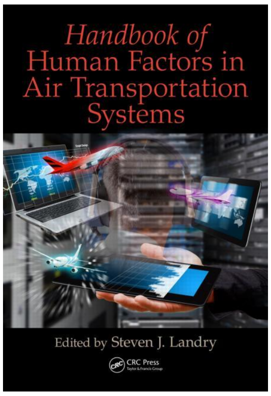

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Steven J. Landry

Error in Air Transportation

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14 Error in Air Transportation

Cees Jan Meeuwis and Sidney W. A. Dekker

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INTRODUCTION

THE PROBLEM OF 'HUMAN ERROR'

> "More than seventy percent of all crashes of scheduled commercial aircraft are caused directly by 'controlled flight into terrain'"

In 2014, the International Air Transportation Association states that "Typically, aircraft malfunction is not the main cause of CFIT accident; rather the accident's probable and immediate causes are often attributed to flight crew or human error, such as non-compliance with established procedures (SOPs), inadequate flight path management, lack of vertical and/or horizontal position awareness in relation to terrain, unstabilized approaches, and failure to initiate a go-around when a go-around was necessary."

We institutionalize safety by making tradeoffs when we try to explain why things go wrong. We want to understand why things go wrong and want to have an explanation for it, and usually we are very happy to settle for a very simple explanation. Two of the most common types of explanation are human error and mechanical breakdown. 'Human error' has—for a long time—been seen as a large problem in air transportation. In fact, human factors in aviation have always been concerned with 'human error.' Estimates in literature indicate that between 70 and up to 90 percent of all aviation accidents can be attributed to or are caused by 'human error' (Boeing, 1993; Fiorino, 2006; Shappell & Wiegmann, 2003; Woods, Dekker, Cook, Johannesen & Sarter, 2010). According to the statistics of Aviation Safety Network, 990 people lost their lives in 2014 in airline aviation. If 'human error' is the enemy of safe operations and is accountable for 80 percent of the accidents, we could have saved close to 800 of the lives lost in 2014 just by getting rid of 'human error.' We see the explanation of 'human error' when things go wrong everywhere; in scientific journals and papers, in formal accident investigation reports, and also in society, on the news, or other media. 'Human error' is socially well accepted as an explanation when things went wrong.

These ideas and observations lead to a seemingly simple and valid plan: Reduce 'human error' and you will enhance aviation safety. Many ideas in safety science use this emotional reasonable and appealing strategy in an effort toward progress. To be able to succeed in the "war on error", a definition of 'human error' is of the essence. Only then it can be made quantifiable, which is a necessity to get a grip on the 'human error' problem.

At first, the tabulation and counting of errors were fruitful investments in safety research (Dekker, 2006). In these controlled laboratory studies, human tasks were shrunk to a bare minimum, and researchers were left with single and measurable errors. The 'human error' queste was handled by researches as a possible cause of failure just like mechanical break-down. As a result 'human error' was seen as a control problem and handled in that way. Typical ideas that emerged in those days were the ideas of Taylor's standardization and compliance in 1911, accident-prone human beings in the 1920s (Burnham, 2009), and Heinrich's domino model in the 1930s. Prior to World War II, the focus was on designing and shaping the human to fit the task and machine. But despite all those efforts, ideas, models, and methods over time, science seemed to be facing a standstill in the effectiveness of this strategy. 'Human error' appeared to be a rather stubborn problem; it was beyond the reach of known or previously tried remedies, or responsive only to a significant mobilization of such remedies (e.g., severe behavioral interventions or removal of 'bad apples').

It was around World War II that the ideas of relationships between 'human error' and failure began to change, when the concept of *interaction* between human and machine was added (Chapanis, 1965; Fitts & Jones, 1947). The focus shifted to designing the machines and shaping the environments and conditions to fit the human in all its diversity. Major accidents in the following decades such as Tenerife, Bhopal, Three Mile Island (TMI), and Chernobyl have led to a search to figure out what is actually meant by 'human error' (Senders & Moray, 1991). The combined results of these efforts do not only challenge the prewar conventional assumptions about the relationship between 'human error' and failure, but also the tenability of the definitions of 'human error' and its ontology.

A closer look at the literature on 'human error' reveals it to be problematic. Not because we have a 'human error' problem, as in 'human error' *is the safety challenge to be resolved* but because *the status of the term 'human error' itself is extremely problematic* as postwar research exposes.

In their search to find a way to tame the 'human error'-beast, researchers were unable to find the necessary universal definition. Instead, they found a whole new way of looking at incident, accidents, failure, and safety. To show the problematic status of 'human error', we will bring forward two arguments, juxtaposed in Table 14.1, toward the claim why it would be better not to use the term 'human error' at all.

The first argument is that 'human error' is never the cause of failure, but merely an effect or consequence. 'Human error' alone is not sufficient to cause failure. It is only jointly sufficient together with multiple latent conditions that already have to be present to trigger the failure. This argument is best illustrated in literature by the work of original human factors figures such as Chapanis and Fitts, and later in the work of Reason and the practical extensions of his work by others.

The second argument is that 'human error' is nothing more than a label; an attribution after the fact.

Parallel to the genesis of Reason's work, Jens Rasmussen has laid the foundations for the second argument as to why 'human error' is problematic. This research originates from a

TABLE 14.1
Two Arguments Regarding Human Error

	Human Error (HE) as a Consequence Not Cause	Human Error (HE) as a Label
Ontology	HE exists	HE does not exist
	HE can be categorized and each category needs a different countermeasure	The label itself is not an explanation for failure nor a guide to countermeasures or improvement
HE definition	Unsafe act	Someone did something wrong according to someone: a judgmental label
The function of HE/Why is HE problematic?	Intermediate finding, not a conclusion, symptom not a cause, only jointly sufficient to create failure	It is an oversimplification of complex interactions and sociology
Effect of the problematic state?	Addressing HE is treating the symptoms not the cause	It does not exist and it diverts the attention from real learning opportunities
Authors	Reason, Shappell, Wiegmann	Rasmussen, Hollnagel, Woods, Dekker
Dominating view	Functionalist view	Interpretivist view
	Etic, judgmental from peer reviewed norms	Emic, not judgmental but describing social norms and their origins
Risk management	Error tabulation, categorization of error, violations, calculation of failure probabilities	Enlarge the ability of operators to manage emergent risks
Accidents	Breakdown or malfunction of normal system behavior	Breakdown in adaptation necessary to cope with the real world (BHE, p.82)
	System thinking LIGHT (Linear complexity)	System thinking (social complexity)
Models	Linear and latent failure models (psychology)	Complexity, control and sociological models
	Failure is seen as the outcome of a process Events in sequence generate outcomes. As a remedy a change in cause and effect sequence or elimination of causes, prevent failure	Failure is the emergent byproduct of interactions between components
How do you deal with erroneous operators?	Reason's just culture Different shades of culpability	There are no erroneous operators, just operators that made sense of the situation they were in and acted according their understanding of a situation. Therefore, they are one of your most valuable assets in the reconstruction and explanation of failure

cognitive engineering perspective that refers to sociology and complexity. A solid case is made for the claim that there is no such thing as 'human error', let alone it is a stable category for performance.

