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Human Error Perspectives in Aviation

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As aircraft have become more reliable, humans have played a progressively more important causal role in aviation accidents, resulting in the proliferation of human error frameworks and accident investigation schemes. To date, however, few efforts have been made to systematically organize these different approaches based on underlying theoretical similarities, and formalized methods for evaluating the utility of these multiple approaches have not been clearly defined. Many safety professionals, therefore, have been at a loss when choosing which error analysis and prevention approach to use within their organizations. As a result, those tasked with instituting human-centered safety programs often rely primarily on personal experience and intuition to address their needs. The purpose of this article is to help remedy this situation by providing safety practitioners with an overview of the prominent human error perspectives in aviation, as well as a set of objective criteria for evaluating human error frameworks.

Over the last several decades, humans have played a progressively more important causal role in aviation accidents as aircraft have become more reliable (Nagel, 1988; National Transportation Safety Board [NTSB], 1994b; O'Hare, Wiggins, Batt, & Morrison, 1994; Shappell & Wiegmann, 1996; Yacavone, 1993). Consequently, a growing number of aviation organizations are tasking their safety personnel with developing safety programs to address the highly complex and often nebulous issue of human error. It is regrettable, however, that many of today's aviation safety personnel have little formal education in human factors or aviation psychology. Instead, most are professional pilots with general engineering and techni-

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cal backgrounds. Thus, many safety professionals are ill-equipped to perform these new duties, and, to their dismay, they soon discover that a standard, "off-the-shelf" approach for addressing human error in aviation does not exist. In fact, human error is a topic that researchers and academics in the fields of human factors and psychology have been grappling with for decades.

Indeed, there are a number of perspectives on human error, each of which is characterized by a common set of assumptions about the nature and underlying causes of errors. Unfortunately, from the practitioner's point of view, there often appears to be as many human error models and frameworks as there are people interested in the topic (Senders & Moray, 1991). Even worse, most error models and frameworks tend to be theoretical and academic, making them of little benefit to the applied needs of practitioners. Therefore, having been left without adequate guidance and objective criteria for choosing a particular approach, many practitioners have resorted to developing error-management programs based on intuition or "pop psychology" concepts rather than on theory and empirical data. The end results are safety programs that, on the surface, produce a great deal of activity (e.g., safety seminars and "error awareness" training), but in reality only peck around the edges of the true underlying causes of human error. Demonstrable improvements in safety are therefore hardly ever realized.

The purpose of this article is to remedy this situation by providing practitioners with a general overview of the prominent human error perspectives within the literature. Examples of frameworks that characterize each approach are provided, as well as a critique of the strengths and weakness of each perspective. A brief discussion of some objective criteria for evaluating error frameworks within each perspective are then presented. Ideally, this overview of error perspectives and evaluation criterion will help practitioners systematically and objectively sort through the choices and will better equip practitioners to develop error management and prevention programs that are theoretically and scientifically based. Perhaps then, definitive improvements in aviation safety will be more readily forthcoming.

TRADITIONAL HUMAN ERROR PERSPECTIVES

Previous reviews of the human error literature (e.g., Hollnagel, 1998; Wiegmann, Rich, & Shappell, 2000) have revealed several perspectives on the nature and causes of human error. Within the context of aviation, however, there are primarily five different perspectives: (a) cognitive, (b) ergonomics and systems design, (c) aeromedical, (d) psychosocial, and (e) organizational.

Cognitive Perspective

Based in large part on general information processing theory, the principal feature of cognitive models is the assumption that information progresses through a series of stages or mental operations (e.g., attention allocation, pattern recognition, and decision making) that mediate between stimulus input and response execution (Wickens & Flach, 1988). Within this approach, errors occur when one or more of these mediating operations fail to process information appropriately. Rasmussen (1982), for example, developed a detailed taxonomic algorithm for classifying various types of information processing failures associated with the erroneous actions of operators. This taxonomic algorithm, as employed within the context of aviation (e.g., O'Hare et al., 1994; Wiegmann & Shappell, 1997; Zotov, 1997), uses a six-step sequence to diagnose the underlying cognitive failures responsible for an error (see Figure 1). As described by O'Hare et al., the algorithm includes stimulus

