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A major challenge for organizations and safety researchers alike is that commonly used measures of safety (e.g., accident/incident rates, safety behavior) support a reactive rather than a proactive approach to safety. We argue that Reason's (1990) widely-accepted model of the causes of error suggests a more useful place to focus measurement attempts: preconditions for unsafe acts. Measuring and investigating preconditions rather than errors or outcomes facilitates a proactive, preventive focus; furthers theory development regarding the role of organizational factors in safety; and offers potential remedies to measurement challenges in safety research.

Introduction

Since the early days of aviation, understanding and improving safety has been, on the whole, a *reactive* endeavor (Maurino, Reason, Johnston, & Lee, 1995). *After* an accident or incident occurred, authorities pinpointed the error(s) that most directly caused the event and identified the individual(s) responsible. These "responsible" individuals would receive some type of disciplinary action and other individuals in the organization would be cautioned to prevent the error from occurring again. While this approach was not without results, it left a great deal to be desired, as this piecemeal approach did little to correct systemic hazards or anticipate errors before an event occurred.

In more recent years, regulatory agencies, airlines and safety researchers have recognized that safety is indeed systemic and research should adopt a focus on a systems approach to safety (e.g. Leveson, 2004; Maurino, 2000; Johnston, et. al, 1997; Reason, 1995; Perrow, 1986). Littlejohn (1983) defines a system as, "a set of objects or entities that interrelate with one another to form a whole." (p. 29). A system can be either a closed system or an open system. Our focus is on open systems, i.e. social systems, which incorporate exchanges with their environment. A rapidly growing body of research has begun to examine the role of the system through organizational-level factors, such as safety culture (Wiegmann et al., 2004), in facilitating or preventing accidents. When accidents or incidents are traced through the causal chain of events to the top levels of the organization, the specific error committed by an individual employee typically represents only a fraction of the problem (von Thaden, Wiegmann, & Shappell, 2006). This research implies that changes made at the organizational level can profoundly improve safety at the level of the individual employee (Zohar & Luria, 2003), and that identifying systemic problems can allow them to be corrected *before* they become safety events (von Thaden, Wiegmann, & Shappell, 2006; Patankar et al., 2005). Thus, a systems approach to safety is intended to be a *proactive* approach.

A number of obstacles remain, however, before this approach can fulfill its proactive promise. Prominent among these obstacles is the need for an appropriate criterion measure. How do we know whether an airline is safe? And how can we determine whether an airline's safety level is improving or has improved? Truly proactive safety requires a means to monitor safety actively over time, to account for system-wide effects and influences on safety, and to identify potential hazardous states before they result in an event such as an accident. In the paragraphs that follow, we briefly discuss the deficiencies of traditional safety criteria from the standpoint of proactive safety. We then present arguments, based on Reason's (1990) model of accident causation, for shifting the point of measurement from active failures to the latent preconditions for unsafe acts. We consider how this change in emphasis may be helpful for both understanding and prevention of accidents and make recommendations for future research.

Traditional Safety Criteria

Accident and Incident Rates

The ultimate safety goal of any organization is to avoid loss due to accidents and incidents. Accident rates, therefore, appear to be a natural, salient metric for evaluating safety. In aviation, however, accident rates tell us remarkably little about an airline's true safety level. Aviation accidents are thankfully infrequent, so large amounts of data and lengthy time intervals are needed before accident rates are even interpretable. This means that an airline that conducts a safety intervention must literally wait a year or more to see improvement, and any such improvement is likely to be small. Further, if causes of accidents are often related to latent factors (Reason, 1995), an accident rate measured at one point provides little information about accidents that may be waiting to happen.

It has long been known that incidents (or "events") occur substantially more frequently than accidents (e.g. Heinrich, 1950; Simonds & Grimaldi, 1956), and so some studies have begun incorporating incident rates into their measures of safety (Zacharatos, Barling, & Iverson, 2005). However, incident rates are strongly confounded with reporting issues. Incident underreporting is widespread and substantial, even when reporting is mandated by law (Probst, Brubaker, & Barsotti, 2006). Employees often have conflicting incentives with regard to reporting, or simply may not have access or time to report, and it is not clear whether a high reporting rate reflects a poor level of safety or a strong safety culture in which the reporting of even minor incidents is encouraged (cf. Reason 1997, 1998).

