From Threat and Error Management (TEM) to Resilience

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Sidney Dekker* & Johan Lundström
Lund University School of Aviation
SE-260 70 Ljungbyhed
Sweden
+46-435-445534 (phone)
+46-435-445464 (fax)
*corresponding author: sidney.dekker@tfhs.lu.se

Abstract Threat and error management (TEM) is a new crucial component of pilot licensing regulations, with the aim to prepare crews with the coordinative and cognitive ability to handle both routine and unforeseen surprises and anomalies. In this paper we argue against a possible technicalization of threat and error management, as if they were objective variables in the environment that determined particular responses. We show instead that the social processes by which the most persuasive rendering of a threat or error is constituted, says more about a crew's ability to handle diversity and adversity then any successful outcome. We propose a differentiation between technical and normative failures, a division that has ramifications for how threat-and-error management can be taught. We conclude with a set of key indicators for resilient crews—crews who are capable of recognizing, adapting to, and absorbing threats and disturbances that went outside what they and their training were designed for.

Introduction

Our knowledge base for creating safety in a complex, dynamic system such as commercial aviation is inherently and permanently imperfect (Rochlin, 1999). We cannot prepare people for every single problem permutation. Rather, when we train new crewmembers, we need to get confidence that they will be able to meet the problems that may come their way—even if we do not yet know exactly what those will be. Hence threat-and-error management as a crucial new component of pilot licensing regulations. Operational life will contain situations whose subtle and infinite variations will mismatch the exact circumstances of training. It may contain surprises, situations that fall outside the textbook. The importance of teaching threat-and-error management turns on the insight that crews must be able to apply skills and knowledge acquired through training, to situations that even the trainer was unable to foresee.

Much of aviation training focuses on technical skills (see Dalhström, Dekker & Nählinder, 2006). These aim to build up an inventory of techniques for the operation of an aircraft, or—nowadays—a set of competencies to that end. From the very first moment, such training is quite context-specific: it is set in, and tightly anchored to, the local technical environment (of an aircraft cockpit) in which all kinds of problem-solving activities are to be carried out. This is analogous to other domains that assert the primacy of learning-by-doing (for example surgery, see Bosk, 2003). But it means that generic abilities like human-machine coordination, communication, problem-solving, or escalation management are left to arise and mature from the exercise of context-specific work. Some have questioned this assumption, for example by suggesting how low-fidelity simulations (that do not attempt to mimic the target technical environment) can actually improve many aspects of learning (Roscoe, 1991; Caird, 1996).

In this paper we discuss the importance, and possible nature, of teaching threat-and-error management as a generic skill to crewmembers. After briefly reviewing the limits of expertise in the aviation industry and the fundamental surprises that this may pose for flight crews, we argue against the technicalization of threat and error management, as if they were objective variables in the environment that determined particular responses. Instead we will show, through examples gleaned from years of field work in flight instructing and type rating training, that the social processes by which the most persuasive rendering of a threat or error is constituted, says more about a crew's ability to handle diversity and adversity then any successful outcome. We propose, after Bosk (2003), a differentiation between technical and normative failures—or failures *in* a role and *of* a role, a division that has ramifications for how threat-and-error management can be taught. We conclude with a set of key indicators for resilient crews—crews who are capable of recognizing, adapting to, and absorbing threats and disturbances that went outside what they and their training were designed for.

Fundamental surprises

There will always be a residue of technical and environmental problems that we have not prepared crews for (i.e. they are not in their inventory, see Dismukes, Berman & Loukopoulos, 2007). This is because formal mechanisms of safety regulation and auditing (through e.g. design requirements, procedures, instructions, policies, training programs, line checks) will always somehow, somewhere fall short in foreseeing and meeting the shifting demands posed by a world of limited resources, uncertainty and multiple conflicting goals. For this residue we have to count on crews' generic competencies in problem-solving and coordination.