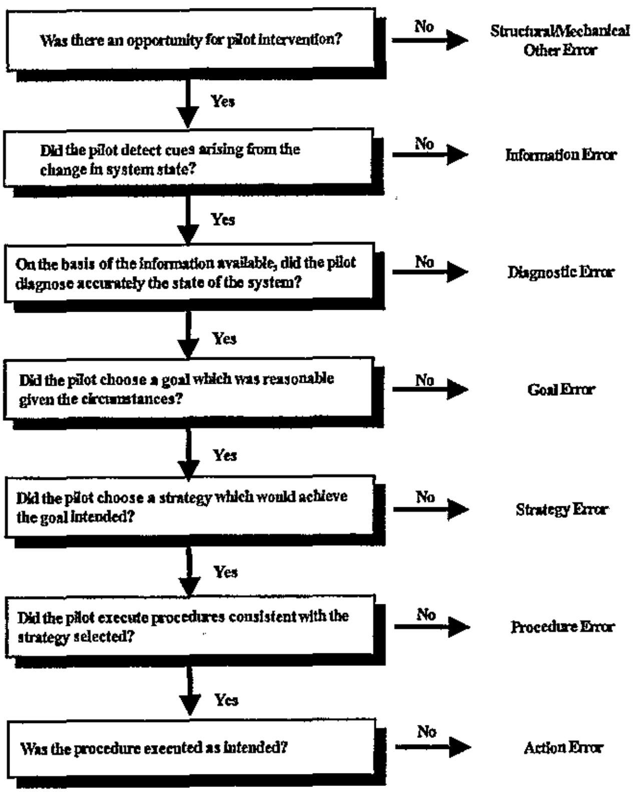

FIGURE 1 Rasmussen's (1982) taxonomic algorithm for classifying information processing failures as adapted by O'Hare et al. (1994). From "Cognitive Failure Analysis for Aircraft Accident Investigation," by D. O'Hare, M. Wiggins, R. Batt, and D. Morrison, 1994, *Ergonomics, 37,* p. 1863. Copyright 1994 by Taylor & Francis Ltd. (http:www.tandf.co.uk/journals). Reprinted with permission.

detection, system diagnosis, goal setting, strategy selection, procedure adoption, and action stages, all of which can fail either independently or in conjunction with one another to cause an error.

Given the popularity of general models of information processing, it is not surprising that cognitive models are one of the most commonly used approaches for analyzing human error in complex systems. These models appeal to many safety practitioners because they go beyond the simple classification of "what" the erroneous action entailed (e.g., the pilot failed to lower the landing gear) to address the underlying causes of such errors (e.g., attention failures or decision errors). As such, cognitive models allow seemingly unrelated errors to be analyzed based on similar underlying cognitive failures. This, in turn, allows for the identification of specific error trends so that intervention and mitigation strategies can be readily developed.

Wiegmann and Shappell (1997) for example, used three cognitive models, including the modified Rasmussen (1982) model depicted in Figure 1, to analyze more than 4,000 pilot-causal factors associated with approximately 2,000 U.S. Naval aviation mishaps. Although the three cognitive models differed slightly in the types of errors that they captured, all three generally converged on the same conclusion. That is, judgment errors (e.g., decision-making, goal-setting, and strategy-selection errors) were associated more with major accidents, whereas procedural and response execution errors were more likely to occur with minor accidents. These findings were similar to those found with other military (Diehl, 1992) and civilian aviation accidents (Jensen & Benel, 1977, O'Hare et al., 1994) using the cognitive approach. Notably, studies such as these have helped dispel the widely held belief that the only difference between a major and minor accident is little more than luck and timing.

