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Developing a Methodology for Assessing Safety Programs Targeting Human Error in Aviation

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16. Abstract

There is a need to develop an effective methodology for generating comprehensive intervention strategies that map current and proposed safety programs onto well-established types of human error. Two separate studies were conducted using recommendations from NTSB accident investigations and several joint FAA and industry working groups. The goal of the studies was to validate a proposed framework for developing and examining safety initiatives that target human error in aviation. The results suggest five approaches to reducing human factors associated with aviation accidents. When combined with the Human Factors Analysis and Classification System, the resulting Human Factors Intervention Matrix will provide a useful tool for evaluating current and proposed aviation safety programs.

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Developing a Methodology for Assessing Safety Programs Targeting Human Error in Aviation

"I believe that the past is prologue.....In our recommendations we try to take what we have learned and correct situations so it shouldn't happen again."

—Former National Transportation Safety Board Chairman James Hall (1996)

INTRODUCTION

Indeed, the National Transportation Safety Board (NTSB), Federal Aviation Administration (FAA), and other safety organizations have committed extraordinary resources to prevent civilian aviation accidents. As a result, aviation in the U.S., particularly commercial aviation, has become one of the safest modes of transportation. Still, accidents can happen, often repeating the same sequence of events played out many times before. As a result, we are often left with the regrettable truth that there are really very few "new" accidents, just different players. Perhaps that is why Chairman Hall chose the operative term "shouldn't" rather than "won't" in 1996.

So if there really are few "new" accidents, why has the aviation accident rate remained relatively stable over the last several years? After all, if we already know what the problem is, why have we been unable to fix it? Perhaps it has something to do with the current state of aviation safety. Truth be told, the industry is extremely safe, and the easy fixes have been identified and remedied. What remains to be addressed is the small fraction of accidents attributable to perhaps the most complex problem facing aviation today – human error.

A closer examination of the current aviation accident record has revealed that anywhere between 70-80% of all aviation accidents are at least partially attributable to human error (Wiegmann & Shappell, 2003). Therefore, it stands to reason that, if quantifiable improvements in aviation safety are to be realized, the primary focus should be on the human operator (i.e., aircrew) and those involved with the safe conduct of flight (e.g., mechanics, supervisors, air traffic controllers) rather than more traditional areas like the aircraft itself.

With this in mind, the FAA has employed the Human Factors Analysis and Classification System (HFACS; Wiegmann & Shappell, 2001, 2003; Shappell & Wiegmann, 2003, 2004) to identify the human factors underlying both commercial and general aviation. Principal among the FAA's findings using HFACS was the observation that, while previous safety programs may have impacted other areas of aviation, there has been little evidence that they have had a significant impact on any specific type of human error (Figure 1). That is to say, the percentage of accidents associated with aircrew error (i.e., skill-based errors, decision errors, perceptual errors, and violations) has remained relatively stable since 1990.

What this implies is that intervention strategies implemented in the 1990s have had, at best, ubiquitous effects on the errors and violations committed by aircrew. More likely, however, there has been no sustained impact of any particular intervention program (Shappell, Detwiler, Holcomb, Hackworth, Boquet, & Wiegmann, 2006). The latter should come as no surprise, given that prior to these FAA studies, no comprehensive analysis of aircrew and supervisory error had been conducted using a human factors approach to accident causation. Not to mention that there has been no systematic human factors examination of the current or proposed safety programs aimed at addressing human error.

But in some ways, that is putting the proverbial cart before the horse. After all, while HFACS provided a theoretically derived and validated framework for accident/incident investigation and analysis, a similar framework did not exist that would allow the FAA and other organizations to evaluate the potential benefits of current and proposed human error intervention strategies. So the better question may be whether a "human factors" analysis of safety programs is even possible.

NASA Intervention Strategies

At least one study (Wiegmann & Rantanen, 2003) suggests that such an analysis can be performed using a set of standards derived from the same body of literature used to develop HFACS. In their book, *A Human Factors Approach to Aviation Accidents,* Wiegmann and Shappell (2003) described an intervention taxonomy clustered around four broad categories:

1. Environment (e.g., the control of temperature, noise, vibration, lighting)
2. Human (personnel selection, incentives, training, teamwork, communication, etc.)
3. Machine (engineering design, capacity, etc.)
4. Task (ordering/timing of events, procedures, standardization, etc.)