Aviation accidents, particularly in the developed world, can reveal such limits in industry expertise (Dismukes et al., 2007), and how we may not have prepared crews to deal effectively with them. Pinnacle Airlines 3701, for instance, exposed limits in knowledge of how the absence of passengers during repositioning flights can erode crew operational margins, and revealed buggy knowledge of high-altitude climbs, stall recognition and recovery and double-engine failures (NTSB, 2007). Swissair 111 revealed gaps in the industry's knowledge of electronic wiring and insulation, and consequently in the industry's ability to effectively handle or monitor its lifecycle inside an aircraft—let alone stem the push for more and more wiring through airplane bodies (TSB, 2001). It also reminded the industry of the immense difficulty crews face in making trade-offs on adapting plans and procedures under duress and uncertainty, and our severe shortcomings in preparing them for this (Dekker, 2001).

These surprises at the edges of an otherwise very safe system stem from limits in the industry's knowledge, or, more often, limits on its ability to put together diverse pieces of knowledge, as well as from limits on understanding operational environments (Lanir, 2004). Often the problem is not that the industry lacks the data. After all, the electronic footprint left by any commercial flight today is huge. The problem is an accumulation of noise as well as signals, which can muddle both the perception and conception of "risk" (Amalberti, 2001; Dekker, 2005). Also, the problem is not that the knowledge was not somewhere available. Pockets of expertise that may have predicted what could go wrong often existed in some corner of the industry long before any accident. For example, the engine types on the Pinnacle aircraft had assembled a history of problems with in-flight restarts during flight tests, and problems with wiring and chafing were not new in the late nineties. But few or no operational crews would have been aware of any of this in part because of structural industry arrangements that formally regulate who gets or needs to know what, and in what depth.

Resilience and the limits of expertise

As a result, some crews will, at some point or another, be left to "fend for themselves" at the margins of a well-built, extremely well-monitored, safe industry. It is at these edges that the skills bred for meeting standard threats need transpositioning to counter threats not foreseen by anybody. The flight of United Airlines 232 is an extreme example. The DC-10 lost total hydraulic power as a result of a tail engine rupture, with debris ripping through all hydraulic lines that ran through the nearby tailplane in mid-flight. The crew figured out how to use differential power on the two remaining engines (slung under the wings, below the aircraft's center of gravity) and steered the craft toward an attempted landing at Sioux City, Iowa, which a large number of passengers (and the crew) subsequently survived.

Thinking outside the box, taking a system way beyond what it was designed to do (even making use of an adverse design quality such as pitching moments with power changes), are hallmarks of resilience. Resilience is the ability to recognize, absorb and adapt to disruptions that fall outside a system's design base (Hollnagel, Woods, & Leveson, 2006), where the design base incorporates all the soft and hard bits that went into putting the system together (e.g. equipment, people, training, procedures). Resilience is about enhancing people's adaptive capacity so that they can counter unanticipated threats. High Reliability Theory has shown before how the adaptive capacity with respect to a narrow set of challenges can grow when an organization courts exposure to smaller dangers (Rochlin, LaPorte, & Roberts, 1987). This allows it to keep learning about the changing nature of the risk it faces—ultimately forestalling larger dangers. Such adaptation could be one explanation behind recent data that suggest that the passenger mortality risk on major airlines that suffered non-fatal accidents is *lower* than on airliners that had been accident-free (Barnett, 2005).

Sioux City is a desperate case. Crews can counter many threats effectively by replicating or slightly varying the technical skills learned in a particular setting. Most situations in commercial aviation, after all, are quite ordinary or recognizable: they fit within the "box," and, accordingly, crew behavior can stay "inside the box." Then there is a huge middle ground. It consists of daily safety threats that feature (or occur because of) subtle variations that call for some adaptive capacity. For example, these threats can ask for extra work (e.g. gathering and processing more data, more communication and coordination), for the recruitment of additional expertise (e.g. dispatch, ATC) and the deployment of new strategies. Resilience here means effectively meeting threats that represent infinite reconfigurations of—or that lie entirely beyond—what the industry could anticipate.

Training for threat-and-error management

Current approaches to teaching threat-and-error management stress replicability, or reliability of performance across recurring situations, but with due attention to changes in context. For example, a trainer must see whether the crew "executes approach according to procedures *and situation*" (IEM FCL No. 1 to Appendix 1 to JAR-FCL 1.520 & 1.525, p. 2-K-8, emphasis added). Still, most of the appreciation of and compensation for "the situation" are assumed to come from adaptations within a crew's competence envelope (which was developed almost solely *in situ*), from the technical and judgmental wherewithal that exists within crewmembers' defined roles (again, a kind of "box").

