Chapter 1

Why CRM? Empirical and Theoretical Bases of Human Factors Training

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Introduction

Section 1.1 of this chapter is the introductory chapter of the 1993 edition of the book. This reprint is important for the reader because it covers the antecedents and history of CRM from 1978 until 1992. Some of the predictions for the future of CRM have been borne out while others have not. Fifteen years ago, CRM was not universally accepted by the pilot community: it was sometimes decried as charm school, psychobabble, and attempted brainwashing by management and some of these criticisms had merit. The evolution of CRM is covered through its third generation.

Section 1.2, CRM Redux, covers the fourth, fifth and the current sixth generation which focuses on the threats and errors that must be managed by crews to ensure safety in flight.

1.1. The Evolution and Growth of CRM

1.1.1. Introduction

One of the most striking developments in aviation safety during the past decade has been the overwhelming endorsement and widespread implementation of training programs aimed at increasing the effectiveness of crew coordination and flightdeck management. Civilian and military organizations have developed programs that address team and managerial aspects of flight operations as complements to traditional training that stresses the technical, "stick-and-rudder" aspects of flight. The original, generic label for such training was *cockpit resource management,* but with recognition of the applicability of the approach to other members of the aviation community including cabin crews, flight dispatchers, and maintenance personnel, the term *crew resource management* (CRM) is coming into general use.

Just as CRM has evolved from "cockpit" to "crew" over its short history, the field of human factors has similarly changed in its scope. From an initial marriage of engineering and psychology with a focus on "knobs and dials," contemporary human factors has become a multidisciplinary field that draws on the methods and principles of the behavioral and social sciences, engineering, and physiology to optimize human performance and reduce human error (National Research Council, 1989). From this broader perspective, human factors can be viewed as the applied science of people working together with devices. Just as the performance and safety of a system can be degraded because of poor hardware or software design and/or inadequate operator training, so too can system effectiveness be reduced by errors in the design and management of crew-level tasks and of organizations. CRM is thus the application of human factors in the aviation system. John K. Lauber (1984), a psychologist member of the National Transportation Safety Board (NTSB), has defined CRM as "using all available resources—information, equipment, and people—to achieve safe and efficient flight operations" (p. 20). CRM includes 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. Thus training in CRM involves communicating basic knowledge of human factors concepts that relate to aviation and providing the tools necessary to apply these concepts operationally. It represents a new focus on crew-level (as opposed to individual-level) aspects of training and operations.

This chapter's title inquires why an industry would embrace change to an approach that has resulted in the safest means of transportation available and has produced generations of highly competent, well-qualified pilots. In seeking the answer, we examine both the historic, single-pilot tradition in aviation and what we know about the causes of error and accidents in the system. These considerations lead us to the conceptual framework, rooted in social psychology, that encompasses group behavior and team performance. In this context we can look at efforts to improve crew coordination and performance through training. Finally, we discuss what research has told us about the effectiveness of these efforts and what questions remain unanswered.

1.2. The Single-Pilot Tradition in Aviation

The evolution of concern with crew factors must be considered in the historical context of flight. In the early years, the image of a pilot was of a single, stalwart individual, white scarf trailing, braving the elements in an open cockpit. This stereotype embraces a number of personality traits such as independence, machismo, bravery, and calmness under stress that are more associated with individual activity than with team effort. It is likely that, as with many stereotypes, this one may have a factual basis, as individuals with these attributes may have been disproportionately attracted to careers in aviation, and organizations may have been predisposed to select candidates reflecting this prototype.

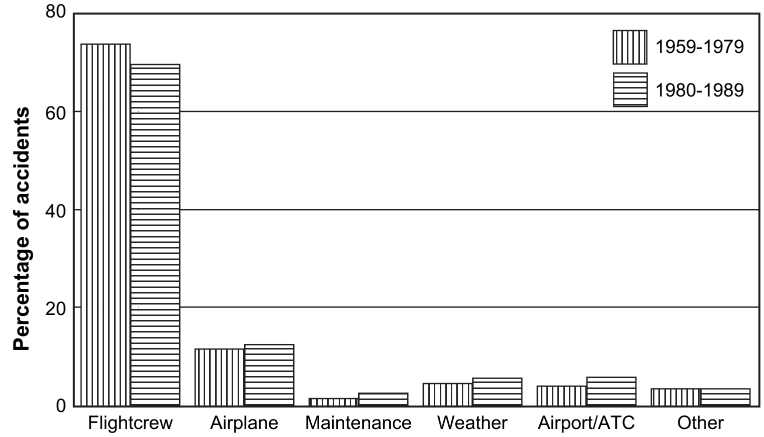
As aircraft grew more complex and the limitations and fallibility of pilots more evident, provision was made for a co-pilot to provide support for the pilot, to reduce individual workload and decrease the probability of human error. However, these additional crewmembers were initially perceived more as redundant systems to be used as backups than as participants in a team endeavor. Ernest K. Gann (1961) and other pioneers of air transport have documented the distinctly secondary role played by the co-pilot in early airline operations.