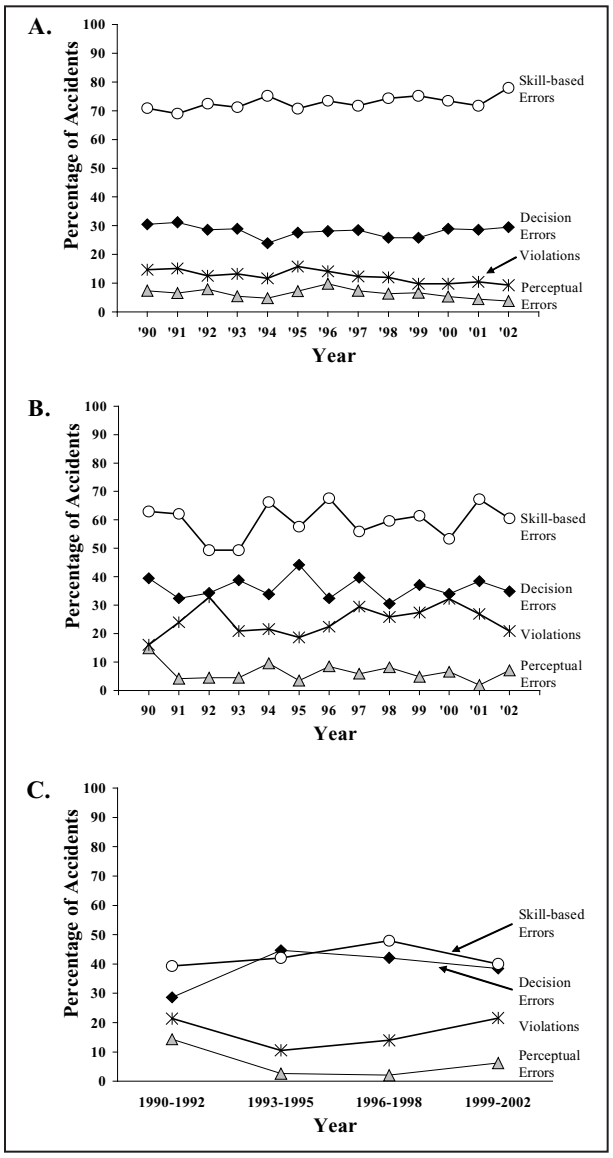

Figure 1. Percentage of unsafe acts committed by aircrew during general aviation (Panel A) commuter (Panel B) and air carrier (Panel C) operations by year. Note that percentages will not add up to 100% due to multiple causal factors associated with most accidents.

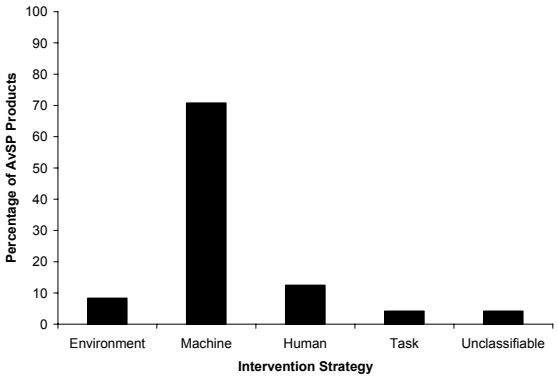

Figure 2. Percentage of NASA safety programs within each intervention category.

Using this framework, Wiegmann and Rantanen (2003) examined a variety of technologies developed by NASA's aviation safety program (AvSP). From energy absorbing seats, restraints, and structures to synthetic vision, each safety program was classified within one of the four intervention categories. As shown in Figure 2, they concluded that NASA's primary intervention strategies targeted the machine rather than the human, environment, or task. Two programs, Incident Reporting Enhancement Tools and Fast-time Simulation of System-wide Risks, were considered unclassifiable by the raters using these categories.

In a separate part of their study, Wiegmann & Rantanen (2003) examined the NASA technologies using the HFACS framework. Surprisingly, it was determined that nearly half of the technologies that NASA was developing were rated as having no impact on aircrew error. What's more, those that might have an impact primarily targeted decision errors, by providing better information, automation, and training. An even smaller percentage of the technologies targeted aircrew error, in general, and only one of the products primarily targeted skill-based errors – the most frequent human error facing both commercial and general aviation. None of the products primarily targeted violations, another area of concern within civilian aviation operations.