Cognitive models, however, are not without limitations. First, the exact procedures for applying cognitive models to error analysis and accident investigation have yet to be fully defined. As such, the application of these models may require analysts and investigators to rely as much on speculation and intuition as they do on objective methods. Furthermore, cognitive models typically do not address contextual or task-related factors (e.g., equipment design) or the physical condition of the operator (e.g., fatigue), and they do not consider supervisory and other organizational factors that often impact performance. As a result, they can often encourage an extreme, single-minded view that focuses solely on the operator (aircrew) as the "cause" of the error. Such single-mindedness may result in blame being unduly placed on the individual who committed the error rather than on the error's underlying causes, over which the individual may have little or no control. Within the context of aviation, this can be seen by those who express the view that pilots are the major cause of aircraft accidents or the pilot and aircrew are the weak link in the aviation safety chain. In effect, pilots may be viewed as being more dangerous than the aircraft they fly (Feggetter, 1985; Murray, 1997). Clearly, such extreme views are detrimental to aviation safety in general and may limit the advancement of the cognitive approach.

Ergonomics and Systems Design Perspective

According to the systems perspective, the human is rarely, if ever, the *sole* cause of an error or accident. Rather, human performance (both good and bad) involves a complex interaction of several factors. In fact, "system models recognize the inseparable tie between individuals, their tools and machines, and their general work environment" (Heinrich, Petersen, & Roos, 1980, p. 51). One of the most well known is Edwards's (1988) SHEL model, which describes four basic components necessary for successful human–machine integration and system design (see Figure 2):

1. Software—the rules, regulations that govern operations.
2. Hardware—equipment, material, and other physical resources.
3. Environmental conditions.
4. Liveware—the human.

According to Edwards (1988) and other systems theorists (e.g., Firenze, 1971), system failures occur when there is a mismatch between these components or

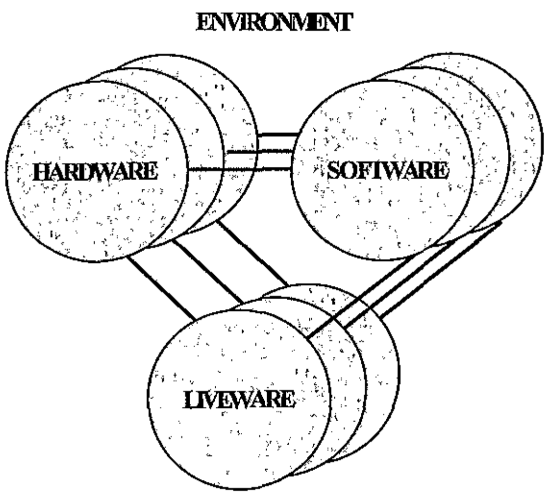

FIGURE 2 Edwards's SHEL Model of Systems Design. From *Human Factors in Aviation* (p. 12), by E. L. Wiener and D. C. Nagel, 1988, San Diego, CA: Academic Press. Copyright 1988 by Academic Press, Inc. Reprinted with permission.

when other environmental or task-related stressors degrade operator performance. Historically, within aviation, the focus has been on the liveware (human)–hardware (machine) interface yielding significant improvements in cockpit layout and other so-called "knobs and dials" issues. These improvements have accounted for much of the decline in accidents realized over the first 50 years of aviation. In fact, the match between the human and the equipment within a given environment is viewed as so crucial to aircraft development that human factors principles are often considered throughout the design process.

The systems approach has some clear advantages over the cognitive failure models described earlier. One advantage is that it considers contextual and task-related factors, including equipment design that affect operator performance. As such, systems models discourage analysts and investigators from focusing solely on the operator as the sole source or cause of errors. Therefore, a greater variety of error prevention methods is available, including the possibility of designing systems that are more "error-tolerant." Systems approaches also have an intuitive appeal, particularly to those not formally trained in aviation psychology or human factors. Approaches, such as Edwards's SHEL model, are very easy to comprehend, are relatively complete from an engineering point of view, and are generally well known across disciplines. Indeed, the International Civil Aviation Organization (1993) recommended the use of the SHEL model as a framework for analyzing human factors during aviation accident investigations. Other organizations like the U.S. Air Force and Air Line Pilots Association have also based portions of their investigative framework on this system.

Unfortunately, the generality afforded by systems models often comes at a cost of specificity. The major drawback to systems models is their lack of sophistication when it comes to analyzing the human component of the system. Because systems models focus on the interaction among components, emphasis is placed almost exclusively on the design aspects of the human–machine interface (e.g., the design of knobs, dials, and displays), as well as the possible mismatch between the anthropometric requirements of the task and human characteristics. The effects of cognitive, social, and organizational factors therefore receive only superficial consideration, giving the impression that these components of the system are relatively unimportant. As a result, the systems perspective may promulgate the notion that all errors and accidents are design-induced and can therefore be engineered out of the system—a view not universally held within the aviation safety community.