The tradition in training and evaluation has similarly focused on the individual pilot and his or her technical proficiency (Hackman & Helmreich, 1987). This begins with initial selection and training, which have historically used aptitude and performance standards developed for single-pilot operations. Indeed, the first critical event in a pilot's career is the solo flight. Even in multipilot operations, the major emphasis continues to be on evaluting the individual proficiency of crewmembers. Regulations surrounding the qualification and certification of pilots reinforce these practices and can even result in negative training. For example, in crewmembers are cautioned not to provide assistance to pilots whose proficiency is being evaluated, a model of individual instead of team action is being reinforced. Indeed, in 1952 the guidelines for proficiency checks at one major airline categorically stated that the first officer should not correct errors made by the captain (H. Orlady, personal communication cited in Foushee & Helmreich, 1988). The critical point is that the aviation community has operated on the assumption that crews composed of able and well-trained individuals can and will operate complicated aircraft in a complex environment both safely and efficiently.

1.3. Human Error in Flight Operations

The introduction of reliable turbojet transports in the 1950s was associated with a dramatic reduction in air transport accidents. As problems with airframes and engines diminished, attention turned to identifying and eliminating other sources of failure in flight safety. Figure 1.1 gives statistics on the causes of accidents from 1959 through 1989, indicating that flightcrew actions were casual in more than 70% of worldwide

Figure 1.1 Primary causes of hull loss accidents (excluding military and sabotage): worldwide commercial jet fleet, 1959–1989. Data from Boeing Aircraft Company



accidents involving aircraft damage beyond economical repair. Recognition of this human performance problem stimulated a number of independent efforts to understand what the term "pilot error" encompassed and what could be done to reduce it.

The formal record of investigations into aircraft accidents, such as those conducted by the NTSB, provides chilling documentation of instances where crew coordination has failed at critical moments.

- A crew, distracted by the failure of a landing gear indicator light, failing to notice that the automatic pilot was disengaged and allowing the aircraft to descent into a swamp.
- A co-pilot, concerned that take-off thrust was not properly set during a departure in a snowstorm, failing to get the attention of the captain with the aircraft stalling and crashing into the Potomac River.
- A crew failing to review instrument landing charts and their navigational position with respect to the airport and further disregarding repeated Ground Proximity Warning System alerts before crashing into a mountain below the minimum descent altitude.
- A crew distracted by nonoperational communication failing to complete checklists and crashing on take-off because the flaps were not extended.
- A breakdown in communication between a captain, co-pilot, and Air Traffic Control regarding fuel state and a crash following complete fuel exhaustion.
- A crew crashing on take-off because of icing on the wings after having inquired about de-icing facilities. In the same accident the failure of a flight attendant to communicate credible concerns about the need for de-icing expressed by pilot passengers.

The theme in each of these cases is human error resulting from failures in interpersonal communications. By the time these accidents occurred, the formal study of human error in aviation had a long tradition (e.g., Fitts & Jones, 1947; Davis, 1948). However, research efforts tended to focus on traditional human factors issues surrounding the interface of the individual operator with equipment. This type of investigation did not seem to address many of the factors identified as causal in jet transport accidents, and researchers began to broaden the scope of their inquiry.

In the United States, a team of investigators at NASA–Ames Research Center began to explore broader human factors issues in flight operations. Charles Billings, John Lauber, and George Cooper developed a structured interview protocol and used it to gather firsthand information from airline pilots regarding human factors in crew operations and "pilot error" accidents. At the same time, George Cooper and Maurice White analyzed the causes of jet transport accidents occurring between 1968 and 1976 (Cooper, White, & Lauber, 1980), while Miles Murphy performed a similar analysis of incidents reported to NASA's confidential Aviation Safety Reporting System (Murphy, 1980). The conclusion drawn from these investigations was that "pilot error" in documented accidents and incidents was more likely to reflect failures in team communication and coordination than deficiencies in "stick-and-rudder" proficiency. A number of specific problem areas were identified, including workload management and task delegation, situation awareness, leadership, use of available resources including other crewmembers, manuals, air traffic control, interpersonal communications (including unwillingness of junior crewmembers to speak up in critical situations), and the process of building and maintaining an effective team relationship on the flightdeck.

