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Culture, Error, and Crew Resource Management[1]

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Abstract

Crew Resource Management (CRM) training is one of the critical elements of an organizational strategy to minimize risk and manage human error. The influences of three cultures that are relevant to the cockpit are described: the professional cultures of the pilots, the cultures of organizations, and the national cultures surrounding individuals and their organizations. A model of threat and error management in aviation is presented with findings from audits of crew performance. Data requirements to maintain a proactive safety culture are discussed. The transfer of training models from aviation to other domains such as medicine and shipping is briefly considered. We close with guidelines for organizations implementing more operationally focused CRM programs.

Culture, Error, and Crew Resource Management

The latest CRM programs explicitly focus on error and its management. CRM training, in its current state, can best be described as one of the critical interventions that can be employed by organizations in the interests of safety. More specifically, pilot CRM skills provide countermeasures against risk and error in the form of threat and error avoidance, detection, and management. In the period just prior to the birth of these new programs, CRM training had been successfully applied to the US and Western cockpit environment, although its acceptance was not universal. As we observed these cockpit programs applied mindlessly to non-Western pilot groups and non-pilot groups such as Flight Attendants, maintenance personnel, dispatch, and even to nuclear power plant and refinery operations, we began to see the effectiveness of the programs slipping. Two approaches were tried. A new research initiative into the dimensions of national culture relevant to the aviation environment and CRM training in particular was initiated. By knowing more about national cultures, we could begin to design CRM programs that were culturally sensitive and that would have greater impact on line operations. The pilot culture, and that of individual organizations also began to be understood as relevant to the success and failure of CRM programs. Simultaneously, we began to revisit the basic concepts of CRM in the hope of better explicating its goals and objectives. Perhaps there were universal objectives that could be derived that applied to pilots of all nations, and even to non-pilot groups. The marriage of these cultural research programs (What aspects of CRM should be tailored to specific organizations and cultures?) and a "back to basics" attempt to refine the goals and objectives of CRM (What are the universal goals?) produced the new generation of CRM programs that we describe as error management CRM (see Helmreich & Foushee, 1993; Helmreich & Merritt, 1998; Helmreich & Wilhelm, 1991; Helmreich, Merritt, &

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[2] The work reported here was completed while Ashleigh Merritt was a doctoral candidate and postdoctoral fellow at the Aerospace Crew Research Project at The University of Texas at Austin. She is now a Project Manager at Dedale, 4 Place de Londres, Roissy CDG Cedex, France. The other authors are with the Department of Psychology at the University of Texas at Austin, Austin, TX 78712.

Wilhelm, 1999; and Merritt & Helmreich, 1997, for discussions of the evolution of CRM and outcomes of CRM training).

In order to better understand how CRM skills fit into the pilot's job description, we began sketching a broad conceptual model. Ultimately, the job of the pilot is to operate the aircraft in a safe manner in order to transport passengers and goods from place to place. The successful management of risk or threat is a primary task. The model we finally produced has four levels: external threats, internal threats (labeled 'crew-based errors'), crew actions, and outcomes. See Figure 1 for our model of threat and error management. At the first level, three types of external threat may confront crews – expected risks such as high terrain surrounding an airport, unexpected risks in the form of system malfunction or changing weather, and errors by external parties, for example, incorrect dispatch releases or air traffic instructions. When either an expected risk or unexpected risk is recognized, crews can employ CRM behaviors for error avoidance by evaluating the threat's implications and using decision making skills to determine a course of action. Threat recognition and error avoidance are associated with situation awareness and represent a proactive response that can be observed when groups share and evaluate the situation and include contextual factors in planning. For example, a crew may recognize the risk associated with bad weather at their destination (situation awareness) and practice error avoidance by increasing the fuel load and reconsidering their choice of an alternate airport to reduce risk and conduct a safer flight. The potential error would be to have insufficient fuel to reach a safe alternate.

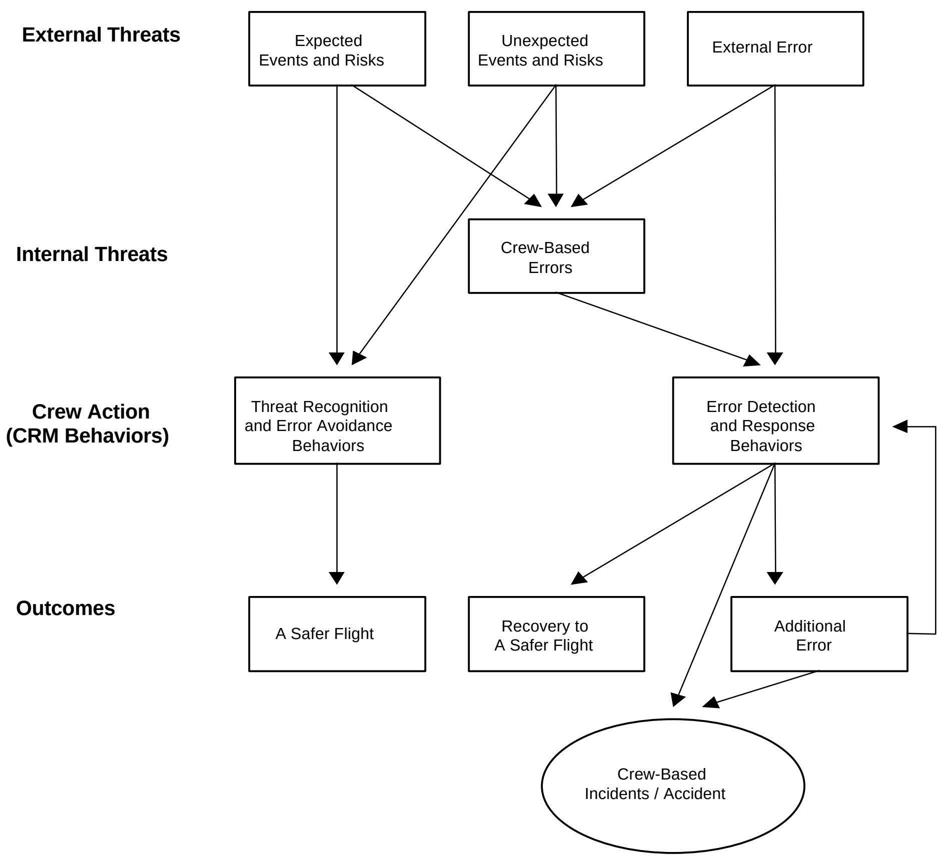

Figure 1. The model of threat and flightcrew error management.

Human error is inevitable, so when an error occurs (whether committed by an external agent or by the crew), it is the crew's task to detect and respond to the error. The behaviors of effective error detection and management are best illustrated by cross-checking and verifying actions, evaluating the quality of decisions made, etc. When errors are not detected or corrected, the level of risk for a flight is increased.

This model does not represent a significant departure from the original training programs that were called *Cockpit* Resource Management in the early 1980s. First generation CRM was developed in response to NASA findings that 'pilot error' was involved in the majority of air crashes and was seen as a method to reduce such error (Cooper, White, & Lauber, 1980). However, the linkage between early curricula and pilot error was unclear and, with the passage of time, the goals of CRM appear to have become lost on many participants in the training (Helmreich, Merritt, & Wilhelm, 1999). The purpose of our model is to re-establish the basic goals of CRM.[3] We also recognize that, in order to implement CRM optimally, the cultural context of flight operations needs to be considered.