Aeromedical Perspective

According to the aeromedical approach, errors are often caused by some underlying physiological condition of the aircrew such as hypoxia, dehydration, fatigue, or spatial disorientation. These conditions in turn are often due to illness, jet lag, self-medication, alcohol, smoking, and so on. Within the aeromedical approach, physiological conditions such as these are viewed as pathogens that exist insidiously within the pilot until they are triggered by environmental conditions and manifest as symptoms (errors). In fact, some theorists believe that a pilot's physiology affects every other interaction between system components as defined by such models as SHEL (Reinhart, 1996). In other words, if a pilot is not "medically airworthy," all other components of the system will be negatively affected. According to the aeromedical perspective, therefore, a pilot's physiology is the essential factor in flight safety and error prevention.

Above all else, the aeromedical approach highlights the crucial role that the physiological status of the pilot plays in safe performance (Lauber, 1996). Although this may seem obvious to many, the point has not always been taken seriously. Military pilots have long been taught about hypoxia, decompression sickness, spatial disorientation, and other physiological factors. However, within the civilian sector, training in flight physiology has often been minimized, and civilian pilots frequently have little respect for the significance of physiological factors within aviation (Reinhart, 1996).

One aeromedical factor that has received considerable attention over the years is fatigue. As knowledge of the physiological underpinnings of circadian rhythms and jet lag have developed, an awareness of the impact that such factors have on errors in both military and civilian cockpits has grown. This growing appreciation was strengthened by the NTSB (1994a) ruling that identified fatigue as a causal, rather than contributory, factor in an airline accident—one of the first of such rulings in the history of the Board. Without a doubt, the aeromedical community has played a vital role in shaping both the military's and industry's view of fatigue and has helped shape policies on such contentious issues as work scheduling, shift rotations, and crew rest requirements.

The aeromedical approach, however, is not without its critics. As alluded to previously, many of the physiological factors touted as important by those who assume the aeromedical perspective are seen by others as relatively irrelevant to flight safety. For example, it is often difficult for some pilots to understand how decompression sickness, trapped gases, and gravity-induced loss of consciousness impact pilot performance in modern commercial and general aviation. Even more detrimental to the aeromedical approach, however, is a general lack of appreciation for the role that these variables play when they are present. For example, how fatigued, self-medicated, or disoriented does a pilot have to be before he or she commits an error that fatally jeopardizes the safety of flight? There is little difficulty in imaging how the presence of such factors may "contribute" to an error, but determining whether these factors "caused" an error or accident is another matter entirely. Although this "cause–effect" problem may seem trivial to some, to others in the aviation industry it bears heavily on how resources and personnel are allocated to improve safety within their organizations.

Psychosocial Perspective

According to the psychosocial perspective, flight operations are best viewed as a social endeavor that involves interactions among pilots, air traffic controllers, dispatchers, ground crew, maintenance personnel, and flight attendants. Obviously, such interactions are operating maximally during commercial and military operations and minimally during general aviation operations, although the private pilot is seldom, if ever, alone in the air or on the ground. According to the psychosocial perspective, pilot performance is directly influenced by the nature or quality of the interactions among group members (Helmreich & Foushee, 1993). These interactions in turn are influenced not only by the operating environment but also by both the personalities and attitudes of the individuals within each group. The major theme of psychosocial models, therefore, is that errors and accidents occur when there is a breakdown in group dynamics and interpersonal communications.