In Europe, Elwyn Edwards (1972) drew on the record of accident investigation and developed his SHEL model of human factors in system design and operations. The acronym represents *software,* usually documents governing operations; *hardware,* the physical resources available; *liveware,* consisting of the human operators composing the crew; and *environment,* the external context in which the system operates. Elaborating his model to examine the functioning of the liveware, Edwards (1975) defined a new concept, the trans-cockpit authority gradient (TAG). The TAG refers to the fact that captains must establish an optimal working relationship with other crewmembers, with the captain's role and authority neither over- nor underemphasized.

In the operational community in the early 1970s, Pan American World Airways management became concerned about crew training issues following several "pilot error" accidents in the Pacific. In 1974, a flight operations review team headed by David D. Thomas, retired Deputy Administrator of the Federal Aviation Administration (FAA), examined all aspects of flightcrew training and made a number of significant recommendations. The foremost of these was to utilize "crew concept training." Under this approach, both simulator training and checking were to be conducted not as single-pilot evolutions but in the context of a full crew conducting coordinated activities. At the same time, Pan Am manuals were revised to incorporate crew concepts and to explain more completely responsibilities for team activities and communications. These actions represented a fundamental change in the operating environment and provided an organizational framework for more effective crew coordination. Although the focus in training was now on crew activities, the shift was not accompanied by a program of formal instruction in communications and coordination. Crewmembers were mandated to operate as effective teams but were left to develop means of achieving this goal without formal guidance and instruction.

Identifying crew-level issues as central to a high proportion of accidents and incidents was a significant achievement in the process of understanding the determinants of safety in flight operations. However, development of successful strategies to improve crew performance requires an understanding of the determinants of group behavior and how they can be influenced. In the following section we describe a model of group processes and performance and its implications for training and organizational actions.

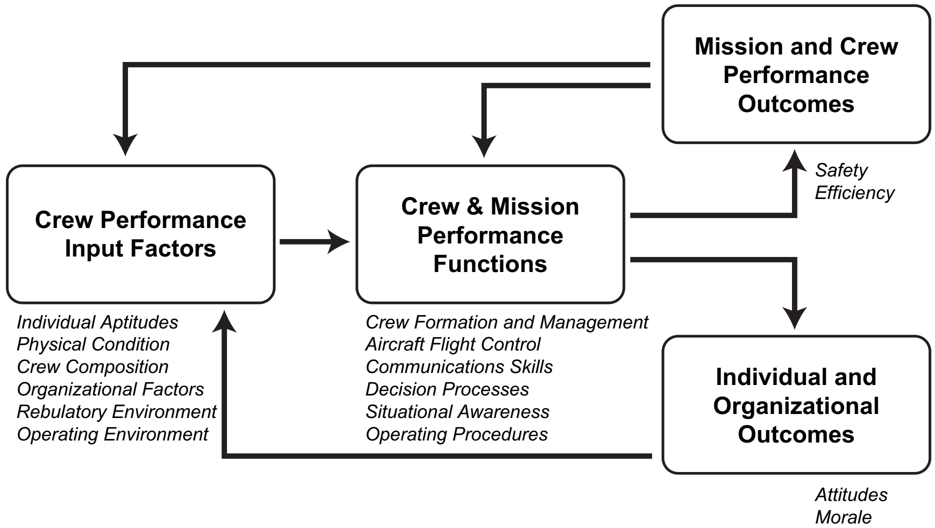
1.4. Group Processes and Performance in the Aviation Environment

The study of group behavior has historically been the province of social psychology and provides the conceptual basis for the three-factor model of the determinants of group performance we presented in an earlier discussion of flightcrew interaction and performance (Foushee & Helmreich, 1988; McGrath, 1964). Subsequent research has enabled us to expand and refine the model, and we present it as a framework for discussing issues surrounding CRM training. The model defines three major components of group behavior: *input factors,* which include characteristics of individuals, groups, organizations, and the operational environment; *group process factors,* which include the nature and quality of interactions among group members; and *outcome factors,* which include primary outcomes such as safety and efficiency of operations and secondary outcomes such as member satisfaction, motivation, attitudes, and so on. The underlying assumption of the model is that input factors both provide the framework and determine the nature of group processes that lead, in turn, to the various outcomes. Figure 1.2 shows the three factors and their interrelationships. A central feature of the model is feedback loops among the factors. Outcomes (right side of figure; either positive or negative) may change components of input factors (left side; e.g., attitudes and norms), and these changes may alter subsequent group processes (middle) and outcomes. Outcomes may theoretically also influence group processes without being directly mediated by input factors. It is the iterative nature of the factors determining group performance that makes its study both complex and challenging.