Culture and Safety

In aviation, the three cultures, professional, organizational, and national, can have both positive and negative impact on the probability of safe flight. Safe flight is the positive outcome of timely risk recognition and effective error management, which are universally desired outcomes. The responsibility of organizations is to minimize the negative components of each type of culture while emphasizing the positive. Both CRM and technical training form part of an error management philosophy and program.

Professional Culture and its Manifestations

Although we recognized the existence of and some of the manifestations of the professional culture of pilots early in our investigations of flight crew behavior and attitudes, we did not immediately understand its potency as an influence on safety. In retrospect, the roots of a strong professional culture are clear—early aviation was an extremely dangerous undertaking, for those in combat, carrying the mail, or stunt flying for awed audiences. To commit to such a hare-brained endeavor required a strong sense of personal invulnerability and efficacy. The respect and envy engendered among generations of adolescents also fostered pride in being one of "the few", to borrow Churchill's description of Spitfire pilots during the Battle of Britain. This image of personal disregard for danger and invulnerability reached its zenith with the early astronauts (all chosen from the ranks of test pilots) and was immortalized by Tom Wolfe in *The Right Stuff* (1979).

When we began systematically assessing pilots' attitudes about their jobs and personal capabilities, we found that the 'pilot culture' showed great consistency among more than fifteen thousand pilots in over twenty countries (Helmreich & Merritt, 1998). What distinguished pilots on the positive side was an overwhelming liking for their job. Pilots are proud of what they do and retain their love of the work. Figure 2 shows the responses of pilots from 19 countries to the stem "I like my job." On a 5-point scale where 1 is disagree strongly and 5 is agree strongly, no group had a mean below 4.5 and several had means over 4.9.[4]

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[3] The definition of CRM in the opening chapter of a 1993 book on CRM did not mention error but described it as the process of 'optimizing not only the person-machine interface and the acquisition of timely, appropriate information, but also interpersonal activities including leadership, effective team formation and maintenance, problem-solving, decision making, and maintaining situation awareness' (Helmreich & Foushee, 1993, p. 3).

[4] Liking for the profession is independent of attitudes about one's organization. Some of those most enthusiastic about their profession expressed passionate dislike for the organization and indicated that morale was abysmal in their airline.

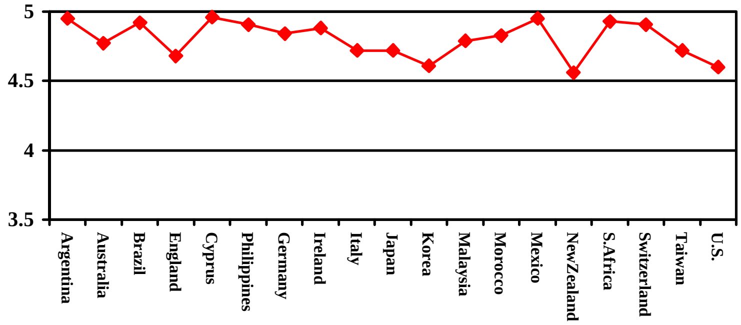

Figure 2. Mean scores of pilots from 19 countries on the item, "I like my job".

On the negative side, there was widespread endorsement of items that reflect an unrealistic self-perception of invulnerability to stressors such as fatigue. Pilots also report that their decision making remains unimpaired by in-flight emergencies and that a true professional can leave behind personal problems on entering the cockpit. These are indeed negative manifestations of the *'Right Stuff.'* Unfortunately, those imbued with a sense of invulnerability are less likely to feel the need for countermeasures against error or to value the support of other crew members. We have found equally unrealistic attitudes about personal efficacy among physicians and mariners (Helmreich & Merritt, 1998). The behavioral implications of such attitudes were illustrated in a CRM seminar observed by a member of our research team. In this session, a pilot remarked that 'Checklists are for the lame and weak.' Figure 3 shows graphically some of the positive and negative influences of pilots' professional culture on safety. As the figure illustrates, positive components can lead to the motivation to master all aspects of the job, to being an approachable team member, and to pride in the profession. On the negative side, perceived invulnerability may lead to a disregard for safety measures, operational procedures, and teamwork.

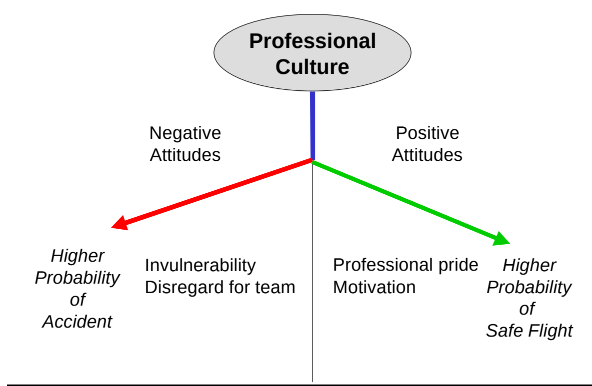

Figure 3. Positive and negative influences of pilots' professional culture on the safety of flight.

Organizational Culture and Safety

Investigations of causal factors in accidents and incidents in technology rich domains are increasingly focused on the critical role of organizational culture. John K. Lauber, the first Ph.D. psychologist and human factors expert to serve on the National Transportation Safety Board, spearheaded an effort to examine and identify the role of organizational culture in aviation accidents where blame would previously have centered on errors by crew members or maintenance personnel (NTSB, 1991). In England, the work of James Reason (1990, 1997) has centered on the role of organizations in industrial disasters, including nuclear power generation and petroleum refining.

A safety culture is the outcome that organizations reach through a strong commitment to acquiring necessary data and taking proactive steps to reduce the probability of errors and the severity of those that occur (Merritt & Helmreich, 1997). A safety culture includes a strong commitment to training and to reinforcing safe practices and establishing open lines of communication between operational personnel and management regarding threats to safety. In our data collection we ask a number of questions about perceptions of management's commitment to safety. Table 1 shows the percentage agreeing with two items in two organizations.

Item	**% Agreement Airline A**	**% Agreement Airline B**
I know the correct safety channels to direct queries	85	57
My safety suggestions would be acted on	68	19

Table 1. Percentage of pilots agreeing with two safety items on the Flight Management Attitudes Questionnaire.

While the majority of pilots in each organization indicate that they know the proper channels for communicating safety concerns, the percentage is substantially lower in Airline B. More telling are the differences in the percent that believe their safety suggestions would be acted on. This ranges from 68% in Airline A to 19% in Airline B, but even in Airline A, there is obvious skepticism about the organization's commitment to safety.

Organizational practices clearly determine the pride that individuals have in working for an organization. These attitudes undoubtedly exert an influence, although indirectly, on safety and compliance. In one airline, 97% of the pilots agreed with the statement 'I am proud to work for this organization' while at another, fewer than 20% agreed. Similar variability was found in attitudes regarding trust in senior management. The organizational culture is important because when it is strong and positive, pilots and other groups may more readily accept new concepts such as CRM and its associated training.