Psychosocial models, such as the one proposed by Helmreich and Foushee (1993), highlight the social and interpersonal aspects of human performance within the context of aviation, a perspective that has historically been overlooked by those in the industry (Kayten, 1993). As a result, a growing number of aviation psychologists are now considering these factors when examining aircrew errors. One such study, which involved an industry-wide analysis of aviation accidents, found that over 70% of all accidents resulted from aircrew coordination and communication problems (Lautman & Gallimore, 1987). This finding is not unique to commercial aviation, because aircrew coordination failures have been recognized as a major cause of military aviation accidents as well (Wiegmann & Shappell, 1999; Yacavone, 1993). As a result, many conventional engineering psychologists are now going beyond the traditional design issues of the human–machine interface to deal with the exceedingly complex issue of the human–human interface. Likewise, those who promote the cognitive approach have also begun to consider the possible impact that social factors have on processes such as decision making (Orasanu, 1993). The end result has been a growing appreciation for social factors in the cockpit and the development of crew resource management (CRM) training and crew-pairing procedures that attempt to reduce errors by improving crew coordination and communication in the cockpit.

In reviewing the literature, however, it is apparent that some of the earlier psychosocial models of human error have not achieved the same popularity that current models seem to enjoy. This may be because many of the early models focused largely on personality variables rather than on crew coordination and communication issues that are at the center of most contemporary approaches. One of these early models included the concept of accident proneness, arguing that some individuals were simply predisposed toward making errors and causing accidents (Haddon, Suchman, & Klein, 1964). Another personality model was based on the psychoanalytic (Freudian) view of human behavior, which proposed that errors and accidents are caused by an individual's unconscious desire to harm others or to gratify unfulfilled sexual wishes (Brenner, 1964)—a view clearly out of the mainstream. Eventually, models such as these were rejected based on both empirical and theoretical grounds.

However, even current psychosocial theories are at risk of suffering the same fate if more is not done to firm up the underlying psychosocial mechanisms that presumably lead to errors in the cockpit. With few exceptions (e.g., Helmreich & Foushee, 1993; Orasanu, 1993), little work has been done to empirically test predictions derived from psychosocial models of human error. Indeed, most supporters of the psychosocial approach often reference the accident statistics cited earlier (e.g., Lautman & Gallimore, 1987; Wiegmann & Shappell, 1999; Yacavone, 1993) as confirmation of their perspective. However, these accident data are the same data that were used to initially formulate such models. Therefore, they cannot logically be used again in reverse as supportive evidence. This lack of clarity is affected even more by the all-encompassing definition of CRM currently used in the industry, which describes CRM as the "effective use of all available resources [by the cockpit crew], including human resources, hardware, and information" (Federal Aviation Administration, 1997, p. 2). As an anonymous reviewer once noted—given this "broad definition, one might conclude that the only human error mishap [not caused by] CRM failures would be the deliberate crashing of the aircraft by a depressed or otherwise disturbed crew member." What once appeared to be a useful concept has been expanded to a point that it may have lost at least some of its value.

Organizational Perspective

Organizational approaches to human error have been utilized in a variety of industrial settings for years but have only recently been embraced within the aviation community. This situation may be due in part to the emphasis placed on the aircraft and aircrew in the early days of aviation. Only now are safety practitioners realizing the complex nature of accident and incident causation and the role organizations play in the genesis and management of human error. In fact, it is the emphasis that organizational models place on the fallible decisions of managers, supervisors, and others in the organization that sets them apart from the other perspectives previously discussed.

One such model, Bird's (1974) Domino Theory is indicative of the models contained within the organizational perspective. According to Bird's theory, accidents can be described by a series of five dominos lined up in a sequence, each one effecting the toppling of the next. The first domino, which initiates the sequence, represents safety or the management of operational losses. When failures occur at this level, basic causes (domino two) such as personal and job-related factors begin to appear. In effect, these basic causes are at the root of both operator errors and substandard working conditions (domino three) that directly lead to an accident (domino four) and personal injury or damage to property (domino five).

Several other organizational theorists have developed frameworks similar to Bird's (1974) Domino Theory, including Adams (1976), Weaver (1971), and more recently, Reason (1990). Reason's "Swiss cheese" model of human error, perhaps more than any other, has influenced a new generation of human error theorists. Much like Bird, Reason described four levels of human failure (Figure 3), each one influencing the next: (a) organizational influences, (b) unsafe supervision, (c) preconditions for unsafe acts, and (d) the unsafe acts of operators. Recently, Shappell and Wiegmann (1997, 2001) built on Reason's work to provide a detailed taxonomy of human error at each level for use by both accident investigators and mishap analysts.

