutter. Physical Environment was found to have significant relationships with Sensory Errors and Decision Errors.

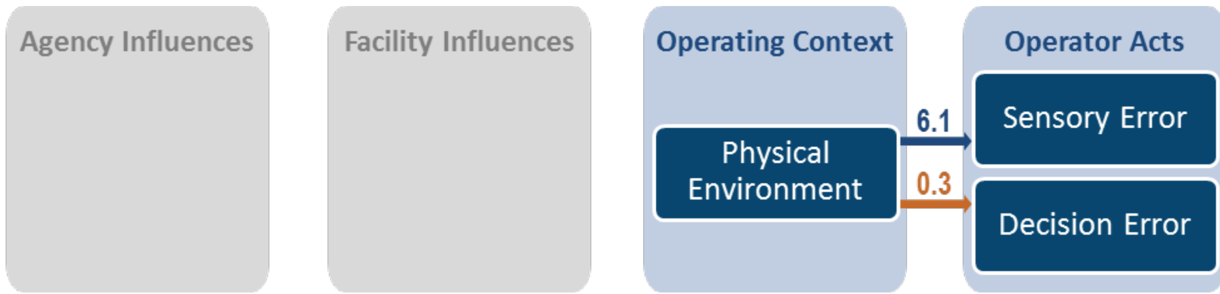

Figure 5: Physical Environment Pathway with Relative Risk Values

A report with a Physical Environment causal factor was 6.10 times more likely to have a Sensory Error causal factor than a report without a Physical Environment causal factor. This suggests that when a controller's workspace is inadequate the controller may have difficulty gathering the necessary sensory information in order to safely control traffic. By contrast, a report with a Physical Environment causal factor was 0.34 times as likely to have a Decision Error causal factor as a report without a Physical Environment causal factor. These relationships suggest that Physical Environment causal factors impact the earlier stages of a controller's decision-making process. The adverse effects occur during the sensory or perception stages of decision-making rather than the decision selection stages. The most prevalent physical environment factors should thus be assessed as sensory information is a controller's first line of defense for identifying and preventing adverse outcomes.

Conclusion

In order to examine the dynamic relationships of causal factors, an expansive human factors taxonomy, AirTracs, was developed to permit safety professional to identify prominent risk pathways. The AirTracs taxonomy, which is a combination of two key human factors taxonomies – HFACS and HERA-JANUS, was utilized in assessing 253 ASRS air traffic control reports. The percentage of reports linked to each causal factor was identified, in addition to the leading causal category for each causal factor. 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. Furthermore, while this methodology was applied the air traffic domain, the approach could be extended to the flight deck domain and any other high-risk, human-centric domain.

References

Baysari, M. T., McIntosh, A. S., & Wilson, J. R. (2008). Understanding the human factors contribution to railway accidents and incidents in Australia. *Accident Analysis and Prevention*, 40(5), 1750-1757.

Berry, K. & Sawyer, M. (2011). Application of a human error taxonomy for the identification of air traffic control errors and causal factors. In *Proceedings of the 16th International Symposium on Aviation Psychology*, 2011, Dayton, Ohio.

Berry, K., Sawyer, M., & Austrian, E. (2012). AirTracs: the development and application of an air traffic safety taxonomy for trends analysis. In *Proceedings of the 1st Annual Conference on Interdisciplinary Science for Air Traffic Management*, 2012, Daytona Beach, Flordia.

Berry, K., Stringfellow, P., & Shappell, S. (2010). Examining error pathways: an analysis of contributing factors using HFACS in non-aviation industries. In *Proceedings of the Human Factors and Ergonomics Society 54th Annual Meeting*, 2010, San Francisco, CA.

Berry, K. & Sawyer, M. (2012). Assessing the Impact of NextGen Trajectory Based Operations on Human Performance. In the Proceedings of the *4th Annual Applied Human Factors and Ergonomics Conference*, 2012, Las Vegas, NV.

Department of Defense (2005). DoD HFACS: a mishap investigation and data analysis tool. Retrieved 2011 from http://www.public.navy.mil/navsafecen/Documents/aviation/aeromedical/DoD_hfacs.pdf,

Federal Aviation Administration (2011). *Destination 2025*. Retrieve 2011, from www.faa.gov/about/plans_reports/media/Destination2025.pdf.

Federal Aviation Administration. (2012). *NextGen Implementation Plan*. Retrieved March 2012, from http://www.faa.gov/nextgen

Government Accountability Office. (2011). *Aviation Safety: Enhanced Oversight and Improved Availability of Risk-Based Data Could Further Improve Safety* (GAO-12-24). Retrieved from http://www.gao.gov/products/GAO-12-24.

Isaac, A., Shorrock, S.T., Kennedy, R., Kirwan, B., Anderson, H., & Bove, T. (2003). *The human error in ATM technique (HERA-JANUS).* (EUROCONTROL Doc HRS/HSP-002-REP-03).

Li, W. C., & Harris, D. (2006). Pilot error and its relationship with higher organizational levels: HFACS analysis of 523 accidents. *Aviation, Space, and Environmental Medicine*, 77(10), 1056-1061.

NASA. (2012). *Aviation Safety Reporting System*. Retrieved from http://asrs.arc.nasa.gov.

Patterson, J. M. (2009). *Human error in mining: A multivariable analysis of mining accidents/incidents in Queensland, Australia and the United States of America using the human factors analysis and classification system framework*. (Doctor of Philosophy, Clemson University). (Clemson University Electronic Theses and Dissertations)

Pounds, J. & Isaac, A. (2002). *Development of an FAA-EUROCONTROL technique for analysis of human error in ATM* (DOT/FAA/AM-02/12). Washington, DC: Office of Aerospace Medicine.

Reason, J. (1990). *Human error*. New York: Cambridge University Press.

Sawyer, M., Berry, K, & Blanding, R. (2011). Assessing the Human Contribution to Risk in NextGen. In the Proceedings of the *Human Factors and Ergonomics Society Annual Meeting*, 2011, Las Vegas, NV.

Senders, J. W., & Moray, N. P. (1991). *Human error: Cause, prediction, and reduction*. Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Shappell, S. A., & Wiegmann, D. A. (2004). HFACS analysis of military and civilian aviation accidents: A North American comparison. In *International Society of Air Safety Investigators*. Queensland.

Sheskin, D. J. (2011). *Handbook of parametric and nonparametric statistical procedures* (5th ed.). Boca Raton: Chapman & Hall.

Wickens, C.D., Mavor, A.S., & McGee J.P. (1997). *Flight to the Future: Human Factors in Air Traffic Control*. Washington, DC: National Academy Press.

Wiegmann, D. A., & Shappell, S. A. (2001). Human error analysis of commercial aviation accidents: Application of the human factors analysis and classification system (HFACS). *Aviation, Space, and Environmental Medicine*, 72(11), 1006-1016.

Wiegmann, D. A., & Shappell, S. A. (2003). *A human error approach to aviation accident analysis: The human factors analysis and classification system*. Burlington, VT: Ashgate Publishing, Ltd.