1.4.1. Outcome Factors

Primary outcome factors are readily recognizable and relatively easily quantifiable. In flight operations safety is paramount, but the efficient completion of missions and compliance with organizational and regulatory requirements are also important.

Figure 1.2 Flightcrew performance model



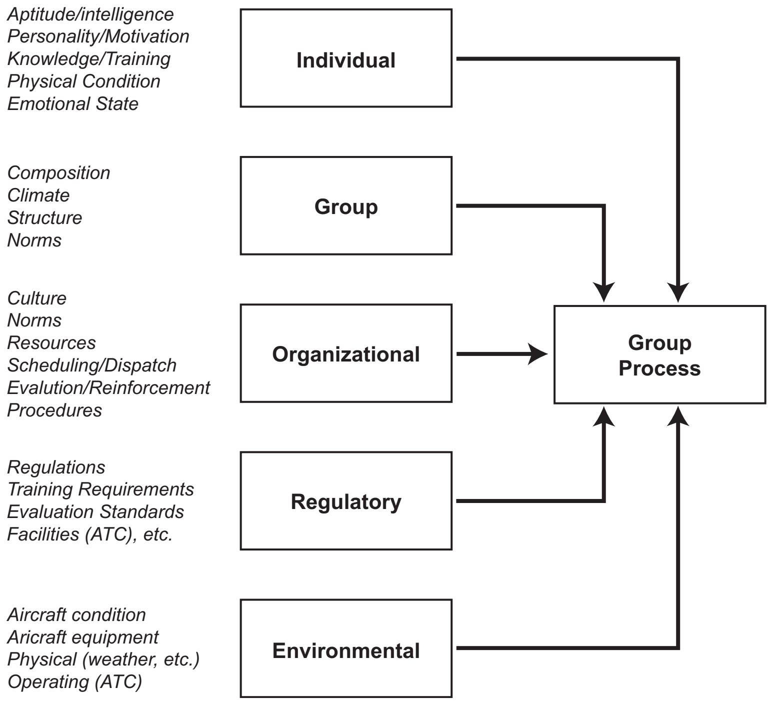
Both experience and training can create changes in crew attitudes and norms regarding appropriate flightdeck management. The quality of group processes, influenced by organizational, group, regulatory, and environmental factors, determines the satisfaction crews experience with operations and their motivation for future operations.

Outcome factors form the criteria against which the impact of interventions such as training or organizational policy changes are measured. While the most compelling measure of effectiveness in aviation would be a decrease in the frequency of accidents, such events are (happily) already so infrequent that reliable statistical evidence can only be found by aggregating data over extremely long periods of time. Accordingly, criteria of group performance need to be drawn from surrogate measures such as records of operational errors, expert ratings of crew effectiveness, and measures of attitude and job satisfaction.

1.4.2. Input Factors

A number of qualitatively different variables form the inputs to group processes. These have multiple components that, singly and in combination, influence the way teams interact. Figure 1.3 expands the input factors portion of the model to include lower-order variables that have a demonstrated influence on group processes and outcomes.

Figure 1.3 Flightcrew performance model: expanded input factors.



Individual factors

Consideration of a flightcrew's job in today's airspace brings to mind a number of background or input factors that can influence the effectiveness of crew activities even before an engine is started. Teams are composed of individuals who bring to the flightdeck their knowledge, skills, personalities, motivation, and physical and emotional states. Each of these characteristics has been identified as causal in one or more aircraft accidents.

Physical condition includes fatigue, which can undermine vigilance in a knowledgeable and motivated pilot. Emotional state is determined by a variety of life stresses (for example, marital discord or worries about the financial condition and viability of an airline) that cannot be left at the gate and can subtly undermine effectiveness. Aptitude (including intelligence and psychomotor skills) has long been recognized as critical to success as a pilot, and selection has emphasized these attributes. Recent research has also confirmed that personality factors are significant determinants of individual and team performance. A full-mission simulation study was run with volunteer, three-person crews in the NASA–Ames Boeing 727 simulator. The study explored the impact of leader personality factors on crew performance (Chidester, Kanki, Foushee, Dickinson, & Bowles, 1990). Crewmembers participating in the study were pretested on a personality battery that had been validated as predictive of flightcrew behavior (Chidester, Helmreich, Gregorich, & Geis, 1991). Three experimental groups were composed on the basis of the captain's personality constellation. One group was led by captains high on both goal orientation and interpersonal skills. A second group had captains who were high on goal orientation but relatively low on the interpersonal dimension. The third group was led by captains who were quite low on both goal orientation and positive interpersonal dimensions.