Purpose

Clearly, if improvements in safety are to be realized, a more systematic methodology is needed for generating intervention/prevention strategies that can tie into human error frameworks like HFACS. Such a methodology would help ensure that factors affecting human performance are addressed at multiple levels and from multiple directions, thereby facilitating the development of effective intervention *strategies* rather than a single, narrowly focused design fix.

This report describes two studies that build upon the methodology originally described by Wiegmann and Shappell (2003) and used by Wiegmann and Rantanen (2003) with NASA safety programs. The first study describes an independent validation of the four intervention methodologies using safety recommendations from the NTSB. The second describes the examination of proposed FAA aviation safety programs using a prototype intervention matrix that maps the unsafe acts of operators (i.e., skill-based errors, decision errors, perceptual errors, and violations) onto several intervention approaches.

STUDY 1: ANALYSIS OF NTSB RECOMMENDATIONS

Investigating accidents, identifying potential interventions, and issuing safety recommendations are central to any safety program and as such are a major function of local, state, and federal safety boards. Indeed, one such national entity, the NTSB, cites safety recommendations as "… the most important part of [their] mandate…" (NTSB, 2002).

Ideally, safety recommendations, when adopted by cognizant organizations, will positively influence future operations in the field and thereby improve overall system safety. However, recommendations are just that … *recommendations* and, as such, are not always adopted. Moreover, they are often based solely on isolated events or at best a few events over a very short period of time rather than more global analyses of the system as a whole. While these interventions may solve a local or single-point problem, they often do not have far-reaching impact.

Further complicating matters, many domains such as aviation and their corresponding safety boards have traditionally strong relations with quantitative disciplines like engineering and physics. Consequently, while these organizations may be especially adept at dealing with mechanical issues, they tend to be less robust when dealing with organizational or human-centered aspects of accidents like human error, organizational failure, communication, and risk assessment (Stoop, 2002).

Recognizing this, the NTSB, like many safety entities, has integrated human factors experts into their organization, presumably leading to recommendations that address the entire system rather than a single engineering or mechanical aspect, per se. However, employing human factors experts alone does not necessarily translate into a breadth of interventions. The question remains, what specific intervention approaches does the NTSB employ? In other words, does the NTSB tend to be uni-dimensional (like NASA) or multi-dimensional with regard to specific intervention approaches?

METHOD

NTSB Safety Recommendations

To examine this question, aviation safety recommendations associated with commercial (14 CFR Part 121 – air carrier and Part 135 – commuter) aviation accidents occurring between 1998 and 2004 were obtained from the NTSB's official Website (www.ntsb.gov). Of the 147 commercial aviation accidents reports that were completed at the time of this study, 622 unique safety recommendations were identified. However, several of the recommendations consisted of compound solutions. In those cases, the original recommendation was separated into sub-recommendations while preserving the intent of the NTSB. This resulted in a revised list of 872 unique recommendations for further analysis.

Clustering Process

The recommendations were independently clustered into categories by two analysts (one with a doctoral-level background in psychology, the other with a graduate background in engineering) based on their similarities. The analysts were not instructed to use any predefined taxonomy or classification scheme. They were simply instructed to independently assign each recommendation to categories of their choosing, based upon the nature of the recommendation.

Not surprising, given the vagueness of the instructions, there were some differences in the terms used by the two analysts, but there were also strong similarities. Wherever disagreements occurred, the analysts were asked to discuss their clustering heuristic and to agree on a single classification scheme. In the end, all 872 recommendations were classified based on their underlying similarities by two independent analysts, who later came to a consensus on the number and labels for each of these clusters.

Results

Ultimately, the analysts generated nine unique categories of recommendations, which included the design of parts/displays, procedures, communication, training, requests to conduct focused studies, rules, manuals, inspection, and human resources. These nine categories were then further clustered into four larger categories based on their similarities: 1) administrative/organizational; 2) mechanical/ engineering; 3) human/crew; and 4) task/mission. Each category and their accompanying subcategories are briefly described in Table 1.

Distribution of recommendations

On average, roughly six recommendations spread across just under three (2.8) intervention subcategories were observed per accident. The actual distribution of recommendations across the intervention categories and subcategories is presented in Table 2.

From a global perspective, it appears that roughly two-thirds of the recommendations were either administrative/organizational or mechanical/ engineering fixes. However, nearly a quarter of the recommendations were aimed at either the task or mission.