One of the benefits of an organizational approach is that it broadens the field of inquiry when it comes to studying and preventing human error. As a result, all the knowledge previously gleaned from the field of industrial and organizational psychology can be brought to bear on the issue of operator error and accident prevention. According to Heinrich et al. (1980), the methods most valuable for error and accident prevention "are analogous with the methods required for the control of the quality, cost, and quantity of production" (p. 21). Indeed, worker productivity is a topic that has long been studied within industrial and organizational psychol-

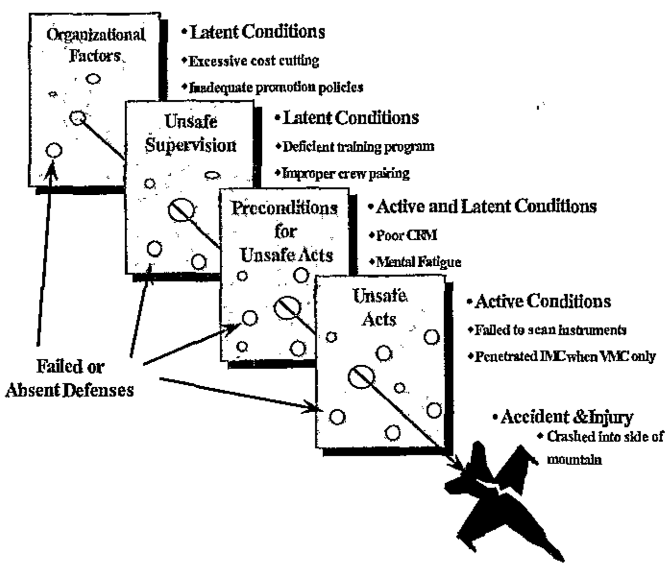

FIGURE 3 Reason's (1990) "Swiss Cheese" model of accident causation. From "Applying Reason: The Human Factors Analysis and Classification System (HFACS)," by S. A. Shappell and D. A. Wiegmann, 2001, *Human Factors and Aerospace Safety, 1*, p. 62. Copyright 2001 by Ashgate Publishing. Reprinted with permission.

ogy. Therefore, the principles and methods of improving worker behavior developed and studied by industrial and organizational psychologists for decades (e.g., selection, training, incentives, and organizational design) might also be effective at reducing human error in aviation. Another advantage of the organizational approach is that it views all human error as something to be managed within the context of risk. The benefits of this operational risk management approach is that it allows the importance of specific errors to be determined objectively based on the relative amount of risk they impose on safe operations.

One criticism of the organizational perspective, however, is that the "organizational causes" of operator errors are often several times removed, both physically and temporally, from the context in which the error is committed (e.g., the cockpit). As a result, there tends to be a great deal of difficulty linking these organizational factors to operator or aircrew errors. Consequently, little is known about the types of organizational variables that cause specific types of errors in the cockpit. Therefore, the practicality of an organizational approach for reducing or preventing operator error can be questioned. Furthermore, as with the other approaches described earlier, organizational models tend to focus almost exclusively on a single type of causal factor. In this case, the causal factor tends to be the fallible decisions of officials within the management hierarchy, such as line managers and supervisors, rather than the aircrew themselves. As a result, organizational models tend to foster the extreme view that "every accident, no matter how minor, is a failure of organization" or that "an accident is a reflection on management's ability to manage ... Even minor incidents are symptoms of management incompetence that may result in a major loss" (Ferry, 1988, p. v).

CRITERIA FOR EVALUATING ERROR FRAMEWORKS

The preceding discussion of the different human error perspectives was provided to help practitioners more easily identify the type of human error approach that is best suited to their individual needs. However, as mentioned earlier, there is no consensus within the field of aviation human factors regarding human error. Therefore, some human factors professionals may take issue, or at least partially disagree, with the way in which one or more of these perspectives and example frameworks were characterized or portrayed. Although this may provide academic fodder for those in the human factors field, that was not the intent of this article. In fact, no perspective may satisfy any one individual's applied needs. What is important is that the reader has a general understanding of the prominent human-error perspectives.