THE BACKGROUND FOR 'HUMAN ERROR'

Research on 'human error' has been an area of interest for a very long time. With an enormous progression on the technical reliability of our safety critical systems, it appeared if the 'human error' became more critical in the urge for continuous improvement. To reduce the increasing problem of 'human error', a clear definition is of the essence. Various researches have undertaken the effort to clearly define 'human error.' However, instead of finding a universal definition, they came up with a completely different view on safety, on how accidents happen, on how to investigate incidents and accidents, and how to organize and manage reactions to failure. This fundamentally different paradigm on our safety problems is now known under various names: The New View, Safety-II, Safety Differently, to name a few. Here is how this new paradigm evolved in the second half of the twentieth century.

CHAPANIS

During World War II, an unusual number of B-17 bombers crashed at landing or after landing due to a confusion in gear and flap controls in the cockpit. Despite all accustomed mitigations, such as additional training and awareness campaigns, the crashes were not eliminated from the operation. The problem seemed to be beyond the reach of those measures. Alphonse chapanis was a psychologist that worked at the Army Air Force Aero Medical Lab in Daytona, Ohio, at the time he was called into the problem. He solved the problem by placing a wheel shape onto the gear switch and little wing shape to the flap switch. A fundamental reverse thinking; instead of trying to (re)shape the human operator by means of training or other behavioral interventions, Chapanis changed hardware that was part of the environment of the operators.

FITTS AND JONES

Just after the World War II, Paul Fitts and Richard Jones conducted studies into airplane crashes related to aircraft controls and instrument displays. These airplane crashes were presumably caused by "pilot error." Fitts and Jones made visible that World War II witnessed a tipping point in which the abilities of technology had outpaced the human skills and possibilities. Human operators were no longer able to adapt and compensate for unreliable system designs. To determine the human performance as erratic was deemed unsatisfactory for Fitts and Jones. These studies led to two major understandings that are the cornerstones of two arguments as to why the term 'human error' is problematic. First, their studies empirically showed that 'human error' are systematically connected to the surroundings and conditions that people work in. 'Human error' was their starting point and not the conclusion of their investigations. Therefore, 'human error' is never the cause of failure, but rather a symptom of failure. Second, Fitts and Jones consequently notate 'human error' with quotation marks. This use of quotation marks shows that they are troubled and uncertain about the term, its use, status, and its definition. The term 'human error' was unsatisfactory.

Chapanis' practical intervention in environment and Fitts and Jones' studies into behavior believed to be "pilot error" are nowadays seen as the birth of modern Human Factors and Ergonomics—understanding why operators do what they do to change their environment and conditions and thereby indirectly shape operators assessments and actions. Decades later their work was extended and turns out to be fundamental for the ideas that answer the challenges in our twenty-first century safety challenges.

Often it appears if there are as many 'human error' models and frameworks as there are people interested in this topic (Senders & Moray, 1991). Reviewing the literature on 'human error' reveals that there are several perspectives on the nature of 'human error.'

From the 1950s, the studies on 'human error' have been extensively reviewed and analyzed. A series of high impact high visibility catastrophes starting in the late 1970s (e.g., Three Mile Island and Tenerife Crash), has triggered numerous industry oriented studies on 'human error' and human reliability (Amalberti, 2001). Two international research networks that turned out to be highly compatible, and later highly competitive, emerged (Le Coze, 2015). Where James Reason's work represents the psychology research tradition on 'human error', Jens Rasmussen worked on the topic from an (cognitive) engineering perspective. For more than 10 years, the two research disciplines were unknown to each other until they crossed paths in the aftermath of one of the major catastrophes, the TMI nuclear accident in 1979.

Le Coze (2015) identified three major aspects that distinguish the two researchers:

- The psychological perspective. James and Freud were of considerable influence in Reason's work. Reason saw error as a way to theorize psychology. Rasmussen on the other hand shows no sign of Freudian influences as he was committed to producing models for engineering purposes.
- Reason focused on categorization of 'human error' types related to unconscious cognitive processes, such as "slips" and "lapses" (Figure 14.1). Rasmussen focused on helping the

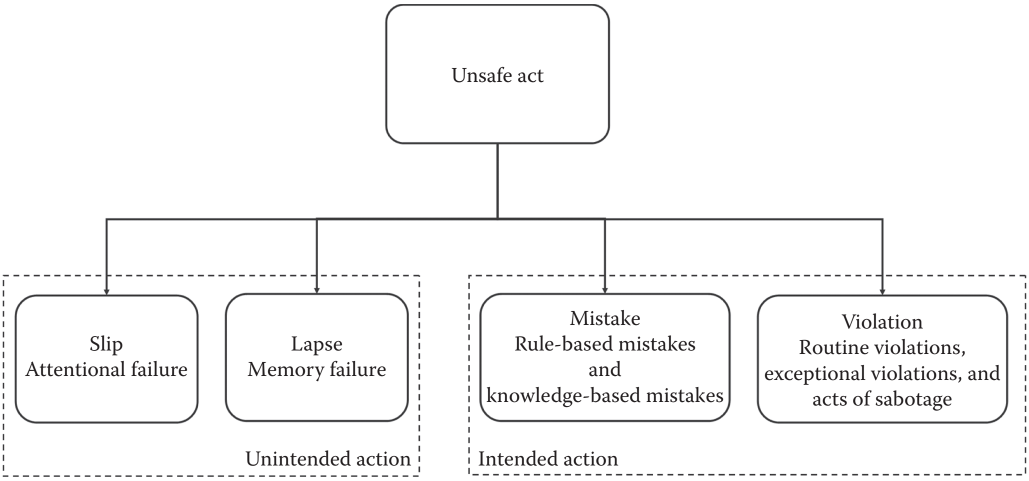

FIGURE 14.1 A taxonomy for 'human error.' (Modelled after Reason, J.T., *Human Error*, Cambridge University Press, New York, 1990. With Permission.)

operator "Coping with complexity" (Rasmussen & Lind, 1981). He saw failure predominantly occur in complex, no-routine situations.

- Reason's studies and frameworks are only based on theory. There are no empirical studies of real-life situations to support his work. However, Rasmussen grounded his model on real-life observations. Research on practical situations brings up valuable information for future design.