Surprisingly few interventions directly targeted operators (aircrew), even though previous studies repeatedly show that more major accidents have been attributed to human error than to any other single cause (Wiegmann & Shappell, 2003; Boquet et al., in review; Detwiler et al.,

Table 1. Proposed categories and subcategories of NTSB recommendations.

Administrative/Organizational

Rules/Regulations/Policies: Issuing, modifying, establishing, amending, and/or reviewing policies, rules, or regulations.
Information Management/ Communication: Improvements in disseminating, storing, archiving and publishing information. Also included are recommendations regarding collecting data; issuing information bulletins, advisory circulars, and reporting activity.
Research/ Special Study: Conducting research to determine the impact of recent technological advances or call for special studies to review processes, develop/validate methodologies, evaluate the feasibility of safety equipment, and/or conduct surveys.
Human Resource Management: Adequacy of staff in specific situations, the need for additional personnel, and the evaluation of individual skills of employees.

Mechanical/Engineering

Design/Repair: Specific manufacturing changes including the design of parts. Also included is the modification, replacement, removal and/or installation, or repair of parts and equipment.
Inspection: Maintenance inspections, overhauling, detecting damage, including day-to-day operations such as inspecting fuel, oil level, and recommended safety checks.

Human / Crew

Training: Reviewing, developing, and implementing training programs. Also included is the training of personnel in handling emergencies.

Task/Mission

Procedures: Amending, reviewing, modifying, revising, establishing, developing, and validating procedures.
Manuals: Reviewing, revising, issuing, amending, and modifying manuals, bulletins, checklists, and other instructions or guidance.

2006; Shappell et al., in press). It has also been observed that wider systemic issues, including the managerial and regulatory context of aviation operations, were also mentioned in a large number of reports (Holloway & Johnson, 2004; Johnson, in review), even though this does not seem to be reflected in the accident record.

A closer examination revealed that, similar to Wiegmann and Rantanen's study of NASA safety programs, design fixes constituted the largest percentage of any individual type of recommendation made by the NTSB

Table 2. Percentage of recommendations associated with each intervention category.

Intervention Category	%	n
Administrative/Organizational	**34.18**	
Rules/Regulations/Policies	9.29	81
Information management/ Comm.	13.76	120
Research/Special study	10.44	91
Human resource management	0.69	6
Mechanical/Engineering	**31.20**	
Design/Repair	23.17	202
Inspection	8.03	70
Human/Crew	**11.47**	
Training	11.47	100
Task/Mission	**23.16**	
Procedures	14.56	127
Manuals	8.60	75

(23.17%) - nearly twice as many as any other category. Considerably fewer were aimed at procedures, training, information management/ communication, and the other subcategories.

SUMMARY

To date, there have been few attempts to systematically study recommendations generated by investigative organizations like the NTSB. This is unfortunate, because the results of such studies may help in understanding why accident rates have stabilized over the last several decades and could lead to the development of more effective intervention strategies. For example, in this study alone there were four broad categories of interventions identified, comprising nine unique categories of recommendations.

When examining the breadth and scope of NTSB recommendations, even at this level, it appears that current safety recommendations in aviation tend to focus more on improving the design of systems or some manner of organizational change rather than focusing on operational personnel. While these recommendations are obviously well-intentioned and often specific to a particular accident, they may be misplaced or too narrow in scope. This may help explain why the percentage of accidents associated with human error has not changed over the last 15 years (Wiegmann & Shappell, 2003; Wiegmann et al., 2005; Shappell et al., in press).

This is not to say that the design of new technology will not have a significant impact on how people perform. After all, advances in aviation technology and engineering have accounted for marked reductions in the aviation accident rate since the late 1950s. On the other hand, some of these advances have led to new, occasionally

catastrophic, errors (e.g., autopilot-mode errors, Sarter & Woods, 1992; 1994). What appears to be required is a broader, systematic approach to accident intervention, particularly if we are to effectively address human error within aviation operations. But how can this be done?

To ensure that safety professionals generate effective intervention strategies, rather than a single "knee jerk" fix to a problem, knowledge of all viable interventions is required. Towards these ends, the present study suggests that there are at least four broad categories of interventions that appear tenable within the aviation industry. These are Administrative/Organizational, Human/Crew, Mechanical/Engineering, and Task/Procedure.