Safety Behavior

Some have sought to overcome the problems associated with accident/incident rates by focusing on employees' safety behavior as the outcome of interest (Fogarty, 2004, 2005). This may be appropriate for jobs in which individuals work alone or in work where tasks are not interdependent (cf. Wallace & Chen, 2006), or for industries in which the primary concern is prevention of occupational injuries to employees (cf. Barling & Frone, 2004). However, as noted earlier, for safety in complex industries, such as aviation, increasingly understood as systemic, the consequences of safety behavior extend far beyond the individual. As a result, assessing individuals' safety behavior provides only part of the overall picture. If one member of a team acts unsafely, the complex interdependencies of this behavior may put the safety of the entire flight at risk. Further, if procedures are flawed, if equipment is faulty, or if communication gaps exist between team members, safe behavior on the part of individuals may not be sufficient to ensure safety.

Taking a Proactive Approach

As discussed above, proactive safety requires addressing systemic safety issues before they become safety events (Patankar et al., 2005). In this light, the criteria discussed above are deficient. Accident/incident rates cannot tell us whether safety measures have been successful in preventing events that might have occurred. Measures of employees' safety behavior cannot tell us the complete story about the context in which that behavior occurs. Where then should we focus our attention? A measure is needed to account for both the unsafe conditions that have not yet resulted in an accident and the factors beyond the immediate control of the individual employee.

We argue that measures for proactive organizational safety should focus on the prevalence of *preconditions for unsafe acts* (Reason, 1990, Shappell & Wiegmann, 2000) as the primary outcome of interest. These preconditions are factors that affect the likelihood of committing an unsafe act. Reason proposed that organizational factors (safety culture, resource limitations, desire to avoid delays, etc.) create these preconditions (time pressure, etc.), which then increase the likelihood of errors or violations of safety procedures. These errors or violations then lead to safety outcomes such as accidents or incidents. Empirical links have been demonstrated between the presence of preconditions and errors/violations and between errors/violations and outcomes (Hobbs & Williamson, 2003). Therefore, Reason's model suggests that interventions that reduce the preconditions should also reduce the incidence of errors and the overall accident/incident rate.

In Reason's model, preconditions for unsafe acts are the mechanism by which organizational factors, such as safety culture, are expected to influence safety outcomes. However, this aspect of the model has not often been considered in a proactive way. Research abounds regarding errors and violations, and research regarding organizational factors is rapidly growing. Additionally, many studies have shown empirical links between the two ends of the model: organizational factors and safety outcomes (e.g., Hofmann & Stetzer, 1998; Mearns, Whitaker, & Flin, 2003; Zohar, 1980). Although some studies do follow Reason's model in its entirety and "connect the dots" across all elements, these studies are typically retrospective and aimed at identifying the causes of accidents that have already happened (e.g., Hobbs & Williamson, 2003; Wiegmann & Shappell, 2001). It bears noting that information resulting from complete studies such as these is a rich source of empirical trend data that provide a basis to inform change. Commonly these studies stand as the proven approach for researchers to inform safety improvement. Our lament is that as safety researchers, necessity or availability of information often times forces us to focus on accident case studies to make the case for safety based on transpired loss.

We propose that focusing more attention on how preconditions for unsafe acts mediate the relationship between organizational factors and safety outcomes is useful for solving a number of theoretical and practical problems in the field of safety research, and in aviation safety in particular. Measuring safety preconditions and considering them as indicators of an airline's safety level can:

(1) increase our ability to prevent errors before they occur;
(2) provide a useful framework for theory development; and
(3) address at least some of the measurement challenges currently associated with safety research.

Preventing New Errors Before They Occur

Reason's model is often conceptualized using a "Swiss cheese" metaphor, in which the different elements of the model are pictured as layers of cheese, with "holes" that may or may not align (Reason, 1990). The model can also be viewed as a branching or logic tree system, in which an element at one level of the model corresponds to several elements at the next level (see Figure 1).

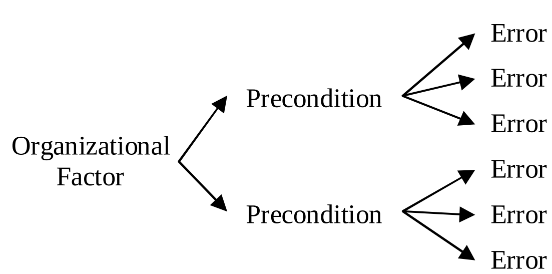

Figure 1. Visualization of Reason's (1990) model as a logic tree system.