As a result, Reason is mainly occupied with taxonomy of error after TMI, whereas Rasmussen focuses on the naturalistic view of errors (Figure 14.2). Both paradigms form a basis for a compelling argument why our universe would be better off with 'human error' cut out of our jargon.

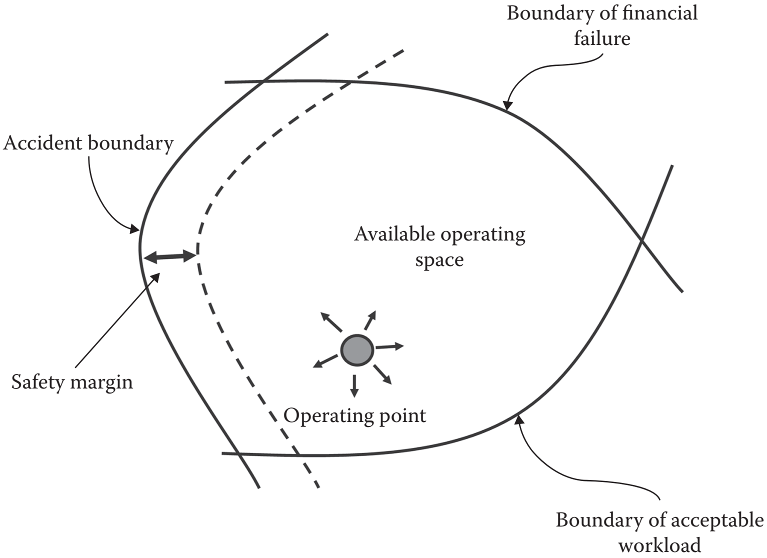

FIGURE 14.2 A naturalistic view of 'human error.' (Modelled after Rasmussen, J., *Ergonomics*, 33, 1185–1199, 1990. With Permission.)

‘HUMAN ERROR’ AS AN EFFECT OR SYMPTOM

In the postwar decades, numerous attempts were made to conceptualize ‘human error.’ The concept of ‘human error’ made contact with a variety of research disciplines resulting in plurality of theories, concepts, definitions, models, and perspectives by the 1980s. This research path started with system and control engineering that rapidly guided the attention to human–machine interface problems and so research was forced into the discipline of ‘human error’ analysis (Amalberti, 2001). In aviation, the second and third research disciplines shape five different categorical perspectives in this ‘human error’ research: the cognitive, the ergonomics and system design, the aeromedical, the psychosocial, and the organizational perspective (Shappell & Wiegmann, 2001).

The cognitive perspective is largely based on the information processing theory. This theory is based on the idea that the human brain does not merely respond to stimuli but that the brain processes the information it receives. When the information enters the human brain, attention will be allocated to it, the human brain uses pattern recognition and decision-making to plan a response execution. According to the cognitive perspective, ‘human error’ occurs when mediating operations between the stimulus input and response execution fail to process information appropriately. Based on the processing theory, Rasmussen is one of the first in literature to develop a taxonomy for ‘human error’ (Rasmussen, 1982).

But cognitive models turn out to have severe limitations:

1. There is no exact procedure defined for applying cognitive models to error analysis or accident investigation. This results in speculation and intuition from analysts and investigators when applying these models.
2. Cognitive models isolate cognitive processes from the context in which they took place. This is often referred to as “cognition in the mind”. When these external factors such as workplace conditions and equipment are not addressed, the cognitive models have an extreme tendency to conclude ‘human error’ as the “cause” of failure. In turn, this often results in blame being placed on the individual(s) who committed the error.

The ergonomics and system design perspective on ‘human error’ focuses on mismatches between components that constitute a system that degrade operator performance. A well-known model is the SHEL model. SHEL is the acronym for the four basic components that are necessary for successful human–machine integration and system design; Software, Hardware, Environment, and Liveware (Nagel, 1988). The limitations of the cognitive model have been anticipated as the ergonomics, and system design does consider workplace equipment and facilities. The SHEL model gains popularity rapidly and quickly became the recommended framework to be used for incident and accident investigations by the International Civil Aviation Organization (ICAO). Initially it appears if the system perspective deflects the attention away from the operator toward the system, but note that the system failure is often still caused by degraded operator performance, in other words ‘human error.’ In the system perspective, the human is rarely the sole cause of failure, but there is still emphasis on operator failure. A limitation of the system perspective is the analysis of human behavior remaining shallow. The system perspective focuses mainly on the ergonomics of the human–machine interface as well as the anthropometric requirements of the task and human characteristics. As a result, the cognitive, social, and organizational factors receive only superficial consideration.

To fill this gap in this system perspective, the aeromedical perspective is added. Within this approach the ‘human error’ is often caused by underlying medical or physiological conditions, such as hypoxia, sleep deprivation, or spatial disorientation. As a reaction to this perspective, the aviation industry has developed and intensified periodical aeromedical checks for pilots, disorientation training, and theoretical training in the field of Human Performance and Limitations. The aeromedical perspective focuses on the physiological conditions of the pilot as it deems to play significant role in safe performance. A well-known physiological condition that has significant influence on human performance is fatigue. Recently International Air Transportation Association has developed a Fatigue Risk Management System together with ICAO and the International Federation of Airline Pilots' Association to present a common approach to pilots, regulators, and operators to the complex issue of fatigue. The major critique on the aeromedical approach is that it is extremely hard to operationalize the issues of fatigue or self-medication or disorientation. Is being tired after a broken night the same as being fatigued? Can a pilot take an ibuprofen capsule during flight? How about two, or four? A problematic issue in this view is that it is extremely hard to draw a line of which we can agree before something bad happens: This is the fatigued and this is not. However, when something went wrong and we possess hindsight knowledge, it is usually not hard at all to construct an account of some aeromedical deficiency. Second, it is imaginable that aeromedical factors can influence performance, but it is extremely difficult to determine whether these factors have a causal connection to failure.

Moreover in the 1990s, a psychosocial perspective is identified in the safety literature. This perspective focuses on the interaction among all users of the system: pilots, air traffic controllers, ground staff, gate agents, dispatchers, maintenance engineers, and flight attendants. The general performance of a system is at its optimum when there is maximum quality in the interactions between all parties involved. The operating environment is not only influenced by these interactions but also by both the attitudes and personalities of individuals. As a result of this logic, accidents are explained by a breakdown of group dynamics and interpersonal communications.

EPISTEMOLOGY

Of all the goals we pursue in safety and human factors, our main drive is to prevent reoccurrence of accidents. To do so, it seems entirely legit to reconstruct past occurrences to establish exactly what happened. This activity has its roots in engineering. It is even a recommended practice in civil aviation accident investigation by ICAO Annex 13; "History of Flight," one of the most endorsed guidelines for accident investigation and report writing in. This is referred to as the epistemological purpose of accident investigation (Dekker, 2015a). A good investigation first collects all the facts and then starts analyzing the facts to conclude with a causal construct of the accident. ICAO Annex 13 even recommends shaping an investigation report in this precise order of chapters: Factual Information, Analysis, Conclusions, and Recommendations.