These four approaches differed slightly from those previously proposed by Wiegmann and Shappell (2003) and utilized by Wiegmann and Rantanen (2003) to analyze NASA safety programs. One category that naturally surfaced from the present analysis, but was missing from the Wiegmann and Rantanen study, was Administrative/Organizational interventions. In contrast, "environmental" interventions did not appear in the current study but were present in the NASA study (Wiegmann & Rantanen, 2003).

In the end, the question is not whether or not there are three, four, five, or more approaches to identifying potential accident interventions as much as there is definitively more than one. Exactly what those approaches are remains to be fully explored. However, the five approaches identified between the present study and the investigation conducted by Wiegmann and Rantanen (2003) is a reasonable first start.

STUDY 2: HFIX ANALYSIS OF JSAT/ JSIT RECOMMENDATIONS

Identifying viable approaches for intervening, however, is only the first step. The ability to map interventions onto specific types of human error is also vitally important. In other words, simply generating a variety of interventions across several domains, whether they are human, mechanical, environmental, and so on, is likely to be ineffective unless such interventions directly target the problem area.

Given that human error continues to be the largest contributor to commercial and general aviation accidents, it makes sense to map different interventions against specific error forms. What is needed is a theoretical framework that captures the underlying causal mechanisms of human error along with the intervention approaches identified in Study 1.

Human Factors Analysis and Classification System

Such an error framework already exists and is widely used within the aviation industry. This framework, the Human Factors Analysis and Classification System (HFACS), describes two general categories of unsafe acts that operators commit: *errors* – the honest mistakes individuals make every day, and *violations* – the willful disregard for the rules and regulations of safety.[1] Within those two overarching categories, HFACS describes three types of errors (decision, skill-based, and perceptual) and two types of violations (routine and exceptional). Each is briefly described below.

Errors

One of the more common error forms, *decision errors*, represents conscious, goal-intended behavior that proceeds as designed, yet the plan proves inadequate or inappropriate for the situation. Often referred to as "honest mistakes," these unsafe acts typically manifest as poorly executed procedures, improper choices, or simply the misinterpretation or misuse of relevant information.

In contrast to decision errors, the second error form, *skill-based errors,* occurs with little or no conscious thought. Just as little thought goes into turning one's steering wheel or shifting gears in an automobile, basic flight skills such as stick and rudder movements and visual scanning often occur without thinking. The difficulty with these highly practiced and seemingly automatic behaviors is that they are particularly susceptible to attention and/or memory failures. As a result, skill-based errors such as the breakdown in visual scan patterns, inadvertent activation/deactivation of switches, forgotten intentions, and omitted items in checklists often appear. Even the manner in (or skill) which one flies an aircraft (aggressive, tentative, or controlled) can affect safety.

While decision and skill-based errors have dominated most accident databases and have, therefore, been included in most error frameworks, the third and final error form, *perceptual errors,* has received comparatively less attention. No less important, perceptual errors occur when sensory input is degraded, or "unusual," as is often the case when flying at night, in the weather, or in other visually impoverished environments. Faced with acting on imperfect or incomplete information, aircrews run the risk of misjudging distances, altitude, and decent rates, as well as responding incorrectly to a variety of visual/vestibular illusions.

[1] A complete description of the entire HFACS framework, including all 4 tiers and 19 causal categories, can be found in Wiegmann and Shappell, 2003.

Violations

Although there are many ways to distinguish among types of violations, two distinct types have been identified based on their etiology. *Routine violations* tend to be habitual by nature and are often enabled by a system of supervision and management that tolerates such departures from the rules (Reason, 1990). Often referred to as "bending the rules," the classic example is that of the individual who drives his/her automobile consistently 5-10 mph faster than allowed by law. While clearly against the law, the behavior is, in effect, sanctioned by local authorities (police) who often will not enforce the law until speeds in excess of 10 mph over the posted limit are observed.

Exceptional violations, on the other hand, are isolated departures from authority, neither typical of the individual nor condoned by management. For example, while driving 65 in a 55 mph zone might be condoned by authorities, driving 105 mph in a 55 mph zone certainly would not. It is important to note that while most exceptional violations are appalling, they are not considered "exceptional" because of their extreme nature. Rather, they are regarded as exceptional because they are neither typical of the individual nor condoned by authority.