This may overly technicalize the management of errors and threats, with a potential regression to limiting the unreliability of human components through a reduction of miscues, errors, mistakes. In contrast, the important finding from emerging work on resilience is that safety does not inhere in the reliability of a system's components—or that, at the very least, this severely underdetermines aggregate system safety (Leveson, 2006). Safety is about maintaining dynamic stability in the face of changing circumstances. Safety is not about what a system *has*, but about what a system *does* (Hollnagel *et al.*, 2006): it emerges from activities directed at recognizing and resisting, or adapting to, harmful influences. It requires crews to both recognize the emerging shortfall in their system's existing expertise, and to develop subsequent strategies to deal with the problem. The adaptive capacity necessary for such recognition and adaptation does not just come from rehearsing technical skills *inside* a role as crewmember. Rather, it comes from getting crewmembers to recognize the obligations, limits and flexibility of that role.

This is also where those involved in teaching threat-and-error management could be hampered by any remaining essentialist assumptions about the nature of threats and errors. Threats and errors do not have some sort of immutable identity apart from the social setting in which understanding of their occurrence emerged (see Bosk, 2003, p. xx). They do not simply exist "out there," equally accessible as ready-made products to be "managed" for everyone. Errors and threats are not objective variables that determine a particular response, but rather issues to be constituted and deconstructed into a whole set of negotiable problems and irrelevancies (see Grint, 2005). What is a threat to one crewmember is a normal day at work to another—and what matters in part is how some renderings of context can be successful while others fail to be compelling. What emerges as the most persuasive account of context (this is a threat! Or, this is not a threat!) can often hinge on authority rather than insight, and anybody training threat-and-error management must be acutely attuned to the processes by which some renderings become superior and some illegitimate. With threats and errors being social constructs, the interpersonal processes by which they are constituted probably says more about a crew's ability to handle diversity and adversity then any successful outcome. A threat-and-error-management training encounter must not be a homily to a predefined list of threats and errors. It is a device to turn failure into an accountable part of everyday life on the line, with different constructions of treats and errors having quite different ramifications.

Technical failures: Errors in a role

The training of flight crews offers many occasions for negotiating whether a failure (an error, a mismanaged threat) occurred, to what extent it was preventable or excusable, and what to do about it. With a formalized focus on threat-and-error management in aviation nowadays, it could be useful to make a distinction between technical and normative failures (see Bosk, 2003). Whether instructors, or anybody in a mentoring role, e.g. more senior crew members, construct a failure as normative or technical has far-reaching consequences for what the flight crew can expect and needs to do.

When a crew member suffers a technical failure, she or he is performing her or his role conscientiously but the present skills fall short of what the task requires (Bosk, 2003, p. 37). For example, when a pilot makes a rough landing, or does not "select the appropriate level / mode of automation" or does not "comply with altimeter setting procedures" (IEM FCL No. 1 to Appendix 1 to JAR-FCL 1.520 & 1.525, p. 2-K-8), this could likely be the effect of skills that have yet to be developed or refined. Technical failures will be seen as opportunities for instructors or colleagues to pass on "tricks of the trade" (e.g. "start shifting your gaze ahead when flaring", or "when facing this type of air traffic control clearance, use this flight path mode"). Instructors are often quite forgiving of even the most serious lapses in technique, as they see these (and have experienced them themselves) as a natural by-product of learning-by-doing. Technical failures do not just have to be connected to the physical handling of an aircraft or its systems; it can also involve interaction with others in the system, e.g. air traffic control or weather services. The crew, for example, may have seen the need to coordinate (and may even be doing just that), but does not have the experience or finely-developed skills to recognize how to be sensitive to the constraints or opportunities of the other members of the aviation system.