National Culture in Aviation

The view has been widespread in aviation that the cockpit is a culture free zone, one in which pilots of all nationalities accomplish their common task of flying safely from one point to another. Data, however, have begun to accumulate suggesting that there are substantial differences in the way pilots conduct their work as a function of national culture and that the areas of difference have implications for safety (Helmreich & Merritt, 1998; Johnston, 1993; Merritt, 1996; Merritt & Helmreich, 1996a; Merritt & Helmreich, 1996b; Sherman, Helmreich, & Merritt, 1997).

Geert Hofstede's (1980, 1991) four dimensional model of culture has proved to be a useful starting place to examine the effects of national culture on flightdeck behavior. We took his survey of work attitudes as a benchmark and augmented his questions with a new set of items that were more directly relevant to the aviation environment (Helmreich & Merritt, 1998). Three of Hofstede's four dimensions replicated and proved to be conceptually relevant to team interactions in the cockpit.

The first, Power Distance (PD), reflects the acceptance by subordinates of unequal power relationships and is defined by statements indicating that juniors should not question the decisions or actions of their superiors and the nature of leadership (i.e., consultative versus autocratic). Figure 4 shows mean scores on our measure of Power Distance, the Command Scale, of pilots from 22 nations. High scores on the scale indicate high Power Distance and acceptance of a more autocratic type of leadership. In high PD cultures, safety may suffer from the fact that followers are unwilling to make inputs regarding leaders' actions or decisions. Countries such as Morocco, the Philippines, Taiwan, and Brazil have the highest scores, indicating the highest acceptance of unequally distributed power. At the other end of the Power continuum are found countries such as Ireland, Denmark, and Norway, with the USA also scoring at the low end of the distribution.

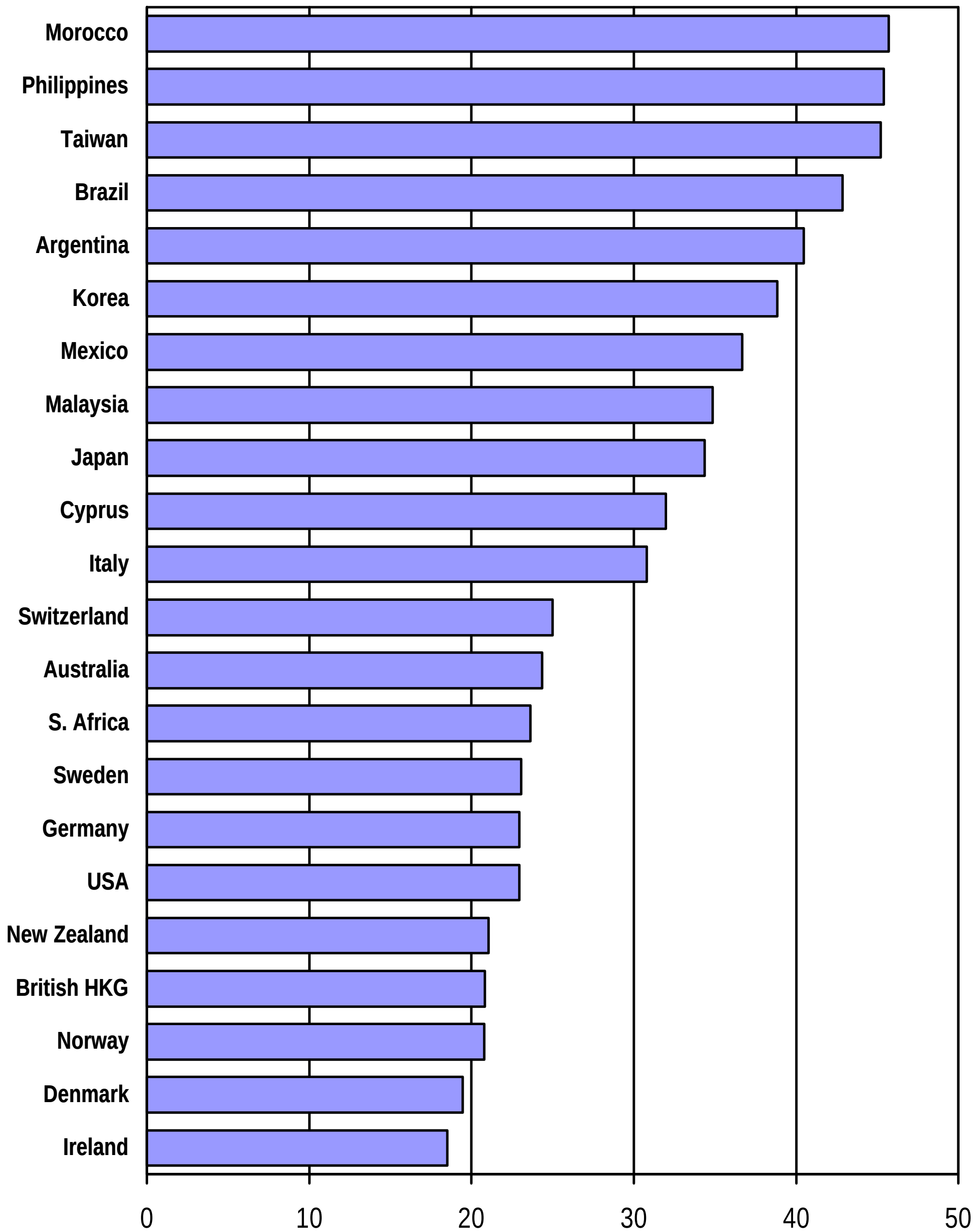

Figure 4. Mean scores of pilots from 22 countries on the Flight Management Attitudes Questionnaire measure of Power Distance (scale range 0 – 100).

The second dimension, Individualism-Collectivism, defines differences between individualistic cultures where people define situations in terms of costs and benefits for themselves and more collectivist ones where the focus is on harmony within one's primary work or family group. The concept of teamwork and communication may be more easily achieved by collectivists than by those with a more individualistic orientation. The USA and Australia score highest in individualism, while many Latin American and Asian cultures rank as highly collectivist.

The third dimension, called Uncertainty Avoidance (UA) by Hofstede, only replicated when it was redefined to focus on the beliefs that written procedures are needed for all situations and that an organization's rules should never be broken, even when it might be in the organization's best interest (Helmreich & Merritt, 1998). This dimension, which we have called 'Rules and Order', can have both positive and negative implications. Those high on it may be least likely to deviate from procedures and regulations, but may be less creative in coping with novel situations. Those low may be more prone to violations of procedures, but may be better equipped to deal with conditions not covered by procedures. On the re-defined measure, Taiwan, Korea, and the Philippines score as highest, while Anglo cultures such as the UK, Ireland, and the USA score very low. Figure 5 shows the means on one scale item, 'Written procedures are required for all in-flight situations.'