Human Factors Intervention Matrix (HFIX)

A prototype matrix, called the Human Factors Intervention Matrix (HFIX), pits the unsafe acts individuals commit against the five different intervention approaches presented in Figure 3. The utility of such a framework seems intuitive. For example, if one were interested in developing interventions to address decision errors, the goal would be to identify prospective interventions within each approach (i.e., organizational/administrative, human/crew, etc.), thereby ensuring that the widest array of interventions were considered. By mapping prospective interventions onto the matrix, it would be readily apparent if the scope of a proposed program was uni- or multi-dimensional.

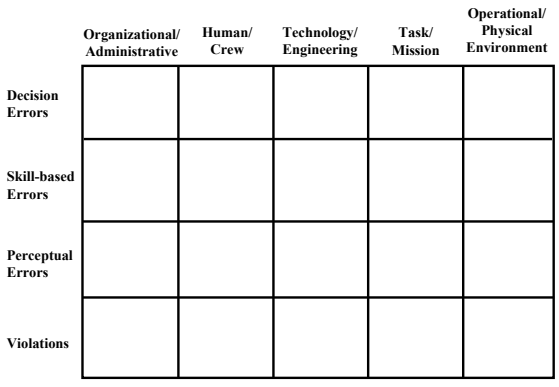

Figure 3. The "Human Factors Intervention matriX" (HFIX).

Alternatively, a framework like HFIX could be used proactively to determine which areas an organization has "covered" and where gaps exist in the current safety program given current trends in the error data. For instance, if you knew that the largest threat to safety within your organization was skill-based errors, followed by decision errors, violations, and perceptual errors (as is the case with general and commercial aviation in the U.S.), HFIX could be used to determine if your proposed and future interventions have the potential to address those needs and which areas are currently being targeted.

Hence, the purpose of Study 2 was to determine if such an approach could be used within the FAA and which types of human error might be affected by current and future interventions. In a sense, this analysis would provide a "benchmark" of current FAA intervention efforts. When combined with existing HFACS data (e.g., Shappell et al., in press; Detwiler et al., 2006; Wiegmann et al., 2005) possible gaps, if any, may be identified.

FAA *Safer Skies* Initiative

As part of the FAA's *Safer Skies* initiative, three teams of experts from government, employee advocacy groups (e.g., the National Air Traffic Controllers Association), the aviation industry, and academia were formed to address civilian aviation accidents. Two of those teams, the Commercial Aviation Safety Team (CAST) and General Aviation Joint Steering Committee (GAJSC), were formed to address specific threats to commercial and general aviation, respectively.

With the CAST and the GA JSC providing oversight, three working groups were formed: 1) Joint Safety Analysis Teams (JSATs), 2) Joint Safety Implementation Teams (JSITs), and 3) Joint Implementation Monitoring Teams (JIMTs). Particularly germane to this study were outcomes derived from the JSAT and JSIT working groups since they represented current and future interventions necessary to address human error associated with commercial and general aviation accidents. In particular, this study was interested in the recommendations from JSAT/JSIT teams examining accidents associated with:

- Controlled flight into terrain
- Approach and landing
- Loss of control
- Runway incursions
- Weather
- Pilot decision-making

METHOD

JSAT and JSIT Recommendations

JSAT and JSIT reports were collected from each CAST and GA JSC committee by researchers at the Civil Aerospace Medical Institute. After eliminating duplicate recommendations, a comprehensive list was compiled electronically for classification. The final list of 614 unique recommendations was then randomized to reduce bias.

Categorization of the Data

Eighteen Master of Aeronautical Science candidates were recruited from Embry-Riddle Aeronautical University for Study 2. Each had experience in the aviation community as either a pilot, maintainer, or at an administrative level, and all had successfully completed a minimum of one graduate-level human factors course.

After a roughly 4-hour training session on the HFACS and HFIX frameworks, subjects were randomly assigned to one of six groups. Each 3-person team was then randomly assigned roughly one-sixth of the recommendations to classify.

Each team member was instructed to independently classify each recommendation into **only one** of the five intervention approaches (i.e., organizational/ administrative, human/crew, mechanical/engineering, task/mission, or physical environment). In addition, they were instructed to identify **any** HFACS Unsafe Acts categories they felt the intervention would impact.

After the initial rating, team members were permitted to discuss their classification within their group to resolve any differences. A final, consensus classification for each recommendation was then provided for further analysis.