Each crew flew five complete flight segments spread across two days. On two of the legs, mechanical malfunctions occurred which were compounded by poor weather conditions at the destination airport. Crew performance was rated by expert observers, and technical errors were coded from computer records and videotapes of the flights. The data showed significant differences in performance between groups that could be attributed to the leader's personality. Crews led by captains high in both achievement needs and interpersonal skills performed uniformly well across all segments. In contrast, crews led by captains low on both of these dimensions were significantly less effective across all flights. Those in the third group, with captains high in achievement needs but low in interpersonal traits, were given poorer performance ratings initially but improved substantially by the fifth leg. One interpretation of this finding is that crews in this condition learned over time how to adapt to this difficult but motivated type of leader. The point relevant to this discussion is that a single input factor (personality) can be isolated as an influence on the performance of a well-trained and qualified crew in a controlled research setting.

Attitudes serve as guides for behavior and are another of the input factors that crews bring to the flightdeck. The *Cockpit management attitudes questionnaire (CMAQ,* Helmreich, 1984; Helmreich, Wilhelm, & Gregorich, 1988) is a 25-item, Likert-scaled battery that allows quantification of attitudes regarding crew coordination, flightdeck management, and personal capabilities under conditions of fatigue and stress. Attitudes measured by the *CMAQ* have been validated as predictors of outcome factors in the form of expert ratings of performance in line operations (Helmreich, Foushee, Benson, & Russini, 1986), thus demonstrating the linkage between input and outcome factors. Measures such as the *CMAQ* can be used both to assess input factors in organizations and as measures of outcomes to determine whether programs such as CRM can change attitudes.

Group factors

Crews are composed of individuals who bring with them all the attributes noted above. They may be cohesive and effective or divisive, rancorous, and ineffectual depending on the mix of individuals and their states that comes together at any given time. The climate that develops in a group is multiply determined by the characteristics of individual members, by the structure imposed by the formal and informal norms of the organization, and by the quality and style of leadership present. Because of the many individual and group factors identified, research into these issues and their effects is difficult and time-consuming. As a result there is not an extensive literature on the outcome effects of systematically varying multiple individual- and group-level variables, especially in the aviation environment.

Organizational factors

The culture of an organization is a critical input factor. If an organization sanctions individual actions rather than team coordination, both processes and outcomes are likely to have a very different flavor from those in organizations that stress crew actions and responsibility. The level of training and type of formal evaluation given to crews are also influential. Manuals and formal procedures also form part of the operational setting, as do the resources that the organization has and makes available for crews (including crew scheduling practices, maintenance support, flight planning, dispatching, etc.).

Another NASA simulation study examined the performance implications of several individual- and group-level factors. Foushee, Lauber, Baetge, & Acomb (1986) examined the interactions and performance of experienced two-person jet transport crews flying a realistic scenario in a Boeing 737 simulator. NASA was directed by the U.S. Congress to investigate the operational significance of pilot fatigue—an individual factor driven by organizational and regulatory practices. The experimental design reflected this concern and divided crews into two groups, pre-duty (defined as flying the scenario after a minimum of two days off as if it were the first leg of a three-day trip) and post-duty (flying the scenario as the last segment of a three-day trip). The scenario was characterized by poor weather conditions that necessitated an unexpected missed approach that was complicated by a hydraulic system failure. Following the hydraulic failure, crews were faced with a high-workload situation involving the selection of an alternate destination while coping with problems such as the requirement to extend gear and flaps manually and fly an approach at higher than normal speed.

Crews in the post-duty condition had less pre-simulation sleep and reported significantly more fatigue, as expected from the research design. The surprising finding, however, was that fatigued crews were rated as performing significantly better and made fewer serious operational errors than the rested, pre-duty crews. This finding was counterintuitive but had major implications relevant to the importance of team formation and experience. By the nature of the scheduling of flight operations, most crews in the post-duty condition had just completed three days of operations as a team, while those in the pre-duty condition normally did not have the benefit of recent experience with the other crewmember. When the data were reanalyzed on the basis of whether or not crews had flown together recently, the performance differences became even stronger. The findings suggest that crew scheduling practices that result in continuing recomposition of groups and a need for frequent formation of new teams can have significant operational implications. For example, three recent takeoff accidents in the United States (one involving a stall under icing conditions, one an aborted takeoff with an over-run into water, and one a runway collision after the crew became lost in dense fog) involved crews paired together for the first time.[1] The implications of crew pairings are discussed further in the chapter by Hackman.