A single organizational factor, such as safety culture, may influence many preconditions, and each precondition may affect the likelihood of several different types of errors. Empirical evidence supports this conceptualization; Hobbs & Williamson (2003) were able to link 619 reported maintenance errors with a taxonomy of ten error-producing conditions.

This suggests that an approach to safety focusing on preconditions can be both *more proactive* and *more general* than an error-focused approach. When errors are the unit of interest, interventions are likely to take place only after a specific error has occurred and to address only that particular error. An intervention targeted at a precondition for error, however, can address the several types of errors that follow from the associated precondition: both those errors that have already occurred and those that have the probability to occur.

A concrete example is likely to be helpful here. The most frequent type of maintenance error found by Hobbs & Williamson (2003) was a lapse in memory, such as forgetting to retrieve tools or materials from an aircraft or forgetting to perform a preliminary check. Hobbs and Williamson found that such lapses were most strongly associated with the contributing factor (or precondition) of time pressure. Consider an organization that experiences a significant incident as a result of the first type of memory lapse: a technician failed to remove a screwdriver from an engine compartment after performing routine maintenance, which led to substantial engine damage and a flight delay. In a reactive approach to safety, the organization might issue memos, post signs, or alter checklists to remind technicians to make sure all tools have been returned to their proper places before closing the compartment. This approach addresses the specific error that was committed, but does not address other types of memory lapses (similar errors) that might occur and leaves the precondition (time pressure) for such lapses intact. By contrast, targeting the precondition by scheduling additional staff or automating procedures represents a proactive approach. Such interventions should reduce the likelihood not only of the initial error, but also of other similar errors – even those that have never occurred before but have the potential to occur. Further, ongoing measurement and monitoring of preconditions can help an organization identify likely risk areas and address reducing the impact of hazards from these areas before any error occurs.

Furthering Theoretical Understanding

In the safety culture literature (and that of its close cousin, safety climate), there are many competing theories regarding how, exactly, organizational factors lead to safety outcomes. A wide variety of mediating mechanisms have been proposed, ranging from employees' safety knowledge & motivation (Griffin & Neal, 2000) to their physical health and strain (Fogarty, 2004) to their regulatory focus (Wallace & Chen, 2006). Each of these hypotheses has received empirical support. Reason's model can be viewed as a competitor to these models, but we contend that it may also be viewed as a framework that can encompass most if not all proposed mediators.

Though Reason (1990) did not initially propose a comprehensive taxonomy of preconditions, several such taxonomies have been developed. Among the most well known is the Human Factors Analysis and Classification System (HFACS; Shappell & Wiegmann, 2000). Many of the mediators of safety culture proposed in other research fit nicely into the HFACS framework. For example, employees' physical health (Fogarty, 2004) corresponds to the HFACS category of "adverse physiological states," while regulatory focus (Wallace & Chen, 2006) might be considered an "adverse mental state." Lack of safety knowledge (Griffin & Neal, 2000) could be viewed as a "physical/mental limitation." In other words, it seems that many if not all of the factors proposed as mediators of organizational factors may fit into the taxonomies of preconditions originally developed from Reason's model. Reason's model therefore provides an overarching explanation of how these proposed mediators may function simultaneously; rather than in competition with one another.

Improving Measurement

Using the prevalence of preconditions for unsafe acts as an index of safety may also help researchers and airlines circumvent some of the measurement problems associated with other safety criteria. The degree to which each precondition is present within a particular airline (or location, or shift) can be measured on a continuous scale, unlike accident or incident rates, which require counts of infrequent events. It is meaningful to consider the prevalence of preconditions over much smaller units of time – a month, a quarter, or a busy holiday season – compared to the year or 100,000 flight hours used to calculate accident rates. This makes it possible to monitor safety on a more continuous basis and to notice changes or fluctuations in safety conditions more rapidly.