For a failure to be constructed as technical, however, it has to meet two conditions (cf. Bosk, 2003, p. 38). One is obviously that the frequency or seriousness should decrease as experience goes up. When a person keeps making the same mistakes over and over, it may be difficult to keep seeing them as purely technical. As long, however, as the person making the errors shows a dedication to learning and to his or her part in creating safety, that person is still conscientiously filling his or her role. Indeed, the other condition for a technical failure is that it should not be denied, by the pilot involved, as an opportunity for learning and improvement. If a crewmember is not prepared to align discrepant outcomes and expectations by looking at him- or herself, but rather turns onto the one who revealed the discrepancy, trainers will no longer see the failure as purely technical:

> We had been cleared inbound to a diversion airport due to weather. We were on downwind when an airliner came on the frequency, and was cleared for the ILS (instrument landing system) toward the opposite runway. The student proceeded to extend his downwind to the entry point he had chosen, even though the field was now fully visible. He was entirely oblivious to hints from air traffic control to turn us onto base so we could make it in before the airliner from the opposite side. When the student still did not respond, I took control and steered our aircraft onto base. We completed the landing without incident before the airliner came in. Upon debriefing, however, the student berated me for taking control, and refused to accept the event as an opportunity to learn about 'fitting in' with other traffic at a dynamic, busy airport. He felt violated that I had taken control (flight instructor).

An insensitivity to unfolding context is a hallmark of limited experience. Instructors will see such insensitivity as a technical issue consistent with the role of student, and a due opening for enlightenment. Sticking to the plan, or behaving strictly in the box, even though a situation has unfolded differently, has been known to lead to problems and even accidents in aviation (see Orasanu). So valuable lessons are those that demonstrate how textbook principles or dogged elegance sometimes have to be compromised in order to accommodate a changing array of goals. Pilots can otherwise end up in a corner. Surgery has a corollary here: "excellent surgery makes dead patients" (Bosk, 2003, p. 46).

The costs of technical failure hardly ever outweigh the benefits. Of course, this is so in part because the division of labor between senior and junior crewmembers, or between instructors and students, is arranged and staggered so that no-one advances to more complex tasks until they have demonstrated their proficiency at basic ones. If aid is necessary, there are almost always only two responses: verbal guidance is offered, with hints and pointers, or the superordinate takes over altogether. The latter option is exercised when time constraints demand quick performance, or when the task turns out more complex than initially assumed. This division of labor can also mean that subordinates feel held back, with not enough opportunity to exercise their own technical judgment. The example above could be an instance of this, where the division of labor is seen by the student as stacked in favor of the instructor. For instructors, the perennial challenge is to judge whether the learning return of letting the student make the mistake is larger than from helping her or him avert it and clearly demonstrating how to do so.

As for crewmembers, they should not be afraid to make mistakes. Rather, they should be afraid of not learning from the ones that they do make. Self-criticism (as expressed in e.g. debriefings) is strongly encouraged and expected of crew members in the learning role. Everybody can make mistakes, and they can generally be managed. Denial or defensive posturing instead squelches such learning, and in a sense allows the trainee to delegitimize mistake by turning it into something shameful that should be repudiated, or into something irrelevant that should be ignored. Denying that a technical failure has occurred is not only inconsistent with the idea that they are the inevitable by-product of training. It also truncates an opportunity for learning, in this case of how to adapt to a changing environment. Work that gets learned-by-doing lives by this pact: technical failures and their consequences are to be acknowledged and transformed into an occasion for positive experience, learning, improvement. To not go along with that implicit pact is no longer a technical failure, it is a normative one.

Normative failures: Errors in assuming a role

Technical failures say something about the crewmember's level of training. Normative failures say something about the crewmember him- or herself. Normative failures are about crewmembers failing to discharge their role obligations conscientiously, by violating the (often implicit) working understandings on which action rests (Bosk, 2003). Technical failures create extra work, both for superordinate and subordinate. That, however, is seen as legitimate: it is part of the game, the inevitable part of learning by doing. The extra work of normative failures, however, is considered unnecessary. In some cases, it shows up when a crewmember asserts more than his or her role allows:

> It was my turn to go rest, and, as I always do, I told the first and second officer 'If anything happens, I want to know about it. Don't act on your own, don't try to be a hero. Just freeze the situation and call me. Even if it's in the middle of my break, and I'm asleep, call me. Most likely I'll tell you it's nothing and I'll go right back to sleep. I may even forget you called. But call me.' When I came back from my break, it turned out that a mechanical problem had developed. The first officer, in my seat, was quite comfortable that he had handled the situation well. I was irate. Why hadn't he called me? How can I trust him next time? I am ultimately responsible, so I have to know what's going on (Senior Captain).