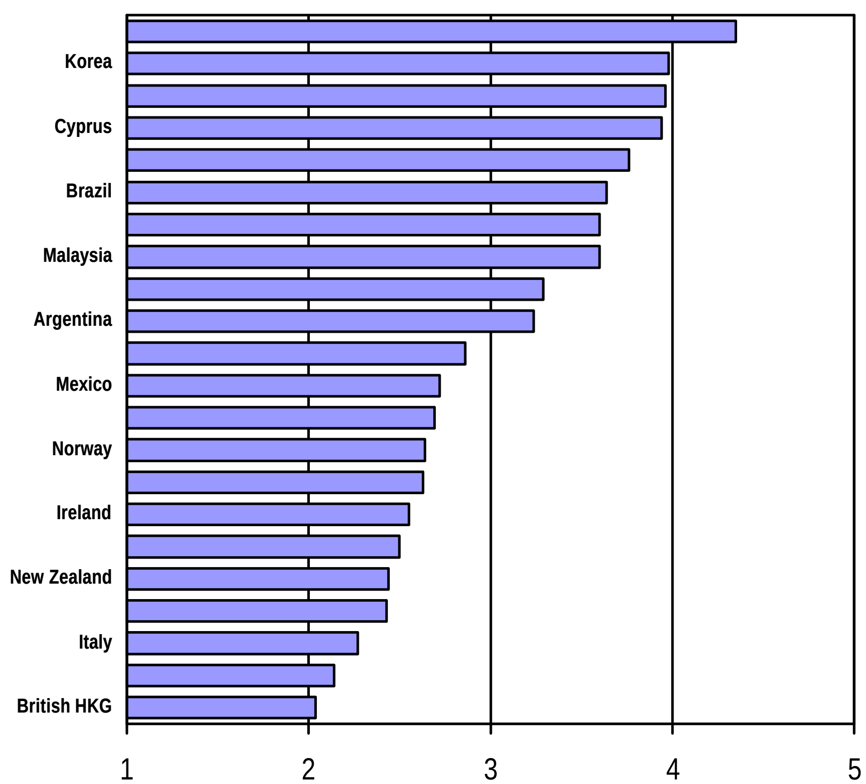

Figure 5. Mean scores of pilots from 22 countries on the Flight Management Attitudes Questionnaire item 'Written procedures are required for all in-flight situations.'

One of the unexpected findings from our cross-cultural research was the magnitude of differences in attitudes about automation – both preference for automation and opinions regarding its use (Sherman, Helmreich, & Merritt, 1997). In particular, pilots from high Power Distance cultures are both more positive about automation and more likely to use it under all circumstances. We have suggested (e.g., Helmreich & Merritt, 1998) that the computer may be anthropomorphized in some cultures as a high status, electronic crewmember not to be questioned, a strategy which is clearly inappropriate in many situations. Figure 6 shows ordered means on a composite measure of preference for and reliance on automation.

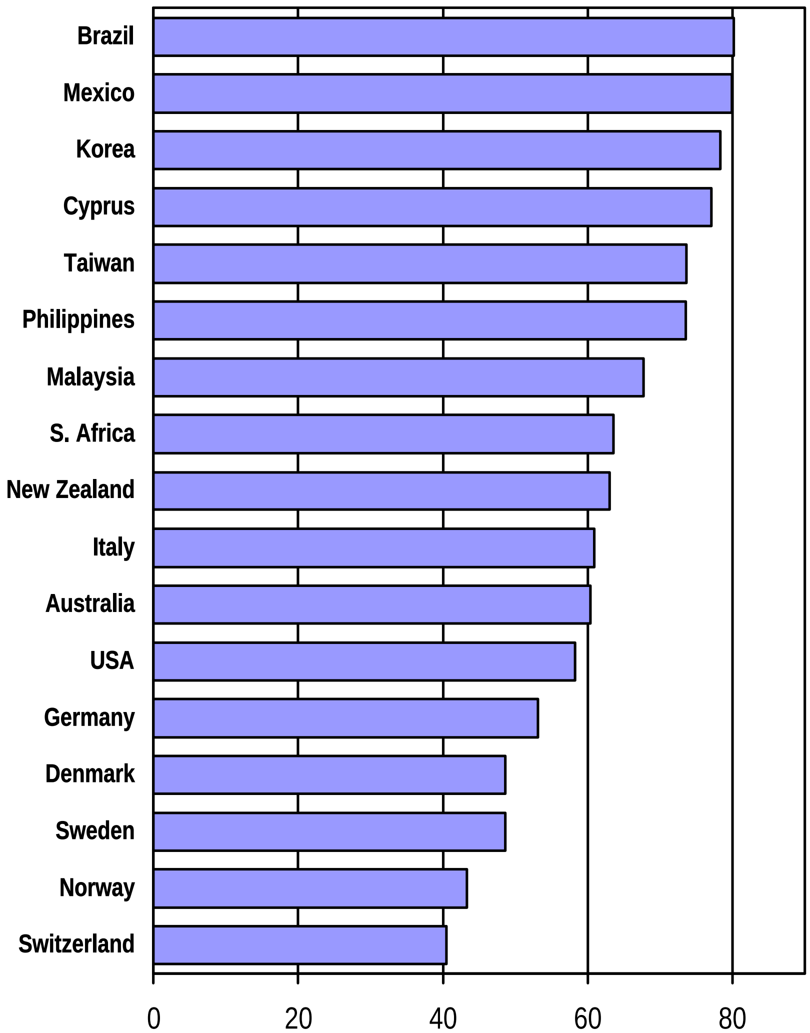

Figure 6. Mean scores of pilots from 18 countries on the FMAQ Automation Preference and Reliance Scale (Range 0 – 100)

There are not 'good' and 'bad' national cultures with regard to the prevalence of human error and the universal goal of safety. Each culture has elements with both positive and negative implications for effective group function as it affects these universal goals. However, there are organizational cultures that actively discourage safety initiatives and eschew efforts to build a safety culture. Ron Westrum (1992) has referred to such cultures as 'pathological' in their rejection of information that might avert catastrophe. In such organizations, the primary defenses are the positive aspects of the professional and national cultures and the diligence of regulatory agencies.

Ultimately, though, it is the responsibility of organizations to promote a safety culture and to maximize the positive and minimize the negative aspects of professional and national cultures.

Threat and Error in Flight Operations

Errors have been extensively studied in the laboratory, in training programs, and in *post-mortem* analyses of crew behavior in accidents and incidents. Similarly, systematic evaluations of the nature of external threats to safety are most frequently conducted when they are associated with adverse events. There is a dearth of systematic empirical data on the kinds, frequency, management, and resolution of threats and errors in *normal* flight operations. If safety efforts are to be optimally effective, such information is essential. In an effort to fill this gap, our research group has started a new program to examine threat and error in line audits of normal operations (described in a following section, Line Audits). An addendum to the Line/LOS Checklist, our form for the collection of systematic data during line flights (LLEC: Helmreich, Klinect, Wilhelm, & Jones, 1999) was developed to record threats and crew-based errors, and crew behaviors during normal flights.