As Richard Cook is fond of saying, the way we see our world is almost entirely shaped through the accidents and disasters we have created. The general ideas of how to build an airplane, what instruments and electronics should be on board, what the layout characteristics of an airport should look like, and how much separation between two aircraft is the minimum for staying in control of the situation is all knowledge that was gathered in the wake of accidents. This means that the models, theories, and methods we use during incident and accident investigation are of major influence on the conclusions of these investigations and the variables we tend to change to prevent a similar occurrence from happening in the future. At the base of the general way we tend to do accident investigations lies the thinking and the laws of Isaac Newton and Rene Descartes (Dekker, 2011). Newton and Descartes have pretty much found the basis for the way we think about science, about truth, and about cause and effect. The Enlightenment can be seen as one of the cornerstones of our modern day Western Society. Newton used mathematics to describe the observed phenomena in our universe, and Descartes relied on the inner process of reason, yet they both believed in a single reality, or objective truth, that can be explored, captured, and understood through reasoning and analysis. Their ideas have become part of our human DNA in a way that we, most of the time, do not even realize that the things we do in daily life or the way we make sense of the world around us are what is often referred to as the "Newtonian-Cartesian Worldview" (Dekker, 2010). This thinking is the basis of our modern world engineering, and it is the motor behind epistemological accuracy; it has let mankind walk the surface of the moon and is motoring today's globalization. We would not be flying airplanes without

Descartes, and we would not have satellites in orbit without Newton. The epistemological purpose of an investigation is to tell the exact story of what happened on the basis of a universal objective truth.

James Reason and the Swiss Cheese Model

There are basically two ways one can look at 'human error.' We can see 'human error' as the cause of failure, or we can see 'human error' as a symptom of failure. Several different scientists acknowledge these two views in literature around the year 2000 (AMA, 1998; Rasmussen & Batstone, 1989; Reason, 1990; Woods, Johannesen, Cook, & Sarter, 1994).

The scattered postwar perspectives were unified in literature by James Reason (1990) in the Organizational Model of accidents; the latent failure model commonly known as the Swiss Cheese Model (Amalberti, 2001). The Swiss Cheese Model is one of the most dominant models in civil aviation over the last decades. The rationale discussed earlier matches the early ideas of Fitts and Jones (1947) and is operationalized in various ways with all sorts of (negative) effects. This makes the Swiss Cheese Model well suited to demonstrate the first argument of why 'human error' should not be used.

> 'Human error' is a symptom of trouble deeper in the system. Continuous use of the term 'human error' redirects the focus on the individual and leads to a setback into the interbellum.

In his work, Reason (1990) describes the two distinct views on 'human error' as a "person approach" and a "system approach". The person approach refers to the ideas of 'human error' prior to World War II. The idea that 'human error' is a human reliability problem and that once we figure out the source of human reliability we can solve the 'human error' problem. The person approach concentrates on the error of individuals, blaming them for forgetfulness, inattention, or moral weakness. The system approach concentrates on the conditions under which individuals work and tries to build defenses to avert errors or mitigate their effects. Reason argues that the system approach is the way to go forward if one wants to achieve progress on safety. The rationale is that 'human error' is not an explanation for failure but instead *demands* an explanation. Effective mitigation therefore does not start with targeting individual human beings, who themselves are at the receiving end of much latent conditions (Reason, 1997), but effective mitigation starts with targeting the conditions and environment that facilitate failure.

The Swiss Cheese Model itself is also a combination of preceding theories and models on accident causation. Especially the sequence of events model is clearly identifiable. This is in line with the Newtonian-Cartesian Worldview in which linear causation exists and broken parts can account for broken systems. The functioning of the whole can be explained by the functioning of its constituent component (Leveson, 2011). The main idea in Reason's Swiss Cheese Model, shown in Figure 14.3, is that disasters are not the result of one single failure (e.g., 'human error') but merely as a range of several smaller failures and contributing events and conditions. These multiple contributors are all necessary but individually insufficient to account for a disaster. The basis for this model can be traced back to Reason's investigations into the TMI accident in 1979.

Systems are described to have a sharp end and a blunt end. The sharp end is the actualizer of the process; people who are performing tasks (pilots, air traffic controllers, etc.) work at the sharp end of a system. The blunt end of a system are the processes and tasks farther away from the action itself, such as regulators, administrators, training activities, and so on. Procedures, barriers, rules and regulations play a major role in Reason's system approach. These defensive layers come in various ways such as physical barriers, personal protective equipment, automatic shutdowns, alarms, and so on. The function of those barriers is to protect a vulnerable object, such as humans or assets from hazards. These hazards have potential energy to inflict harm or damage, and the barriers are there to control or deflect that energy. Ideally these barriers are flawless; however, in practice, there

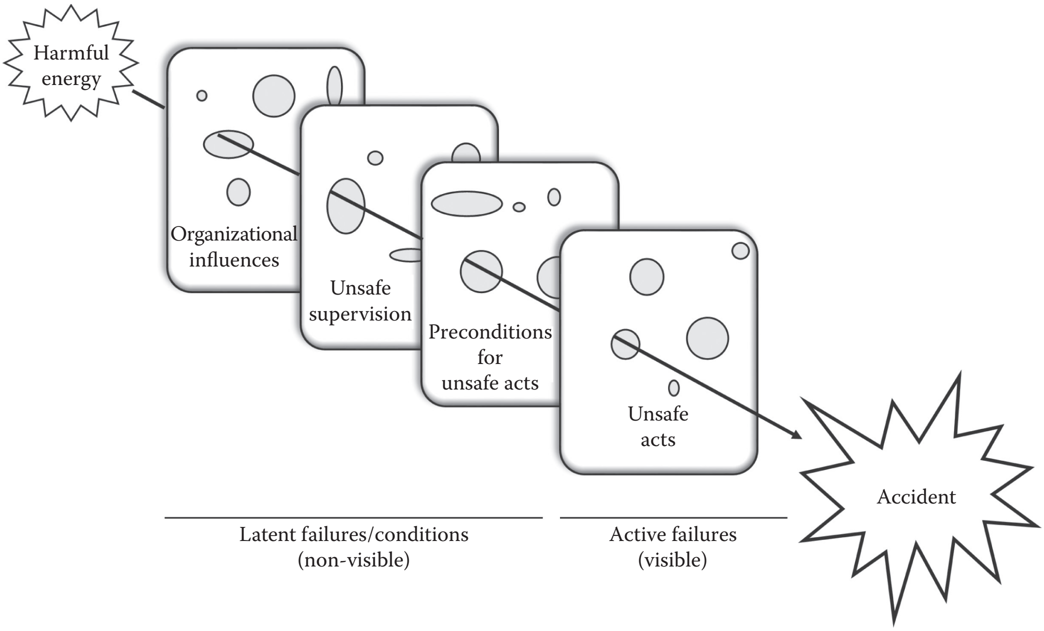

FIGURE 14.3 The Swiss Cheese Model by Reason. (Adapted from Shappell, S.A. and Wiegmann, D.A., The human factors analysis and classification system—HFACS, National Technical Information Service, 2000. With Permission.)

are always holes in these barriers similar to there are holes in Swiss Cheese, hence the analogy. According to Reason, these holes are, unlike in cheese, constantly changing shape and shifting position. Each slice of cheese is an opportunity to stop failure. In this analogy, accidents occur when these holes to multiple layers of defense momentarily line up. As a result, the potential energy of the hazard can reach the vulnerable object.