The situation was left less resilient than it could (and, in the eyes of the superordinate, should) have been: leaving only two more junior crewmembers, with no formal responsibility, in charge of managing a developing problem. There are losses associated with calling: the superordinate could think the call was superfluous and foolish, and get cranky because of it (which the first officer in the example above may have expected and, as it turned out, misjudged), and the subordinate foregoes the learning opportunity and gratification of solving a problem her- or himself. But the safe option when in doubt is always to call, despite the pressures not to. That is, in many cases, how a subordinate crewmember is expected to discharge her or his role obligations.

In other cases, fulfilling those obligations is possible *only* by breaking out of the subordinate role:

> My problem is with first officers who do not take over when the situation calls for it. Why do we have so many unstabilized approaches in (a particular area of our network)? If the captain is flying, first officers should first point out to him that he is out of bounds, and if that does not work, they should take over. Why don't they, what makes it so difficult? (Chief Pilot)

The Chief Pilot here flagged the absence of what may turn out critical for the creation of resilience in complex systems: the breaking-out of roles and power structures that were formally designed into the system. Roles and power structures often go hand-in-glove (e.g. Captain and First Officer, Doctor and Nurse), and various programs (e.g. Crew Resource Management training in aviation) aim to soften role boundaries and flatten hierarchies in order to increase opportunities for coordinating viewpoints and sharing information. What examples of resilience could have in common, is that operational success in the face of extreme or shifting demands hinges on people going beyond the formal role assigned to them or it by the designed system (remember Sioux City). Where people do not do this, they fail to discharge their role obligations too—in this case by not acknowledging and deploying the flexibility inherent in any role.

The example taken up by the Chief Pilot hints not only at how decision-makers in different roles are active in constituting the context in which they work (including the threat-to-be-handled, how it is defined—Captain: no worries, we'll make it in. We've done it before, after all. First officer: this is an unstabilized approach and we should go around). It also reveals something about the dynamics of discovery and creativity: how individuals recognize emerging shortfalls of existing roles and help reconstitute social structures (including the power affiliated with them) to fit their developing construction of the problem. Not taking over, i.e. not reconstituting the social structure, could be the result of a first officer's inability to see the threat-as-constructed by her or him as ever gaining primacy. Not taking over is not about a lack of action. First officers 'do not take over,' because the threat defined from within their role of subordinate is too peripheral, too uncompelling to warrant an exit from that role. Thus, the failure to take over is not about the first officer not persuading the captain that the situation is different and that it calls for a different response, but about persuading her- or himself that it is so. The Chief Pilot's observation of first officers' inaction is consistent with earlier characterizations of sensemaking as indivisibly anchored to (and fundamentally limited by) known and rehearsed roles (see Weick, 1993)—a strong current for Crew Resource Management training to row against if that were so.

Conventional theories of threat-and-error management suggest that for team performance to be effective, it must be matched to context. People must recognize and appropriately respond to threats (events that occur beyond the influence of the flight crew, but that increase operational complexity and must be managed to maintain safety margins). For example, a threat that is an emergency (e.g. the dual engine failure of Pinnacle 3107) may call for more rapid decision-making and consequently a leadership style that facilitates speed and decisiveness. Either way, an accurate account of context is a critical decision-making device. Again, what misses from such theory is where that persuasive rendition of context comes from in the first place. An emergency is not just "out there;" it is recognized and described as such by the people facing it—they are the ones who "construct" the threat as an emergency. Indeed, even generically there is disagreement on how much immediate threat there is in an emergency, as there is almost always more time than we think. But once a crewmember has made the mayday call, or announced to her or his fellow crew that they now face an "emergency," this legitimizes a particular mode of engagement with that situation (and perhaps a different style of team interaction). This mode and style may not have been legitimate before the explicit construction of that situation as an "emergency." In short, crews are not just recipients of threats, they are constitutive of them. This contradicts the simple linear idea that there is first a threat, and then a response (appropriate or not). Rather, it is the response that constructs the threat. This construction in turn sanctions a particular repertoire of plausible or desirable countermeasures.