Between July, 1997 and November, 1998, formal studies to investigate CRM, threat, and error management were conducted at three airlines using the LLEC[5]. The first was a commuter airline, where we observed 123 flight segments. The second and third were major airlines, with a focus on international, long haul operations. In these audits, we observed approximately 100 segments in each airline. For a detailed look at results of these audits, see Klinect, Wilhelm & Helmreich (in press). Of the flights observed, 72% experienced one or external threats (such as adverse weather, high terrain, mechanical malfunctions, language problems with ATC, etc.), with an average of 1.91 per flight and a range of from 0 to 11. While many of the situations experienced were not serious in themselves, they did increase the level of risk and the probability of error. When a large number of external threats are associated with a particular flight, demands on the crew are greatly increased. We have found in earlier audits that conditions of high complexity with off-normal conditions may either stimulate crews to superior performance or lead to performance breakdowns (Hines, 1998).

Let us now consider the right side of the threat and error model presented in Figure 1—the side that deals with crew-based error and error management. We operationally define this type of error as *crew action or inaction that leads to deviation from crew or organizational intentions or expectations*. Violations of formal requirements such as regulations, SOPs, and policies are included in this definition. We are indebted both to James Reason (1990, 1997) and Patrick Hudson (1998) whose work has greatly influenced our efforts. While we recognize the distinction made by Reason and Hudson between errors and violations, we have labeled violations *intentional noncompliance errors* because we realize that the intent in violations is usually to shortcut what is seen as an unnecessary procedure or regulation or to use a more effective strategy. In developing a model of crew-based error, we found that the usual taxonomies and classifications of flightcrew error management did not fit our data well. This led us to develop a revised taxonomy of cockpit crew error that we feel may be of value for both research and operational evaluation. This model is shown in Figure 7.

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[5] Excluded are cognitive errors that do not result in observable behaviors or verbalizations. It should also be noted that those observed are experts (as opposed to novices used in laboratory research or those in training) and that the crews' behaviors are highly consequential. Observers, especially on long flights, were not present at all times on the flightdeck (normally taking a rest period during cruise at altitude). As a result, the recorded incidence of error is a conservative estimate of the actual frequency.

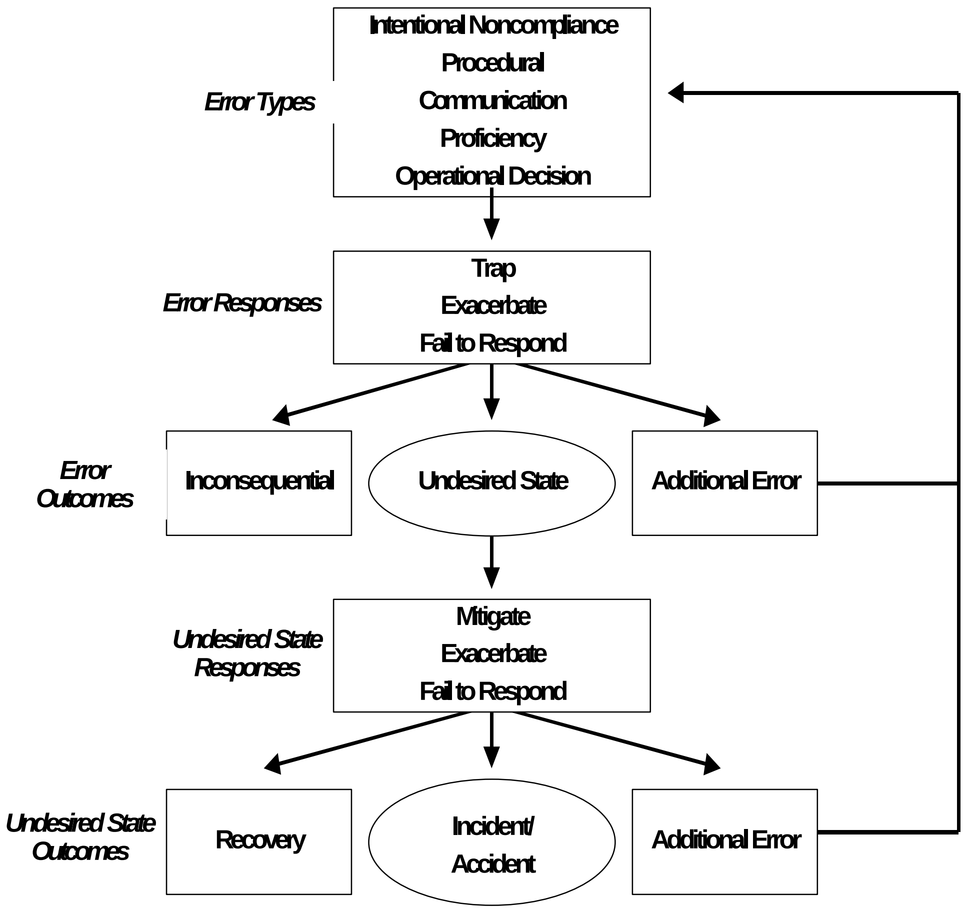

Figure 7. A model of flightcrew error management.

We use a five-way classification of error. As discussed earlier, violations such as checklists from memory or failure to observe sterile cockpit are called *intentional noncompliance errors* and consist of cases where crews choose to shortcut or ignore procedures. *Procedural errors* include slips, lapses, and mistakes in the execution of regulations or procedures where the crew intended to follow procedures but made an error in execution. Specific procedural errors observed include incorrect entries in the flight management computer and unintentionally skipping items on checklists. *Communications errors* occur when information is incorrectly transmitted or interpreted. These include not only errors within the flightcrew, but also in interactions with air traffic control, such as incorrect readbacks. The fourth classification, *proficiency errors* is reflected in events where one or more crew members lack the knowledge to perform a needed action such as a flight management computer procedure or lack necessary stick and rudder skill to properly fly the aircraft. The final category consists of *operational decision errors.* These errors are discretionary decisions not covered by SOPs where crews make a decision that unnecessarily increases the level of risk on the flight. These often reflect deviations from policy in cases where there are no formal procedures. Examples include 1) all crew members focusing their attention on reprogramming the flight management computer on final approach which is discouraged by the company's automation philosophy, and 2) crew accepting an ATC command that leads to an unstable approach. Table 2 shows the percentage of each error type observed.

Type of Error	% of All Errors
Intentional noncompliance	54%
Procedural	29%
Communications	6%
Proficiency	5%
Operational decision making	6%

Table 2. Percentage of each error type observed in line audit.

Error responses that can be made by the crew are limited. Three responses to crew error are identified: 1) *Trap* – the error is detected and managed before it becomes consequential; 2) *Exacerbate* – the error is detected but the crew's action or inaction leads to a negative outcome; 3) *Fail to respond* – the crew fails to react to the error either because it is undetected or ignored.