Environmental factors

Weather conditions constitute an environmental input factor outside the control of flightcrews. The ability of organizations and the government to provide accurate, timely information on weather constitutes one of the factors governing both group processes and outcomes. The physical condition of the aircraft (including inoperative equipment, etc.) also determines part of the field in which the crew must operate as does the availability and quality of navigational aids.

Regulatory factors

Regulatory practices also influence the nature of crew interaction and performance. For example, the "sterile cockpit" rule in the U.S. proscribes non-operational communications below 10,000 feet. As described above, the focus of regulation has been on individual training and evaluation, and this has been echoed in organizational policies (recall the prohibition on first officers correcting captain's mistakes during proficiency checks). Ambiguity in regulations can also impact crews' decisions and actions. If the regulations governing an operation are unclear, responsibility shifts to the organization that can direct operations to meet operational goals and to the captain who must take ultimate responsibility for decisions regarding the safety of flight.

1.4.3. A Case Study: The Interplay of Multiple Input Factors in a Crash

Investigation of the human factors surrounding the crash of a Fokker F-28 on takeoff in Canada demonstrates the interplay of input factors at the regulatory, organizational,

[1] One involved a DC-9 taking off in a snowstorm at Denver, the second a rejected take off by a B-737 at New York-LaGuardia, and the third a DC-9 that erroneously taxied onto the active runway and collided with a B-727 taking off.

environmental, and individual levels. In this accident it can be seen how all of these can intersect to create an operational environment that fails to provide needed safeguards against pilot error (Helmreich, 1992; Moshansky, 1992). On a snowy winter afternoon the crew of Air Ontario Flight 1363 attempted a takeoff from Dryden, Ontario, with an accumulation of snow and ice on the wings and crashed because the aircraft could not gain enough lift to clear trees beyond the end of the runway. In the crash and resulting fire, 29 passengers and crewmembers, including both pilots, were killed. In attempting to understand how a crew with many years of experience operating in the severe winter, weather of northern Ontario could make such a serious operational error, a number of input factors were uncovered which, operating in concert, set the stage for a tragically wrong decision.

At the *environmental* level, the weather was poor and deteriorating, forcing the crew to select distant alternate landing sites and to carry extra fuel. Because of the poor weather, the flight was operating more than an hour late and was full, operating at maximum gross weight. The aircraft itself had a number of mechanical problems, the most serious of which was an inoperative auxiliary power unit (APU). With an inoperative APU, it was necessary to keep an engine running during stops at airports without ground start capabilities. Dryden had no such facilities.

At the *regulatory* level, the Canadian regulations regarding de-icing prohibited an aircraft from commencing a flight "when the amount of frost, snow, or ice adhering to the wings, control surfaces, or propeller of the aeroplane may adversely affect the safety of flight" (Moshansky, 1989).[2] The problem facing the crew under existing regulations was how, under time and operational pressures, to determine what constituted enough contamination to "adversely affect" safety of flight. The regulation as written made the takeoff decision at the captain's discretion and, at the same time, failed to provide safeguards against personal and organizational pressures to complete the mission at all costs.

The regulatory agency's surveillance of the airline had not focused on the newly initiated jet operation. While an audit of the airline's operations had been completed during the preceding year, the audit did not include the F-28 operation. A more complete examination might have revealed procedural and organizational discrepancies in the F-28 operation, as noted below.

A number of *organizational* factors served to increase the stress level of the crew. The airline had just begun operating jet transports and had little operational experience with

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[2] In response to a recommendation by the Commission of Inquiry into the crash, the regulation was changed to prohibit operation with any contamination of lifting surfaces.

this type of equipment. Initial crews for the Fokker had been trained at two different U.S. airlines before the operation was initiated. The airline had not developed its own operating manuals, and some crewmembers were carrying manuals from one airline and others from another. The organization had not developed an approved minimum equipment list (MEL) specifying what equipment could be inoperative in normal passenger operations. Dispatchers had received only minimal training for this type of aircraft and were experienced only with small propeller-driven equipment. The flight release for the day of the accident contained a number of errors. In sum, the crew was operating without a high level of organizational support and resources.

The airline itself was the product of the merger of two regional airlines with very different operational cultures. One had operated in the north of Canada as what was often called a "bush" operation. The other had operated in southern Ontario in a more traditional airline environment. The chief pilot of the Fokker fleet had come from the northern operation and had himself had two serious incidents involving take-offs with ice on the wings—experiences that had earned him the nickname of "Iceman." These practices suggest the possibility that norms and pressures existed to operate with wing contamination. The ambiguous regulation (see p. 13) provided no safeguard against such norms and pressures.