HFACS UNSAFE ACTS	Organizational/ Administrative	Human/ Crew	Technology/ Engineering	Task/ Mission	Operational/ Physical Environmen	
	INTERVENTIONS					
Decision Errors	25.9%	26.9%	13.4%	5.7%	0.8%	72.6%
Skill-based Errors	13.8%	20.7%	12.5%	2.4%	0.2%	49.7%
Perceptual Errors	9.0%	12.7%	12.4%	2.4%	1.1%	37.6%
Violations	14.3%	7.8%	2.8%	1.3%	0.7%	26.9%
	36.6%	32.6%	22.2%	7.3%	1.3%	

Figure 4. Percentage of JSAT/JSIT recommendations classified by intervention approach and specific HFACS Unsafe Act addressed.

RESULTS

The results of both classification tasks are presented in Figure 4. Several observations can be made from the data. First, as with the NTSB recommendations, a large percentage (36.6%) of the JSAT/JSIT recommendations were directed at organizational/administrative levels. Likewise, several (22.2%) of the recommendations involved technological/engineering approaches. However, unlike the NTSB where relatively few recommendations targeted the human, nearly one-third of those obtained from the JSAT/JSITs did so. This may be because, unlike the NTSB recommendations, we selectively chose those JSAT/JSIT reports that addressed human error issues like pilot decision-making and runway incursions. In that sense, the JSAT/JSIT data were much more homogenous (i.e., they did not contain non-human related accidents) and the proposed interventions may simply reflect that inherent bias. However, if that were true, one might actually expect that an even larger percentage of the recommendations would target the human/crew than was actually observed.

When examining the HFACS classifications, remember that, unlike the specific approaches to accident interventions where subjects were instructed to select only one approach, they were permitted to select **all** of the HFACS Unsafe Act categories that they felt would be impacted by a given recommendation. Therefore, unlike the intervention approaches whose percentages added up to 100%, the total percentages associated with each Unsafe Act category did not.

Perhaps not unexpected, interventions aimed at decision errors were associated with nearly three out of every four JSAT/JSIT recommendations examined. In contrast, skill-based errors were associated with roughly 50% of the recommendations followed by perceptual errors (37.6%) and violations (26.9%). Of note, these numbers are slightly different than the percentage of accidents associated with each type of error where skill-based errors account for between 45-80% of the accidents, depending on whether one is talking about commercial or general aviation, respectively (see Figure 1). Likewise, roughly 1/3 of the accidents were associated with decision errors, yet 72.6% of the interventions have some component that will potentially affect pilot decision-making.

This is not to say that there should be a one-to-one relationship between the percentage of accidents associated with a given error category and the percentage of recommendations aimed at addressing these errors. After all, it may take more effort to address one error form than another, or more interventions may naturally address pilot decision-making. In either case, the global analysis presented here suggests that additional review of this apparent incongruity is necessary.

Perhaps more important, however, was the mapping of each intervention within both the intervention approach and the HFACS Unsafe Acts category (Figure 4). As can be seen (white boxes), three of the 20 possible boxes (organizational/ administrative by decision error, human/crew by decision error, and human/crew by skill-based error) contained 20% or more of the JSAT/JSIT interventions. On the surface, this appears to reflect a narrow rather that a broad approach to accident intervention/mitigation by these committees. It is not that the interventions contained within these categories will not be effective, just that other, potentially equally viable, interventions may have been overlooked.

It is interesting to note, however, that if one examines those boxes that contained between 10-20% of the possible interventions, nearly all of the remaining boxes among the organizational/ administrative, human/crew, and technology/ engineering approaches are included. What was not accounted for were human/crew and technology/engineering approaches dealing with violations of the rules and regulations. Obviously, these approaches might prove beneficial if an organization wanted to modify or curtail a particular unsafe pattern of behavior (e.g., flight into instrument conditions while on a visual flight rules flight plan) through training or technological means.

More notable was the general lack of interventions targeting the specific task/mission of the aircrews or the environment they are faced with. Perhaps a closer examination of the operations these aircrews are engaged in or the environments they are expected to operate in is warranted. In any event, there may have been options along these lines that were not considered by these select committees.

SUMMARY

Ideally, tools such as HFIX provide a *Gestalt* of the safety program as a whole rather than an item-by-item accounting of each intervention in an organization. After all, it is hard to know if pieces are missing in a puzzle until you put them together. HFIX allows administrators and safety managers to put the intervention pieces together in such a way that they can get a "quick look" at the strengths and weaknesses of their programs. Additionally, it provides decision makers within an organization the ability to ensure that a broad spectrum of interventions has been considered. After all, only the most elementary of puzzles is comprised of just a few pieces; obviously, something as complex as human error in aviation will consist of a number of pieces.