To explain this set of multiple contributors and the rise of holes in the defenses, Reason uses the terms "active failures" and "latent failures" (Reason, 1990). Active failure refers to "unsafe acts" that in turn parallels the term 'human error.' Active failure occurs at the sharp end of the system. This indicates that 'human error' has an entity and is ontologically "real". The latent failures are the embodiment of the multiple contributors at different levels in the system. Latent failure occurs at the blunt end of a system. In this model, the human operator at the sharp end is either the last straw to break the camel's back, or the hero who deflected the harmful energy to escape a black day (Reason, 2008).

The aim and effect of this distinction between active and latent failure is to redirect the focus from the frontline operators that made 'human error' toward the conditions that set the stage for that behavior. Unsafe acts are only jointly sufficient together with organizational influences, unsafe supervision, and preconditions for unsafe acts to create accidents. As Reason put it in 1990:

> Rather than being the main instigator of an accident, operators tend to be the inheritors of system defects created by poor design, incorrect installation, faulty maintenance and bad management decisions. Their part is usually that of adding the final garnish to a lethal brew whose ingredients have already been long in the cooking.

Reason provides us with a definition of error as it were a process outcome (1990):

> Error will be taken as a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some chance agency.

Again, in this definition Reason stresses the importance of the circumstances in which failure occurs. Yet no clear definition of ‘human error’ is given. In fact, he leaves space for interpretation and utility, or as Reason puts it himself (2008):

> Although there is no one universally agreed definition of (human) error, most people accept that it involves some kind of deviation. (...) Just as there are several possible definitions, so there are also many ways errors may be classified. Different taxonomies serve different purposes. These depend upon which of the four basic elements of an error – the intention, the action, the outcome and the context – is of greatest interest or has the most practical utility.

Reason classified errors based on Rasmussen’s three levels of performance; a path of maturity for performance. In order of decreasing levels of familiarity with the task, these are (Rasmussen, 1983) as follows:

- *Skill-based*: Stored patterns of preprogramed instructions
- *Rule-based*: Familiar problems are addressed by application of stored rules
- *Knowledge-based*: Novel situation in which actions must be planned, using conscious analytic processes and stored knowledge

Reason highlights the notion of intention in his definitions when considering the nature of error and suggests an error classification based upon the following questions:

- Were the actions directed by some prior intention?
- Did the actions proceed as planned?
- Did they achieve their desired goal(s)?

The combination of the importance of intention of an individual and Rasmussen’s three levels of performance lead to a well-known and widely accepted ‘human error’ classification:

- *Slips* can be thought of as actions not carried out as intended or planned, for example, “finger trouble” when dialing in a frequency or “Freudian slips” when saying something.
- *Lapses* are missed actions and omissions, that is, when somebody has failed to do something due to lapses of memory and/or attention or because they have forgotten something, for example, forgetting to lower the undercarriage on landing.
- *Mistakes* are a specific type of error brought about by a faulty plan/intention, that is, somebody did something believing it to be correct when it was, in fact, wrong, for example, switching off the wrong engine.

In addition, Reason addresses operator violations. Based on etiology, two distinct types are identified: routine violations and exceptional violations.

- *Routine violations* are considered rule-breaking actions by operators that are routinely, for example, the consistent accidence of a speed limit by 5–10 mph. These violations are indicative for individual or a group’s typical behavior pattern.
- *Exceptional violations* are the breach of any kind of rule because the situation facilitated in that behavior. This behavior is not considered exceptional because of their extreme nature, but because they do not fit the typical behavior of an individual or group.

What is interesting about Reason’s classification and handling of ‘human error’ by classification is that there seems to be a paradox. On the one hand, Reason argues that ‘human error’ is not the problem, and it is a waste of time to put effort in error management, as it is the systemic issues that allowed failure to happen in the first place. On the other, he presents an exhaustive taxonomy for 'human error', putting flesh on the bone of the alleged 'human-error' problem. One explanation for this is that 'human error' is regularly the starting point for the search for improvement. In this way, it would make sense to provide taxonomy as it guides the search toward the best way to deal with the 'human-error' problem and thus general improvement. Another explanation is that the taxonomy is needed to pursue protagonists of the person approach on 'human error.' Simply telling them that 'human error' is not mental or moral deficiency of an individual (person approach) might be too big of a mental leap. In this explanation, the taxonomy functions as a deflector for the primary reaction to act on the 'human error.'

In summary, the tenets underlying the Reasonian view, concept, and model on 'human error' are the following:

- Everyone commits errors. Fallibility is part of the human condition. 'Human error' is not intrinsically bad and even essential for learning. The identification of 'human error' is not an actionable conclusion, because
- 'Human error' is generally the result, consequence, or symptom of circumstances beyond the control of those committing the errors.
- System or processes that depend on perfection of performance are inherently flawed.

Reason's work is an ultimate attempt to analyze failure by deduction in a traditional engineering way. It leads to the conclusion that 'human error' is not the concept that requires a lot a focus. It is not the problem to be solved and cannot be the conclusion of an investigation. Yet the continuation of use of the same denotation and de delivered taxonomy for 'human error' strengthens the tenacity of the folk model on 'human error', or reinvention of 'human error.' In the next section, we will explain how.

OPERATIONALIZATION OF THE LATENT FAILURE MODEL

Human Factors Analysis and Classification System

In the late 1990s and early 2000s, Scott Shappell and Douglas Wiegmann made an attempt to bridge the gap between theory and practice by identifying and defining the holes in the cheese at the level of 'human error' described in Reason's work: the "Human Factors Analysis and Classification System" (HFACS) (Shappell & Wiegmann, 1997, 2000, 2001a, 2001b, 2003). Their starting point is where Reason has left them:

> ... Simply writing off (…) accidents merely to (human) error is an overly simplistic, if not naive, approach. (…) After all, it is well established that accidents cannot be attributed to a single cause, or in most instances, even a single individual. (Shappell & Wiegmann, 2001)

The HFACS framework, shown in Figure 14.4, consists of the four operational levels taken from the Swiss Cheese Model:

(1) Unsafe Acts of Operators, (2) Preconditions of Unsafe Acts, (3) Unsafe Supervision, and (4) Organizational influences. The first operational level is divided into the three types of 'human error' and the violations that Reason provided in his legacy. Shappell and Wiegmann made error taxonomy for the second through fourth operational levels. The result is a basic coding framework consisting 19 categories of error organized hierarchically in four levels.