After an error occurs and the crew responds, there is an outcome that can be classified into one of four categories. An *undesired aircraft state* is a condition where the aircraft is unnecessarily placed in a condition that increases risk to safety. It includes incorrect navigation, fuel state, unstable approach, long landing, etc. An outcome is *inconsequential* when an error is discovered and trapped without leading to an undesired state. Undetected or ignored errors can also be inconsequential when they have no adverse effects on the safe completion of the flight (luck?). *Additional error* refers to an outcome where the initial error leads to (or is closely associated with) a subsequent one, either through no response or an exacerbating response on the part of the crew. For example, failure to run a landing checklist may lead to a failure to lower landing gear. After entering an undesired aircraft state, the condition can be managed by a crew response that corrects (mitigates) the error or in a manner that exacerbates the severity by leading to another error or to an accident or incident. For some undesired aircraft states, the crew may not have the option to respond – the state is the end of the sequence. An example of this would be a long landing. If one error causes another error at any point, we can start again at the top of the model and the situation represents the classic "error chain." Figure 8 gives examples of errors classified using the methodology. As the figure shows, intentional non-compliance errors were the most frequently observed (54%), followed by Procedural (29%), Communications (6%), and Operational Decision Making (6%), and Proficiency (5%). As we discuss below, the consequences of each error type and their distribution across organizations differ widely.

Trapped Error

Error Type - Procedural Error
During pre-departure, FO punched a wrong waypoint into the Flight Management Computer
Error Response –Trap
The crew caught the error during the crosscheck
Error Outcome – Inconsequential

Ignored error

Error Type – Intentional Noncompliance
F/O performs the After Takeoff Checklist from memory
Error Response – Fail to respond (ignored)
Captain notices the SOP violation but says nothing
Error Outcome – Additional error
F/O failed to retract the landing gear.

Exacerbated Error

Error Type – Communication
F/O told the Captain to turn down the wrong runway
Error Response – Exacerbate
Captain turned down the runway
Error Outcome – Undesired State
The aircraft is on the wrong runway
Undesired State Response - Mitigate
Undesired State Outcome - Recovery
After reviewing the taxi chart, the crew taxied to correct runway

Undetected Error

Error Type – Procedural
Asked to level off at 22,000 feet, the Captain double clicked the altitude hold button on the mode control panel [engaged it, then disengaged it] and it was never engaged.
Error Response – Fail to respond (undetected)
The crew did not notice the error.
Error Outcome – Undesired state
Crew flew through the assigned altitude.
Undesired State Response – Mitigate
Undesired State Outcome – Recovery
The altitude deviation was noticed by the captain, who returned the aircraft to the proper altitude and mode.

Figure 8. Examples of errors classified.

The distribution of errors, however, is not symmetrical across flight segments. There was at least one error on 64% of the flights observed. An average of 1.84 errors were recorded per flight, with a range of from 0 to 14. The distribution of errors by flight is summarized in Table 3. The distribution of errors by phase of flight is shown Table 3. The highest percentage of errors, 39%, occurred during the approach and landing phase of flight. Boeing's compilation of worldwide jet accidents between 1959 and 1997 comes up with 55% occurring during this phase of flight (Boeing, 1998). The British civil aviation global accident database shows 70% of accidents in the approach and landing phase, but it also includes non-jet and air taxi operations (Civil Aviation Authority, 1998). The data validate the importance of proactive steps to reduce risk and error in this phase of flight (Khatwa & Helmreich, 1999).

Phase of Flight of Error	**% of Errors**	**Consequential**
Pre-flight	23%	
Take off/climb	24%	
Cruise	12%	
Approach and landing	39%	
Taxi/park	2%	

Table 3. Distribution of observed crew errors by phase of flight.

Of course, not all errors become consequential. Fortunately, the error tolerance of the aviation system is such that most flights, even in the face of threat and flightcrew error, end uneventfully. We operationally defined as consequential errors that resulted in either an additional error or in an undesired aircraft state. Additional crew errors and undesired aircraft states can result from either a failure to respond to an error (undetected or ignored by the crew), or from the crew actions that exacerbate the error. The least consequential error type was intentional noncompliance. For this type of error, only 2% of observed errors became consequential. Pilots show good judgement in choosing to violate those regulations that have a low probability of becoming consequential. At the other extreme, 69% of proficiency errors and 43% of operational decision making errors resulted in consequential outcomes. Although these occurred relatively infrequently, they were often consequential. Intermediate were communications errors consequential 13% of the time, and procedural errors 23% of the time. Since procedural errors occur relatively frequently, they still account for a high proportion of consequential outcomes.

In addition, errors that occurred at some phases of flight were more potent in causing consequential outcomes than those that occurred in others. Descent/approach/land errors were the most potent – 39% become consequential. Thus not only are more errors made in this critical phase of flight, but they also become more consequential. Takeoff errors and cruise errors became consequential 12% of the time and pre-flight errors 7%. We do not have enough errors in the taxi/park phase to adequately judge their potency.

One of the main findings of our study is the striking difference between organizations on our measures of threat and error management. The between organization (and between fleet) differences demonstrated have several important implications. The first is that organizations cannot assume that their operation will correspond to normative data from the industry. The high degree of variability observed corresponds to differences in the operating environment and, most importantly, demonstrates the power of organizational cultures and subcultures (Reason, 1997).

	Airline A	Airline B	Airline C
Threats per segment	3.3	2.5	0.4
Errors per segment	.86	1.9	2.5
Error Management - % consequential	18%	25%	7%

Table 4. Threats and errors in three airlines.

Implementing Threat and Error Management

Early CRM advocates fell into the trap of thinking and asserting that it would be a universal panacea for the problem of human error. This did not happen. In today's more restricted, but realistic, model, CRM is seen as a tool that can be used to build a safety culture in the framework of the three cultures that influence flight operations.

Policy, Trust and Data

An essential for effective CRM is a credible organizational policy that recognizes the inevitability of human error and elucidates a credible commitment to error management. This policy must be built on trust and a non-punitive stance toward error. Rather than seeking to blame and punish those who err, management needs to understand the roots of error in the organization and to develop an array of defenses against future recurrences. We are in no way advocating that organizations tolerate the intentional violation of their rules or those of the regulatory agency. No organization can expect to survive if it allows its employees to disregard procedures and safety standards.

To specify needed actions and to determine if safety efforts are effective, organizations must have current and accurate data on the state of their operations and the nature and number of threats and errors in their operation. To obtain complete and accurate data requires a high level of trust on the part of employees. They must be willing to share their mistakes without fear of reprisal. Their trust must also include the belief that management will act on safety issues when they are uncovered. If this trust is established, organizations can obtain meaningful data and use them both to guide the development of appropriate training and as a yardstick for assessing trends in performance and error.

Sources of Data on Organizational Performance and Error

Since the accident rate in commercial aviation is extremely low, surrogate measures must be used as safety and organizational effectiveness indicators (Helmreich, Chidester, Foushee, Gregorich, & Wilhelm, 1990). One indicator is pilot performance during formal evaluations by company evaluators or the regulator (the Federal Aviation Administration in the USA). Although these data demonstrate that those evaluated have the ability to perform their jobs, they do not reveal how they behave when not under surveillance. Having above average intelligence and valuing their jobs, pilots can adhere strictly to rules when being checked and are also in a state of higher vigilance during evaluation. Although they may not be diagnostic of system performance, checks do have great value for modeling and reinforcing appropriate behaviors.