Indicators of resilient crews

In training and beyond, instructors or superordinates may find normative failures more difficult to deal with, more difficult to explain or excuse, than technical ones. There is no good excuse for a normative failure, even if it has no adverse consequences. Technical failures are a normal part of learning; normative failures put the trainee outside the reach of learning. Normative, rather than technical failures, are seen as more serious breaches precisely because the knowledge base for creating safety in a dynamic and complex domain is inherently and permanently imperfect. Crews always have to keep on learning, because neither they nor the industry will ever know it all for sure. Normative failures implicitly deny that the system needs to constantly invest in its awareness of the models of risk it embodies in its safety strategies and countermeasures. Normative failures can lead to stale coping mechanisms, to misplaced confidence in how safety is regulated or checked, and to unrecognized pathways to breakdown.

What are some possible indicators of resilient crews, then? Counting the number of threats and errors that get successfully managed is useless, for two reasons. First, positive outcomes correlate badly with the quality of the process that led up to it (see Orasanu & Connoly, 1993). Second, neither threats nor errors are objectively countable variables in the environment, but constructed notions that are negotiable, and whose rendering of context can succeed or fail to be persuasive for the others present. Of course, those features that may be constructed as threats or errors could be recurrent and pretty stable across repetitive situations. But rather than just checking off whether crews actually "see" the same threats and errors as the instructor does, and manage them the way she or he would, it is more interesting (and safety-critical) to consider processes by which crews construct risk, or not:

- How does the crew handle sacrificing decisions? Pressures for faster, better and cheaper service are often readily noticeable, and can be satisfied in an easily measurable way. But how do crews consider and negotiate how much they are willing to borrow from safety in order to achieve those other goals? When faced with sacrificing decisions, resilient crews are able to take small losses in order to invest in larger margins (e.g. exiting the take-off queue to go for another dose of de-icing fluid).

- Does the crew take past success as a guarantee of future safety? Having been in that same situation many times before (and succeeded at it) may have crews believe that acting the same way will once again produce safety. In a dynamic, complex world, this is not automatically so.

- Is the crew keeping a discussion about risk alive even when everything looks safe? Continued operational success is not necessarily evidence of large safety margins, and crews who actively engage in a risk analysis of their next plan may be better aware of the edges of the safety envelope and how close they are to it.

- Has the crew invested in the possibility of role flexibility and role break-out? For example, they may include what to do in case of an unstabilized approach during the briefing of that approach, with a particular emphasis on giving the subordinate the confidence that taking over is all right and desirable, and that any disagreements over the interpretation of the situation can be sorted out later, on the ground.

- Does the crew distance themselves from possible vicarious learning through differencing? In this process, crew members would decline to look at other failures and other situations, as they are judged not to be relevant to them and their setting. They discard other events because they appear to be dissimilar or distant. This is unfortunate, as nothing is too distant to contain at least some lessons at some level.

- Is the crew's problem-solving fragmented? With information incomplete, disjointed and patchy, none of the crew members may be able to recognize the gradual erosion of safety constraints.

- Is the crew open to generating and accepting fresh perspectives on a problem? Systems that apply fresh perspectives (e.g. people from another backgrounds, diverse viewpoints) on problem-solving activities seem to be more effective: they generate more hypotheses, cover more contingencies, openly debate rationales for decision making, and reveal hidden assumptions.

The limits on our ability to prepare crews in detail for the precise operational problems they may encounter, come from the intersection between our finite knowledge and the infinite configurations of problems-to-be-solved in any complex, dynamic domain. Today, threat-and-error management is a possibly useful new way of teaching crews, throughout their lifetime, about the construction, perception and management of risk. “Threats” and “errors” are not recent discoveries that nobody thought to manage in the past (e.g. Hawkins & Orlady, 1993). They are merely another grammar through which trainers and trainees can turn risk and failures into accountable features of flight crew work; into devices for improvement and learning.

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