Although there is no doubt about the intentions of improvement of Shappell and Wiegmann, their attempt to operationalize the systems approach (or new view) becomes a reinvention of 'human error' (Dekker, 2001). Two assumptions in this attempt are illustrative of this phenomenon:

1. Error classification is the same as analysis.
2. Relating operator to systemic conditions means we should seek for failure higher up in hierarchy.

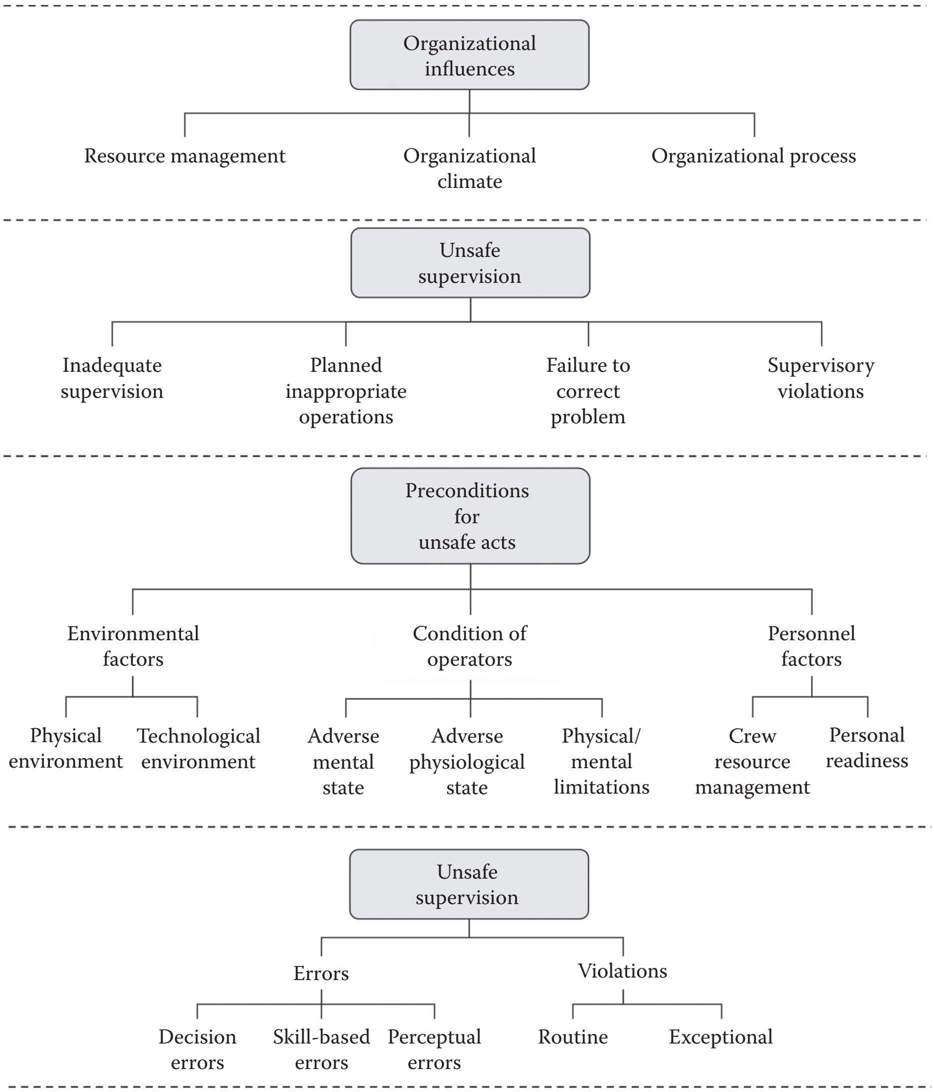

FIGURE 14.4 The human factors analysis and classification system (HFACS). (Modelled after Shappell, S.A. and Wiegmann, D.A., *A Human Error Approach to Aviation Accident Analysis: The Human Factors Analysis and Classification System*, Ashgate Publishing, Aldershot, UK, 2003. With Permission.)

In practice, when applying HFACS one would take the identified 'human error' in the fourth operational level (unsafe acts) and try to push it up the hierarchy ladder as high as possible. Driving an observation up the hierarchy into higher levels of a system is classification on different levels. But that activity fails to explain what the dynamics behind the label of 'human error' are. Classification is not the same as analysis. In addition, this classification reinforces the person approach to 'human error' and safety by pointing out 'human error' on a higher level. HFACS does not deflect the attention away from 'human error' toward deficiencies in the system, as Reason proposes in his Swiss Cheese Model, but it replaces it away from the sharp end of a system. "Inadequate Supervision" for example (in the third operational level) is nothing more than a euphemistic way of saying 'human error' all over again; in fact, all 14 categories at the blunt end of the system are. The attempt to operationalize Reason's theory brings us back to the person approach that Reason is so determined to get away from. In this way, Shappell and Wiegmann have inadvertently strengthened the biases that are so difficult to overcome in safety science. HFACS reinvents 'human error' as the cause of failure; it is just no longer necessarily situated on the work floor (unsafe acts).

An example:

This phenomenon of reinvention of 'human error' at other levels then the sharp end of organizations or systems is seen a lot in recent safety investigations in an attempt to adopt a system-perspective. Following are three statements regarding the risk assessment prior to the MH17 disaster. The Dutch Safety Board (2015) writes in their report:

> "The Dutch Safety Board considers this risk assessment to be incomplete because it does take threats to military aircraft into account, but does not account for the consequences to civil aviation of potential errors or slips." (p.207)
>
> "This investigation reveals that, prior to the crash of flight MH17, none of the parties involved adequately identified potential threats that the conflict in the eastern part of the Ukraine posed to civil aviation flying over the area." (p.244)
>
> "In the system of responsibilities, the emergence of a weak link (the airspace management) did not lead to other parties taking action to help ensure the safety of civil aviation earlier the conflict area." (p.245)

These quotes demonstrate an attempt to deflect the attention of the human operators in these systems toward the system itself by naming processes or addressing entire organizations instead of individuals. Although not explicitly expressed and against the intentions, we are back to square one; (indirectly) appointing humans to be at fault, causally connected to the disastrous outcome. These statements persuade us to silently ask questions about responsibility for the risk assessment processes and those responsible for decisions taken in the organizations involved. Therefore, we are still appointing blame to individuals but this time higher up in the system. In our attempt to get away from 'human error' and try to find what systemic factors lie behind it, we still end up saying that 'human error' is the problem:

- Someone must have been negligent in passing an incomplete risk assessment. "Errors and slips" on the sharp end are even mentioned although it is impossible to understand what they are and how to deal with them.
- How can parties involved be so indifferent about threat identification? Who is responsible for that?
- Other parties "did not take action." So here we found incompetent airspace management? Someone must take responsibility for that recklessness.