Another organizational indicator is performance in training, but this is also an imperfect predictor of behavior during line operations since it also measures the *ability* of the individual or crew to perform appropriately while under surveillance.[6] Because of these limitations, organizations need to develop alternative sources of data that minimize the jeopardy/best behavior problem. We will describe three other sources of data that organizations can utilize to gain understanding of the efficacy of their safety and training efforts and to plan the most effective use of their resources. Our view of the data necessary to manage error effectively parallels that of Captain Daniel Maurino of the United Nations' International Civil Aviation Organization. Based on his global experience with air transport, Maurino (1998a, 1998b, and in press) concludes that the most valuable data on the health of operations come from the monitoring of normal operations.

Line audits

We have collaborated in the conduct of line audits in a number of airlines (three were the source of the error data discussed earlier). It is our belief and that of participating airlines that such data provide a reasonably accurate and comprehensive picture of line operations. The key to success of an audit is the credible assurance to crews that all observations are without jeopardy and that no identifiable information on any crew will be revealed to management or regulators. In practice, we have trained a group of expert observers from the airline (pilots from training, flight standards, the union, etc.) in the use of our Line/LOS Error Checklist (Helmreich, Klinect, Wilhelm & Jones, 1999). Using this form, systematic evaluations of crew CRM skills are made at various phases of flight, along with threat and crew error, and their management. The team of observers samples flights in all fleets and types of operations, usually for a period of a month. That a realistic picture of the operation is being captured is shown by the

[6] This is more of a problem in low Uncertainty Avoidance cultures such as the USA where individuals do not feel compelled to adhere to procedures under all conditions. In high UA countries, performance in training is likely to be a much better predictor of line performance.

fact that observers frequently see violations of SOPs and regulations. For example, as part of a line audit we observed instances of failure to complete (or even use) checklists. This was particularly prevalent in one fleet of one airline. Neither line checks nor Federal Aviation Administration inspections had suggested that this might be a problem. The line audit database gives clear guidance to management as to what to emphasize in training and also indicates where problems of leadership or poor safety norms may be present. Analyses of the aggregated, de-identified data from line audits give the industry insights into ubiquitous problems such as the use of flightdeck automation, the variability of performance in the system, and standardization of procedures and practices (Helmreich & Merritt, 1998; Helmreich, Hines, & Wilhelm, 1996; Hines, 1998).

Confidential surveys

Organizations can augment line audit data with confidential surveys, often using an instrument such as the Flight Management Attitudes Questionnaire (FMAQ: Merritt, Helmreich, Wilhelm, & Sherman, 1996). Surveys provide insights into perceptions of the safety culture and illuminate aspects of teamwork among flight crews and other organizational elements including maintenance, ramp, and cabin. At the most detailed level, survey data also indicate the level of acceptance of fundamental concepts of CRM among line crews. They also show where differences may have developed between operational units of organizations, such as fleets and bases. Data from surveys can be used effectively to guide curriculum development for recurrent training by helping the organization target the most important operational issues.

Incident reporting systems

Incidents provide invaluable information about points of potential vulnerability in the aviation system. Confidential, incident reporting systems such as NASA's Aviation Safety Reporting System and BASIS (British Airways Safety Information System) programs are very useful for the overall system. In the USA, the Aviation Safety Action Programs (ASAP, Federal Aviation Administration, 1997) concept was designed to give organizations more complete data on incidents in their own operations. ASAP encourages participation by providing crew members with protection from regulatory reprisal for many types of incidents and rapid feedback about organizational efforts to prevent their recurrence. Each reported incident is reviewed by a team (including representatives of management, the pilots' union, and the FAA) which develops a plan of action along with feedback to the reporter. American Airlines has the longest experience with ASAP and is receiving reports at a rate of over 3,500 per year. As long as crews feel safe in submitting information to programs such as ASRS, BASIS, and ASAP, the data can give organizations an invaluable early warning system about potential threats to safety. Our research group, in cooperation with several U.S. airlines, has initiated a project to develop a new ASAP form to probe more deeply into human factors issues in incidents (Jones & Tesmer, in press). The object of this effort is to generate data that can be combined with those from other sources such as audits, surveys, and training records to provide organizations with a more comprehensive view of their operations and better guidelines for operations and training.

We also recognize the value of data collected during normal operations from flight data recorders under programs such as the FAA's Flight Operations Quality Assurance (FOQA). Such data provide critical information on the nature and location of instances where normal flight parameters are exceeded. A limitation of flight recorder data is that they provide no insight into why events occurred and the human factors issues associated with them. Line audits, confidential surveys, and incident reporting systems can augment FOQA programs and lead to a better understanding of causal factors.

Using data proactively for safety

The data collected in support of safety can be directly utilized in safety and error reduction initiatives. By examining the categories of error observed in their own observations, organizations obtain a valid report card on the effectiveness of their operation that different elements of the organization can use to plan necessary action. For example, a high frequency of operational decision errors may suggest a need for additional SOPs. Conversely, a large number of noncompliance errors may indicate inappropriate or too many and too complex SOPs (see also Reason, 1997 for discussion of SOPs and compliance).

Focusing CRM on threat and error

CRM courses have matured from the presentation of general concepts of team interaction and personal styles to become much more technical and operationally relevant training programs.
Encouraging progress has been made toward the seamless integration of CRM and technical training that was identified as a major goal at the second NASA CRM conference in 1986 (Orlady & Foushee, 1987). One of the outcomes of this movement toward defining CRM in terms of specific behaviors has been a trend toward proceduralization of CRM, requiring interpersonal behaviors and communications as part of technical maneuvers. The positive side of this is clear guidance for crews as to expected behaviors and, concurrently, the ability to assess and reinforce their practice. There are several negative aspects of proceduralization. One is the possible loss of understanding of CRM's broader, safety goals when it becomes a set of required actions appended to technical maneuvers (Helmreich, Merritt, & Wilhelm, 1999). The second, clearly identified by Reason (1997) is that the proliferation of procedures may serve to *reduce* compliance. As more and more well-intentioned procedures find their way into operations, they may lose impact and significance, almost inviting violations. A third is that it may cause CRM programs to lose sight of important, phase independent skills such as leadership and team building.

Placing CRM in the framework of threat recognition, error avoidance, and error management should help maintain awareness of the organization's commitment to safety. The formal review of known risks and off-normal conditions can be made part of a crew's preparation. This type of review also represents a readily observable behavior that can be assessed and reinforced by training and checking personnel. One of the major venues for decision making should be the formulation and sharing of error avoidance strategies in response to recognized threats. Similarly, detection and management behaviors are usually observable and can be evaluated and reinforced. As Tullo and Salmon (1998) have noted, monitoring and assessing these behaviors present a new challenge for instructors and evaluators, especially those dealing with behavior in normal operations.

CRM training should address the limitations of human performance, a problem evidenced by the high level of denial of personal vulnerability which is characteristic of the professional culture of pilots and other demanding professions. This denial works to the detriment of threat recognition and acceptance of the inevitability of error. There is empirical evidence that these attitudes can be modified by training [see Helmreich & Merritt (1998) for an example of attitude change about the effects of fatigue on performance]. Awareness of human limitations should result in greater reliance on the redundancy and safeguards provided by *team* instead of individual actions. This training can best be accomplished by providing understandable information about the psychological and physiological effects of stress, with examples drawn from aviation experience. The narrowing of attentional focus under stress provides a compelling example of the deleterious effects of stress. Positive examples of using CRM in crises—for example, the performance of the crew of United Airlines flight 232 after losing aircraft control following the disintegration of an engine, can build acceptance of team concepts (Predmore, 1991). It is also important to define the nature and types of cognitive errors to which all humans are prey (e.g., Reason, 1990). Making these slips and omissions salient to pilots through everyday, operational examples can also foster endorsement of the use of CRM countermeasures against error.