As *individuals,* both crewmembers had extensive experience in Canadian operations. The captain had more than 24,000 flight hours and the co-pilot more than 10,000. However, neither had much experience in jet transport operations, the captain having accumulated 81 hours in the F-28 and the first officer 65. The captain had been a chief pilot and instructor and was known for adherence to procedures. The first officer was a former captain described as having a somewhat abrasive personality. He also had a history of difficulties in completing some stick-and-rudder maneuvers and had required additional supervision and training before qualifying in new aircraft.

As a *group,* the crew had only flown together for two days. The fact that the crew lacked operational familiarity with each other and with the aircraft, along with the fact that both were accustomed to flying as captains, may have influenced the processes surrounding their conduct of the flight. In addition, the captain came from the more structured southern airline, while the first officer's experience was in the less formal northern operation.

When the aircraft landed to pick up passengers at Dryden, the crew faced a complex and stressful situation. Weather was deteriorating further, with heavy snow falling. Refueling was needed before departure, but this would necessitate keeping an engine running because of the inoperative APU. The cabin manual prohibited refueling with passengers aboard and an engine running, but the cockpit manuals were silent on this issue. The flight attendants were not alerted to the need to refuel with an engine running. The manufacturer's manual further prohibited de-icing with an engine running because of possible ingestion of fluid into the powerplant. The flight was falling further behind its schedule, and many passengers were facing the prospect of missing connecting flights if there was an additional delay for de-icing.

Faced with these contingencies, the crew chose to refuel with passengers aboard and an engine running. It is known that the captain considered de-icing, because he inquired about the availability of equipment and was told that it could be provided. Ultimately, however, the crew chose to take off without de-icing. Having reached this decision, a further environmental factor intervened in the form of a small plane, flying under visual flight rule (VFR) conditions, which made an emergency landing, causing additional delay until the runway was cleared.

There were also several experienced pilots, including two airline captains, seated as passengers in the main cabin. They survived and testified to being aware of the need for de-icing and the associated threat to safety. One of them expressed his concerns about icing to the lead flight attendant but was told (falsely) that the aircraft had automatic de-icing equipment. These credible concerns were never communicated to the flightdeck by the flight attendants. This failure in communication is understandable in light of organizational norms regarding cabin-cockpit communication on safety issues. One of the managers of flight attendant training testified that flight attendants were trained not to question flightcrews' judgment regarding safety issues.

Because the cockpit voice recorder was destroyed in the fire following the crash, it is impossible to reconstruct the interaction processes that led to the decision to depart Dryden without de-icing. While there was unquestionably human error in that decision, to stop at this conclusion would be to ignore the extent to which the input factors set the stage for the outcome.

1.4.4. Group Process Factors

Group process factors have historically been the least studied and least understood aspects of team performance. Much of the research that has been done, especially in operational settings, has looked at input and outcome factors, leaving the intervening process as a block box (e.g., Foushee, 1984; Foushee & Helmreich, 1988; Hackman & Morris, 1975). Input factors are manifested in the types of interactions that occur when individuals and machines come together to execute complex tasks in a complex environment. The fact that process variables have been largely ignored in research does not indicate a lack of awareness of their importance; rather, it reflects the difficulty of conceptualizing and measuring them. There are a number of important and theoretically interesting questions regarding flightcrew group processes: (1) How do individuals come together as strangers and forge a cohesive team that can operate effectively after only a brief acquaintance? (2) How is team workload managed and delegated? (3) What means are used to integrate ambiguous and incomplete data to reach optimum decisions? (4) How does stress induced by fatigue, emergencies, and personal experiences influence the way teams communicate and operate? (5) What is the nature of effective and ineffective leadership among flightcrews?

Group processes are manifested primarily through verbal communications, and these provide the record that we can use to understand how teams function in flight operations. Fortunately, there is a growing base of empirical research on group processes among flightcrews, much of it from experimental flight simulations. As Foushee (1984) has pointed out, modern flight simulators provide investigators with an extraordinarily useful research setting. Simulation provides high experimental realism including visual, motion, and auditory cues. Major aspects of flight operations can be reproduced, including mechanical problems, weather, air-to-ground communications, and cabin—cockpit interactions. Flight-plans can be generated and normal and abnormal operations between real airports simulated. Having experienced crews "fly" familiar equipment using normal procedures and manuals further enhances the external validity and generality of findings from simulations. Participants in experimental simulations report that realism is high and that motivation is comparable to that in regular line operations. Because simulators can be programmed to provide an identical operating environment for each crew, it is possible to gain statistical power by exposing many crews to the same conditions. To isolate causal factors, operational factors can be experimentally varied for different subgroups of participants: for example, the manipulation of recent experience in the simulation addressing fatigue. The simulator computer provides a record of the crew's physical actions controlling the aircraft, while video and audio recordings capture the interpersonal aspect of flight. The simulations described earlier have yielded important data on the impact of input factors such as operational experience and personality and have also allowed quantification of the processes involved.