That being said, the results from Study 2 using JSAT/JSIT interventions, although clearly more multi-dimensional than NASA's safety programs, still did not appear to fully address the current accident trends in commercial and general aviation. At least on the surface, it appears that there are gaps in the safety program that should be addressed.

For example, there was an apparent bias toward interventions aimed at pilot decision-making, particularly those utilizing organizational and human approaches. While this is not inherently bad, previous HFACS analyses suggest that additional effort should be placed on skill-based errors and violations, two areas that appear underrepresented, given current trends in the accident data.

Also noteworthy, few interventions attempted to modify/change the task itself or the environment. A closer examination of the actual types of errors may suggest changes in routes people fly or the actual type of flights being flown.

However, while HFIX may prove useful when generating comprehensive intervention strategies, organizations simply cannot implement every recommendation. Other factors may need to be considered before employing a given intervention. Factors such as *effectiveness* (i.e., what is the likelihood that it will work?), *cost* (i.e., can the organization afford the intervention?), *feasibility* (i.e., how easy will the intervention be to implement or does it actually exist?), and *acceptability* (i.e., will the workforce accept the proposed intervention?) all must be considered.

As such, HFIX may actually be HFIX^3 mapping human error against the intervention approaches and evaluations criteria (Figure 5). Although it may appear complex, in reality organizational decision makers utilize this third dimension all the time. To apply it to the two-dimensional HFIX framework is really not that great a leap. However, even without this third dimension, the mapping of specific interventions onto a matrix that combines the five intervention approaches with general categories of human error can provide a broader perspective of the FAA's safety programs.

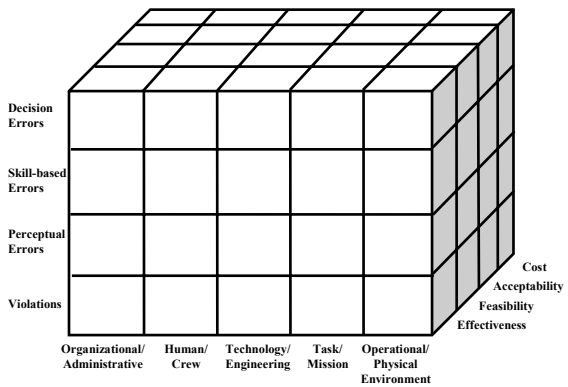

Figure 5. The HFIX^3 framework.

GENERAL DISCUSSION

Historically, most safety professionals have been heavily acculturated by their own academic disciplines. While such indoctrination and training can facilitate the development of highly specialized interventions, it can also lead to "mitigation myopia," in which provincial prevention measures prevail. This is not to say that such dogmatism is intentional. Rather, these biases or "cognitive constraints" placed on our creativity are quite simply the natural byproducts of the acculturation process associated with each academic discipline or society in which one lives. It should come as no surprise then that, while engineers have traditionally blamed the operator for errors and behaviorists have wanted to fault system design for inducing errors, the fixes have been predictable. That is, engineers tend to recommend engineering solutions, and psychologists tend to recommend behavioral/human-centered fixes. In a broader sense, even societies that emphasize individual responsibility for one's own actions tend to emphasize punitive fixes.

In essence, safety recommendations are not simply based on empirical findings surrounding an accident. Rather, they are based on one's philosophical view of what actually constitutes a "cause" of an event, coupled with one's own biased view of how changes in human or system behavior can even be accomplished. Therefore, thinking "outside the box" when it comes to generating intervention strategies is extremely difficult to do; yet failure to do so can leave other potentially viable and effective alternatives unexplored.

What shall we say then, that we are forever helpless victims of our own acculturation and training? Absolutely not! Just like other cognitive biases (e.g., confirmation bias and hindsight bias), we must first acknowledge and recognize the potential impact that our own "mitigation bias" has on constraining our judgment and then generate tools and techniques for circumventing these constraints.

In the end, perhaps Reason (2005) put it best when he said, "[Human errors] are like mosquitoes. They can be swatted one by one, but they still keep coming. The best remedies are to create more effective defenses and to drain the swamps in which they breed." Where the HFACS framework provides a view of the swamp, HFIX makes certain that we are draining the right swamp in the most efficient and thorough manner.

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