Given that one selects a perspective or perspectives, the next logical question is which framework within each perspective is best. Indeed, some researchers have proposed objective criteria for evaluating the utility of error frameworks in applied settings (Hollnagel, 1998; O'Connor & Hardiman, 1997). Unfortunately, very few error frameworks have been systematically validated using these or any other criteria. Therefore, a detailed presentation or objective summary of each error framework's utility is not available. Furthermore, a standardized set of objective criteria does not even exist in any one place. Consequently, an informal discussion of five criteria that practitioners can use when comparing and choosing among approaches is presented here. These criteria are reliability, comprehensiveness, diagnosticity, usability, and validity.

Reliability

An error framework should produce reliable insights. In other words, its application should result in different users discovering similar factors associated with the same error event (O'Connor & Hardiman, 1997). There are several mathematical indexes of reliability. One of the most common is simply the number of times different users of a framework agree on the same underlying causes or classification of an erroneous action. However, such percentage-agreement indexes do not take into account the likelihood that two people may agree simply by chance. Therefore, an alternative index is Cohen's kappa, which is an index that has been corrected for chance agreements. Cohen's kappa is generally regarded as the best index of inter-rater agreement for error analysis or other similar tasks (see Primavera, Allison, & Alfonso, 1996, for review of methods for quantifying reliability). By conventional standards, index values of .60 to .74 are considered "good" and values of .75 or higher are considered "excellent" levels of agreement (Fleiss, 1981).

With few exceptions (e.g., Wiegmann & Shappell, 1997), little research has been conducted to evaluate and compare the reliability of different error frameworks in applied settings. This is due primarily to the fact that most error frameworks were designed for the sole purpose of addressing the needs of the individual academic researchers using them. Consequently, applied users may initially need to select a few frameworks that appear relevant to their desired purpose and then compare the reliability of these approaches in a real-world context. Indeed, some may find that no existing framework is sufficiently reliable for a particular applied purpose, and therefore, changes or improvements may need to be made. In any case, practitioners should be aware that not all frameworks are equally reliable and that there are many ways of quantifying reliability, some of which are better than others. Reliability is necessary, however, if a framework is to be an effective tool for identifying and preventing human error.

Comprehensiveness

Comprehensiveness is also an important feature of an error framework. Comprehensiveness refers to the extent to which a framework captures all the information or context surrounding an error or accident (O'Connor & Hardiman, 1997). However, a framework's comprehensiveness is relative and depends on the level of analysis that is most desirable in a given context. For example, cognitive frameworks may be very complete when it comes to identifying and classifying information processing errors (e.g., decision errors, diagnostic errors, perceptual errors, attention errors, goal errors, etc.), but they fall short in addressing other contextual and organizational factors. This is not a problem if one is only interested in information processing errors of pilots in the cockpit. In contrast, organizational frameworks often span the gamut of possible error-causing factors (e.g., supervisory, working conditions, policies, procedures, etc.) without getting into the specifics of cognitive error modes. Therefore, they are more thorough at a global level but much less so at the specific cognitive level. Hence, the comprehensiveness of a framework refers to its ability to capture all of the relevant variables at the level of analysis one is interested in pursuing.

Some practitioners will find that available frameworks need to be expanded to meet their applied needs. However, practitioners should avoid simply creating a "laundry list" of causal factors to ensure a framework's comprehensiveness. Such an approach negatively affects other facets of the framework. For example, numerous irrelevant categories may distract investigators and analysts, which in turn will likely reduce the reliability of the framework. Furthermore, smaller organizations may have relatively few critical errors or incidents over a given time period. Therefore, the likelihood that investigators will come across each of the "causal factors" listed in a given framework is much less. As a result, many error databases become littered with "missing values" and only a smattering of unrelated factors, making the identification of causal trends and subsequent interventions virtually impossible.

Diagnosticity

For a framework to be effective, it must also have high diagnosticity. Diagnosticity refers to a framework's ability to identify the interrelations between errors and to penetrate all levels of the system to reveal previously unforeseen trends or causes of errors (O'Connor & Hardiman, 1997). In other words, the framework should not only address "what" error occurred but "why" it happened. A framework with high diagnosticity therefore illuminates those areas ripe for intervention rather than relying solely on intuition and insight. It also means that changes in error trends can be readily identified, allowing for the effectiveness of interventions to be monitored and assessed.