The result of all research on 'human error', including Reasons unifying work, is not difficult to summarize: We still do not have one objective, universal, unproblematic definition of 'human error.'

The definition that comes closest to that is

> 'Human error' is when someone did something wrong according to someone

It is this unsatisfying result that has led researchers to rethink the feasibility of the quest of defining 'human error'. The absence of a universally unproblematic definition, method, and model is maintaining the status quo on the topic. This status quo is the motive to start thinking differently about safety and 'human error'. It is the motivation to exert a different vocabulary and to vacate the Newtonian-Cartesian Worldview when it comes to safety and 'human error.' This paradigm is referred to as "complex system thinking" (Woods et al., 2010) or "Safety-II" (Hollnagel, 2014b) or "Safety Differently" (Dekker, 2015b). The paradigm is founded, in large part, on the work of Jens Rasmussen.

THE LABEL 'HUMAN ERROR' (ATTRIBUTION)

Today, although 'human error' is still a common explanation for accidents, the term itself turned into the topic of scientific discourse decades ago. Interestingly, this school of thought can be traced back to in literature as Reason's legacy: Fitts & Jones and Jens Rasmussen.

'Human error' is a label.

To build up the understanding of what an attribution is, a few concepts require explaining as to why they are problematic in the understanding of 'human error' and improvement in safety.

> 'Human error' does not exist; it is merely an attribution or judgment after the fact; therefore, it has no value in understanding failure.

To support this argument, a clarification is of the essence on a couple of assumptions often taken for granted in safety. The argument on the nonexistence of something such as 'human error' is best to be seen as a cocktail of busted "safety myths," explaining some fundamental cognitive shortcuts and understanding human sociological needs. It is this cocktail that came about by critically thinking and questioning these assumptions that formed the New View or Safety-II paradigm.

THE EXISTENCE OF 'HUMAN ERROR'

In August 1983, the NATO Conference on Human Error was held in Bellagio, Italy. Erik Hollnagel presented a position paper called Human Error (Hollnagel, 1983). The paper is a result of a series of questions asked by the organizers of the conference. Hollnagel argues in an almost agitated tone that it is merely impossible to answer these questions one by one. Instead of answering these questions, Hollnagel starts an argument to decompose the bias that underlay these questions about 'human error' as this is "necessary to discuss (…) before trying to answer the questions."

Hollnagel uses several steps to decompose the assumption that there actually exists something called 'Human Error.' As a result, 'human error' gets the "status of a concrete phenomenon", as it were ontologically real. This would mean that it is observable and one would be able to define it. However, Hollnagel argues that none of this is actually possible. Instead of being able to observe 'human error' directly, it must be inferred (concluded from reasoning) from observations. To conclude 'human error', there has to be a mismatch between the actual and the intended state of a system. In other words, a situation in which goals are not (entirely) met is fundamental to conclude 'human error.' The observation of a mismatch in turn assumes that a description of a desired system state is available, and an explanation for the mismatch can be reasoned. If there are no indications in the technical part of a system, the solution is generally to explain the performance variability to the human component. Hence, 'human error' becomes an "assumed cause" of failure. This makes 'human error' not unique but only one explanation out of many others. In this way, the detection of a mismatch is thus fundamental for inferring the existence of 'human error.' Further, Hollnagel notes it is important to realize that human performance variation is also present in situation in which there is no mismatch present or observed. Yet in these situations, there is no reason to look for a cause and therefore 'human error' cannot be concluded.

This means that concluding 'human error' can only take place when there is an undesired outcome evident, although the same human behavior may be present but not judged as being 'human error.' The human behavior is not of interest at all in the conclusion of 'human error', it is the mismatch that is leading. This leads to the significant consequences of hindsight bias for the existence of 'human error.'

THE HINDSIGHT BIAS

As Hollnagel illustrates in his argument, outcome knowledge is of the essence to conclude 'human error.' Hindsight bias is the tendency for people to "consistently exaggerate what could have been anticipated in foresight" (Fischhoff, 1975). Studies have consistently shown that people have a tendency to judge the quality of process by its outcome. In hindsight, everything appears to be obvious. In hindsight, having the outcome knowledge in hand, we clearly seem to know that this could happen. It even shows us all hints and clues available to the operators involved. With all information readily available, we unwittingly start to simplify the complexity into order, structure, and causality (Reason, 1990). By doing this, we isolate a construct of causality, which makes the outcome seem inevitable, from its original context. The hindsight bias is well documented and studied in psychology. It relates to how we perceive probability of an event we know it happened. Research has also shown that the hindsight bias is extremely difficult to overcome. Even for those who are warned for the existence of hindsight bias, it remains difficult to exclude this phenomenon from their judgments (Fischhoff, 1982).

Counterfactuals are a well-known expression of the hindsight bias. Counterfactual reasoning is explaining after-the-fact what people could or should have done to avoid the outcome. Although emotionally satisfying stakeholders, counterfactual reasoning is not very useful in safety. For once, it does not explain how and why things went wrong but it is only a substitutionary description of what happened by saying what did not happen. Second, counterfactual reasoning is impossible to prove empirically as it is impossible to reconstruct the path of failure in all its complexity. People tend to explain complexity through simplifying heuristics. Heuristics are extremely handy to make sense of situations and produce decisions as described by, for example, Tversky & Kahneman (1974) and Fischhoff (1982).

In practice, the hindsight bias leads to judging people involved in accidents. Hindsight means being able to look back on an event with more information available than the people involved. Judging from this, knew-it-all-along point of view gets in the way of understanding failure.

Outcome Bias

Outcome bias is the phenomenon in which outcome knowledge influences the evaluation of decision quality. This means that we make use of the Newtonian idea of symmetry between cause and effect. If the outcome is bad, the decision that led up to that outcome must be equally bad. Although both hindsight bias and outcome bias make use of outcome knowledge, they are often mixed up.

CAUSALITY AND ACCIDENT INVESTIGATION

'Human error' is closely connected with how we think about accidents and safety. Our social models on how accidents come about incorporate a few assumptions that have been taken for granted and still are taken for granted today. These are as follows: Accidents have causes, causes can be found, and the functioning of systems can be reduced to the functioning of its individual components. The existence of something called 'human error' can be traced back to these assumptions. Closer research on these assumptions shows them clearly to be myths. These assumptions are however deeply baked into our human DNA. 'Human error' is nothing but an outcome of a social process in explaining why bad things happen.