Further, because preconditions are somewhat removed from specific errors, reporting preconditions is expected to be less personal (and therefore less problematic) than reporting either incidents or safety performance. While some of the common preconditions identified by Hobbs & Williamson (2003), such as physiological limitations or fatigue, apply largely to individuals, most target group or organizational level issues (e.g., pressure, training, supervision) and do not require individuals to "incriminate" themselves or their colleagues. Some social desirability and self-presentation effects are likely to remain; however, we expect that such effects will be substantially less for measures of preconditions than for measures of personal safety performance. Some preconditions are relatively objective and could be assessed by independent observers, bypassing the self-report issue altogether. For example, well-trained observers or auditors could easily evaluate preconditions such as the work environment, equipment, and procedures.

Research Agenda

Reason's (1990) model has been highly influential in aviation safety research, but it has not yet lived up to its full potential in terms of promoting a proactive systems approach to safety. Focusing attention on the level of preconditions for unsafe acts, rather than on the unsafe acts themselves, offers considerable promise for facilitating such an approach. However, a great deal of research is needed to translate this promise from the theoretical into the practical. We therefore offer a brief preliminary agenda for researchers interested in exploring the role of preconditions in proactive aviation safety.

First, psychometrically sound measures of preconditions must be developed. As mentioned previously, much of the research that considers preconditions is retrospective. While it is clear that preconditions relating to a particular error can be identified after the fact (e.g., Hobbs & Williamson, 2003), what is needed is a means by which all preconditions operating within an airline at a given time can be assessed simultaneously. To our knowledge, this has not been attempted. We noted above that a well-trained observer could reasonably evaluate several preconditions, such as equipment or procedures. Others (such as supervision, etc.) may require surveys or other more participatory methods. Establishing quality measures will require careful consideration of level of measurement issues. Some preconditions, such as pressure, clearly affect the workgroup as a whole, and should be assessed at the group level. Others, such as the physiological and psychological categories, are concerned with the individual employee. It may still be desirable to aggregate these preconditions to the group level, but such aggregation must take the variance among group members, as well as the group mean, into account.

Further, measures of safety preconditions must show discriminant validity with measures of organizational factors and individual factors such as safety values. It is unfortunate that much of the existing research assesses all three elements of the model under consideration (e.g., safety culture, mediating processes, and errors) in a single self-report questionnaire administered at one point in time (e.g., Fogarty, 2004; 2005). True causal inferences cannot be drawn from such studies, and the possibility that method bias inflates the observed relationships is strong. Effective measurement of safety preconditions requires that they be clearly distinguished from measures of related variables: in method, in time, and ideally in source (i.e., all information should not come from a single sample of employees).

As good measures of preconditions are developed, it should become possible and desirable to establish forward-looking predictive links between preconditions and errors. Laboratory research may prove fruitful here in that a controlled lab study can demonstrate a clear causal link between the presence or absence of a precondition and categories of error. Such research can then be translated into field studies of controlled interventions, targeting a particular precondition and examining the subsequent incidence of related errors or improved operational conditions.

Existing research (Hobbs & Williamson, 2003) has begun to establish links between specific preconditions and specific errors. It is also desirable to specify more precisely the connections between specific organizational factors and specific safety preconditions. Just as certain preconditions are more likely than others to lead to certain types of errors, we should expect that certain organizational factors should be more likely than others to create or assuage particular preconditions and improve operational safety. For example, Wiegmann and colleagues (e.g., Gibbons, von Thaden, & Wiegmann, 2006; Wiegmann, et al., 2004) have developed a model containing four major factors and twelve subfactors of safety culture. Many of these factors can be conceptually mapped to existing taxonomies of preconditions, such as HFACS (Shappell & Wiegmann, 2000) or that used by Hobbs & Williamson (2003). Foe example, the cultural factor Organizational Commitment to Safety, which is concerned in part with senior management's willingness to spend money to improve safety, might be most closely connected to preconditions such as equipment. One of the strengths of Reason's model is its generality, but research that more clearly specifies these connections can flesh out the theory and make it more useful on a practical level.

Conclusion

The lack of appropriate criterion measures has long hindered the development of truly proactive approaches to aviation safety. Reason's (1990) model, already widely accepted among aviation researchers, provides a potential solution to this dilemma: shift the measurement focus from after-the-fact measures such as errors or safety outcomes to the preconditions for unsafe acts, which occur prior to error. In the present paper, we have argued that devoting more attention to measuring and evaluating safety preconditions can greatly enhance our ability to promote proactive safety and understand the mechanisms underlying safety in organizations. Though such an approach presents numerous research challenges, the opportunity to move beyond the traditional reactive approach to active prevention is well worth the effort.

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