Similar to comprehensiveness, an important issue that often arises when evaluating a framework's diagnosticity is the level of granularity to employ for the evaluation. The question typically raised is why one should stop looking for the causes of errors and accidents at a particular level. Presumably, everything has its own cause. Therefore, a framework with the best diagnosticity would potentially trace the cause of every error and accident all the way back to the dawn of creation! Stopping at any point prior to this is just arbitrary. To circumvent this issue, most theorists have tended to adopt the strategy of searching for "remediable causes." A remediable cause is defined as a cause that is most readily and effectively curable, "the remedy of which will go farthest towards removing the possibility of repetition" (DeBlois, 1926, p. 48). In other words, a framework with high diagnosticity should force analysts and investigations to search far enough back in the sequence of events to identify factors that, if corrected, would render the system more tolerant to subsequent encounters with conditions that produced the original error event (Reason, 1990).

Usability

Usability refers to the practicality of a framework, or how easily it can be turned into a practical method or made operational (Hollnagel, 1998). Given that most error frameworks were designed "in the laboratory," their usability often needs improvement. The degree of usability of a framework can be assessed and improved based on inputs from those in the field who may be using the framework, as well as feedback from those who may be the beneficiary of the safety programs based on the framework. Some changes that often improve usability include the rephrasing of technical or psychological terminology (e.g., slips, lapses, and mistakes), to create terms that aviators could better understand (e.g., attention failures, memory errors, and decision errors). Another improvement may simply require changing the name of the framework from something that implies blame (e.g., Taxonomy of Unsafe Operations) to something more palatable such as the Human Factors Analysis and Classification System (Shappell & Wiegmann, 2001). In general, however, usability is more a qualitative than a quantitative dimension. Nonetheless, it is vital for a framework to be accepted if is to be effective within an operational setting.

Validity

Validity is the most important aspect of an error framework. The concept of validity concerns what a framework captures or measures, and how well it does so (Anastasi, 1988). There are multiple types of validity, including content, face, and construct validity. Theoretically, the maximum validity of a framework is determined by the extent to which it meets the other four criteria (i.e., comprehensiveness, diagnosticity, reliability, and usability). For example, content validity refers to whether a framework covers a representative sample of the error domain to be measured. Face validity, on the other hand, refers to whether a framework "looks valid" to personnel who will use it or to administrators who decide on its use. Finally, construct validity refers to the extent to which the framework taps into the underlying causes of errors and accidents. Hence, content validity is directly related to comprehensiveness and reliability, whereas face validity is directly related to the usability of a framework. Construct validity, in turn, is directly related to diagnosticity, or the ability of a framework to penetrate all levels of the system and reveal the underlying causes of errors and accidents.

Assessing the validity of a framework can be a very difficult and overwhelming task. Indeed, several methodological and statistical analyses for testing the validity of analytical techniques and measurement tools have been proposed (Anastasi, 1988). Again, however, given the origin of most error frameworks, little work has been done to examine and compare the validity of different error models in an applied context. Thus, most practitioners will need to infer the validity of an approach based on other, more easily assessable features such as reliability, diagnosticity, usability, and comprehensiveness. Furthermore, because most human factors professionals are aware of this situation, they often avoid using the term *validity* when discussing error frameworks in an academic context. Still, in most everyday conversations, the term *validity* tends to be used more liberally in reference to a particular aspect of a framework's utility. What is often meant, however, is not validity per se, but rather one of the other characteristics of a framework. Therefore, it is important for the practitioner to be aware of what is meant by the term *validity* in a given context, so that a correct interpretation can be made.

CONCLUSION

The purpose of this article was to provide practitioners with a general overview of the prominent human error perspectives typically espoused in the aviation human factors literature. Examples of frameworks that characterized each approach were provided, as well as a critique of the relative strengths and weakness of each perspective. A brief discussion of some objective criteria for evaluating error frameworks was also presented. The hope is that this critical overview of human error perspectives and evaluation criteria will help make practitioners better "consumers" of error-analysis systems and will allow for more informative discussions to occur between practitioners and human factors professionals when developing error management programs.

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