Accidents investigations are usually identifiable as root cause analysis, although rarely a methodology is described in investigation reports. The starting point of an investigation is usually the outcome; the event that triggered the need for an investigation in the first place. By looking at the proximate events and then reason backwards to distal causes, or the root cause, explanations for the accident are constructed and mitigating actions for reoccurrence in the future can be taken.

Looking at, for example, the investigation report of the Dutch Safety Board into the crash of MH17 we exactly see, “If accidents or near accidents [nevertheless] occur, a thorough investigation into the causes, irrespective of who are to blame, may help to prevent similar problems from occurring in the future” (DSB, 2015). The path of this investigation is set on a typical Newtonian cause-and-effect stage. The journey starts at the event of the crash, the effect, and because effects cannot take place without a cause, the journey will therefore end at the root cause that triggered all subsequent events.

In the first part of the investigation (part A), the causes into the crash of the aircraft are investigated. In the second part (part B), the investigation focuses on the flight route of flight MH17; why the aircraft was flying over a conflict zone at that time. In the first part of the investigation, Newton was of great help in understanding how the aircraft broke up into pieces in flight and ended up in the eastern part of the Ukraine on that summer afternoon in 2014. Newtonian, mechanistic thinking in cause and effect was able to compose an impressive forensic analysis of the cause of the intervention in normal flight.

“The combination of the recorded pressure wave, the damage pattern found on the wreckage caused by the blast and the impact of fragments, the bow-tie shaped fragments found in the cockpit and in the body of one of the crew members in the cockpit, the analysis of the in-flight break-up, the analysis of the explosive residues and paint found, and the size and distance of some of the fragments, led the Dutch Safety Board to conclude that the aeroplane was struck by a 9N314M warhead as carried on an 9M38-series and launched by a Buk surface-to-air missile system.” (DSB, 2015).

Looking at the second part of the investigation, the Newtonian investigation seems to be more of a struggle with lots of loose ends that are hard to connect. Although the Newtonian-Cartesian Worldview is highly successful at explaining the physical cause of the crash of MH17, there lies a risk in this success as well; the risk of becoming unable to make further progress on safety. Taking a closer look at the second part of the investigation, the traditional investigation strategy becomes problematic.

BYPRODUCT OF CAUSALITY

Although it is not the intention of the Dutch Safety Board, or any investigation modeled to ICAO Annex 13, to apportion blame or liability, a side effect of the Newtonian reconstruction is that it unavoidably will blame. Although not made explicit, the Ukraine government is blamed for preparing the stage for the accident by not closing the Ukrainian airspace. The Dutch Safety Board states in the summarized version of its investigation report:

> The Investigation revealed that Ukraine did not adequately identify the risks to civil aviation. (…) According to the Dutch Safety Board these reports gave enough reason for Ukraine to close its airspace as a precaution. However, this did not happen.

The connotation of this sentence easily leads to the interpretation that the Ukraine government has been negligent in the decisions to restrict the airspace for civil aviation. Note that this judgment of the Dutch Safety Board can only be made *after the fact*, in possession of outcome knowledge.

‘Human Error’ Is a Judgment

Both hindsight and outcome biases instigate how we explain failure and the role of ‘human error.’ With outcome knowledge, after the fact, we tend to believe that the negative outcome was foreseeable and preventable, and we are comfortable with making negative judgments about people’s decisions and behavior. Accident investigations tend to focus on the mismatch between actual performance and written guidance, standardized performance, procedures, and regulations. Pointing out to this mismatch does not explain the actual behavior. Judging behavior to be ‘human error’ stands in the way of learning from failure.

Euphemisms for 'Human Error'

If 'human error' is an attribution, or a judgment about what other people should have done (or what we ourselves should have done), then it has not stopped us from finding and popularizing new ways of labeling such judgments. Still, these putative "explanations" only judge people for not doing what they (in hindsight) should have done. Modern human factors concepts of this sort heavily populate the various error classifications, for example, loss of effective Crew Resource Management; complacency, noncompliance; and loss of situation awareness. Although masquerading as explanations, these labels do little more than saying 'human error' over and over again, judging performance instead of explaining it:

- Loss of Crew Resource Management is one name for human error—the failure to invest in common ground, to share data that, in hindsight, turned out to have been significant.
- Complacency is also a name for human error—the failure to recognize the gravity of a situation or to adhere to standards of care or good practice.
- Noncompliance is a name for human error—the failure to follow rules or procedures that would keep the job safe.
- Loss of situation awareness is another name for human error—the failure to notice things that in hindsight turned out to be critical. We merely judge people for not noticing what we now know to have been important data in their situation, calling it *their* error—their loss of situation awareness.

That these kinds of phenomena occur and even help produce trouble is indisputable. People do not coordinate perfectly across workplaces; people adjust their vigilance and their working strategies over time on the basis of their perception of threat; people locally adapt written guidance; and there is always a mismatch between what people observed and what we can show was physically available to them in hindsight. But simply labeling these phenomena fashionably, and stopping there because it now fits a category of the error classification, does not explain anything.

Beyond 'Human Error'

Current safety thinking suggests that to prevent 'human error' (or bad outcomes, rather), we should altogether move toward identifying and enhancing the positive capacities that ensure that things go right (Hollnagel, 2014a). The last thing we should do is declare a "war on error," as it will simply be a war on our own attributions; chasing our shadow. This is the premise of resilience engineering, as well as Safety II (Hollnagel, Nemeth, & Dekker, 2009). We should not be obsessed with identifying and filling the 'holes' (or minor incidents and errors) that show up in our investigations and safety management systems—because these kinds of conditions and events probably happen all the time, even when nothing goes wrong. Instead, this strand of research says, we should study success. We should study typical work and understand how success is created. The presence of positive capacities can help assure a system's continued functioning even under varying circumstances, so that the number of intended outcomes is as high as possible (Hollnagel, 2014b), for instance:

- the ability to say 'no' in the face of acute production pressures (Woods, 2006b)
- the willingness of superiors to hear bad news (Dekker, 2014)
- the acceptance and encouragement of dissenting views (Weick & Sutcliffe, 2007)
- the commitment to learning and the restoration of trust and relationships if vulnerabilities and problems have been identified (Dekker, 2016)

To ensure a continued improvement in the safety of aviation, we need to form a deep understanding of how things actually go right, despite the shortcomings, obstacles, and frustrations of quotidian work in a safety-critical system, and then seek to enhance the system's capacity to make even more things go right (Hollnagel, 2014c; Woods, 2006a).

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