National culture and CRM

Although threat recognition and error management are universally valued, this does not imply that the same CRM training will work as well in Turkey as in Texas. The rationale provided to flightcrews for error management and the description of relevant behavioral countermeasures need to be in a context that is congruent with the culture. For example, assertiveness on the part of junior crew members can be accepted as an effective strategy and practiced comfortably in individualistic, low power distance cultures such as the U.S. In contrast, simply advocating the use of assertion by juniors in many high power distance cultures is likely to be seen as a bizarre and unworkable proposal. On the other hand, assertive behavior could be acceptable if it is seen as a means of protecting the organization (or in-group) and as a means of saving the face of the captain by keeping him from making a consequential error. However, there is still much to be learned about fitting training strategies to cultures. We see testing the error management approach as a challenge for both researchers and practitioners and an area where cross-cultural collaboration will be essential.

Implementing CRM in Other Domains

The operating room

One of the more advanced applications of CRM concepts has been in medicine, specifically the function of teams in operating and emergency rooms (see Davies, this volume, for a detailed discussion). Most of the original impetus came from anesthesiologists such as David Gaba at Stanford and Hans-Gerhard Schaefer at the University of Basel/Kantonsspital who saw parallels between the operating room (OR) environment and the cockpit (Gaba & DeAnda, 1988; Helmreich & Schaefer, 1994; Helmreich & Davies, 1996). In reality, the OR is a more complex environment than the cockpit with multiple groups composed of anesthesiologists and surgeons (both attendings and residents), nurses, orderlies, and, of course, a patient. In the OR, the lines of authority between the surgical and anesthetic teams are unclear and this in itself can be a source of conflict (Helmreich & Schaefer, 1994).

The development of resource management for the OR has taken a rather different course from that in aviation. While aviation programs had their foundation in formal awareness training, normally in an interactive seminar context with subsequent training and reinforcement in full mission simulation (LOFT), the medical programs were built around simulation with only cursory discussion of more global issues (Davies & Helmreich, 1996). A major limitation of most programs has been a focus only on the anesthesia team rather than the full OR complement, usually with an actor paid to role-play the surgeon (see Wilkins, Davies, & Mather, 1997, for a discussion of simulator training in anesthesia). Such programs involve part-task rather than full mission simulation, which is problematic since our observations suggest that most of the observed difficulties in the OR come at the interface between teams (Helmreich & Davies, 1996; Sexton, Marsch, Helmreich, Betzendoerfer, Kocher, & Scheidegger, 1997a).

A more comprehensive approach to training was developed by the late Hans-Gerhard Schaefer and his colleagues at the University of Basel. The group there focused on building a complete OR simulator that allows members of the surgical team as well as the anesthesia team to conduct meaningful work (laparoscopic surgery) and captures the richness of inter-team interactions (Helmreich, 1997; Helmreich & Schaefer, 1997). As yet, systematic data have not been developed to validate the impact of such training programs on medical participants, although self-reports indicate that the experience is perceived as valuable by those who receive it (Sexton, Marsch, Helmreich, Betzendoerfer, Kocher, & Scheidegger, 1997b).

Shipboard

Another logical venue for the application of CRM is in maritime operations. The National Transportation Safety Board (for example, NTSB, 1993) has been urging maritime operators to adopt *Bridge* Resource Management as a parallel to CRM on the basis of accidents showing maritime human factors problems to be similar to those in aviation. One of us (RLH) has collaborated with the Danish Maritime Institute and the Risoe Institute in Denmark to develop a new instrument conceptually similar to the FMAQ. Results of preliminary surveys of mariners in several countries show similar human factors issues and a professional culture as prone to the denial of personal vulnerability as those of aviation and medicine (Helmreich & Merritt, 1998).

In both the medical and maritime environments the tendency has been to lightly adapt cockpit training programs to build awareness of human factors issues. This approach, which disregards the realities of the environments and the cultures involved, is reminiscent of early CRM programs, which also lacked specificity and relevance. One exception to this has been training developed by the Danish Maritime Institute, which is similar to later generation CRM programs and augments seminar training with the marine equivalent of full mission simulation using a high fidelity ship simulator (e.g., Andersen, Soerensen, Weber, & Soerensen, 1996).

Overall, it is our belief that error management concepts are highly applicable to other domains where teamwork and technology are required. We feel equally strongly that programs must be embedded in organizational threat and error management efforts.

Summary and guidelines for organizations implementing more operationally focused programs

Crew Resource Management is not a fully realized concept. Cultural effects are not fully understood and the nature of errors in the normal, operational environment must be further explored. There is also need for the involvement of the research community to develop new approaches and build databases showing the nature and frequency of errors and the multiple strategies involved in coping with threat and responding to error.

The actions necessary to develop and apply resource management programs go far beyond the design and delivery of training programs. If an organization is not receptive to the training initiative and contextual effects are ignored, programs are unlikely to achieve the desired outcomes and may inappropriately raise questions about the training itself. Those charged with developing and delivering training need to establish with senior management a common view of goals and to obtain commitment that the program will be supported with appropriate resources. The following guidelines are essential and can provide a checklist for program development:

- **Guideline 1: Building Trust.** Senior management, in co-operation with employee groups must establish a relationship of trust that will encourage and reward individuals and teams that share safety related information.

- **Guideline 2: Adopting a non-punitive policy toward error.** Management's policy toward error must be to elicit information without punishing those who make errors while trying to accomplish their jobs in accordance with regulations and SOPs.

Effective programs clearly involve management at the highest levels and extend beyond the purview of program developers and trainers. The task is much more daunting than simply developing a training program for operational personnel. There is little to be gained and much to be lost by initiating training that falls short of expectations. On the other hand, with the appropriate level of commitment, programs can be initiated that should yield measurable improvements in safety and efficiency – and the side benefit of better organizational communication and morale.

- **Guideline 3: Providing training in error avoidance, detection, and management strategies for crews.** With the supportive infrastructure provided by the above points, formal training can give crews the tools and countermeasures to error that they need to optimize flight operations.

- **Guideline 4: Providing special training in evaluating and reinforcing error avoidance, detection, and management for instructors and evaluators**. Key personnel responsible for training and evaluation of performance need special training in the concepts and assessment of threat and error management. It is essential that error management be evaluated and reinforced not only in training but also in line operations. The major change here is in formally recognizing that error, in itself, is part of system operations and that effective error management can represent effective crew performance.

- **Guideline 5: Demonstrating a willingness to reduce error in the system.** The organization must establish mechanisms to deal with safety-related information and to make changes necessary to reduce or mitigate error.

- **Guideline 6: Collecting data that show the nature and types of threat and error.** Organizations must commit resources necessary to obtain and analyze data showing its operational status. These data sources can include line audits, surveys, incident reports, and training evaluations.

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