Although not designed as a study of group processes, an experimental simulation sponsored by NASA and conducted by the late H. Patrick Ruffell Smith (1979) is a powerful demonstration of the operational significance of crew interactions. Eighteen airline crews flew a two-segment flight in a Boeing 747 simulator. The scenario consisted of a short flight from Washington, D.C., to John F. Kennedy Airport in New York and a subsequent leg from New York to London. After departing from New York, the crew experienced an oil pressure problem that forced them to shut down an engine. Because the flight could not be completed with a failed engine, the crew had to decide where to land. This decision was complicated by the further failure of a hydraulic system, deteriorating weather at possible landing sites, complex instructions from air traffic control, and a cabin crewmember who repeatedly requested information and assistance from the flightdeck at times of high workload. The study showed a remarkable amount of variability in the effectiveness with which crews handled the situation. Some crews managed the problems very well, while others committed a large number of operationally serious errors, including one miscalculation of more than 100,000 pounds in dumping fuel. The primary conclusion drawn from the study was that most problems and errors were induced by breakdowns in crew coordination rather than by deficits in technical knowledge and skills. For example, many errors occurred when individuals performing a task were interrupted by demands from other crewmembers or were overloaded with a variety of tasks requiring immediate action. In other cases, poor leadership was evident and resulted in a failure to exchange critical information in a timely manner.

The cockpit voice data from the study were subsequently analyzed by Foushee & Manos (1981) to quantify the processes related to variability in group performance. Their approach grew out of social psychological research into information flow within groups (e.g., Bales, 1950) and involved classifying each speech act as to type (i.e., observations regarding flight status, inquiries seeking information, etc.). The findings were clear: crews who communicated more overall tended to perform better and, in particular, those who exchanged more information about flight status committed fewer errors in the handling of engines and hydraulic and fuel systems and the reading and setting of instruments.

This methodology has been subsequently refined by Barbara Kanki and her colleagues at NASA—Ames Research Center and applied to communications records from additional experimental simulations. Kanki, Lozito, & Foushee (1989) and Kanki & Foushee (1989) examined communications patterns among crews in the previously described fatigue simulation (Foushee et al., 1986). For example, in the Kanki et al. study, sequences of communications were classified in terms of initiator and target as well as content. Initiating communications were classified as *commands, questions, observations,* and *dysfluencies* (e.g., ungram-matical or incomplete statements), while responses were classified as *replies* (responses greater than simple acknowledgments), *acknowledgments,* or *zero response.* Over and above the typical (and prescribed) occurrences of command–acknowledgment sequences, this study found that greater information transfer in the form of "commands" structuring activities and acknowledgments validating actions was associated with more effective crew performance.

Communications sequences were contrasted between crews committing a large number of operational errors and those making few. Although some specific patterns (such as that noted above) are worth special note, the primary finding of the study was the homogeneity of patterns characterizing the low-error crews. This was interpreted as the adoption of a more standard, hence more predictable form of communication. High-error crews, in contrast, showed a great diversity of speech patterns. Kanki and Palmer further discuss the status of communications research as it relates to flightcrews in their chapter.

Orasanu (1991) has conducted additional analyses of decision-making by crews in this simulation and has identified four components that support the decision process and differentiate effective from ineffective crews. This decision strategy includes *situation assessment, metacognitive processes* in forming action plans, *shared mental models* based on intra-crew communication of both situation assessment and plans, and *resource management* that encompasses task prioritization and delegation of specific responsibilities. Orasanu's formulation is congruent with basic principles of CRM and can be translated into prescriptive training. Several airlines have incorporated these findings and concepts into their CRM training. This research and a growing empirical and theoretical literature question traditional theories of decision making that are based on the assumption of a "rational," but biased, Bayesian decision maker (e.g., Klein, Orasanu, Calder-wood, & Zsambok, in press). In particular, this approach emphasizes differences between decision-making by experts in natural settings with high stakes and time pressure, and the processes employed by naive subjects in the constrained, laboratory environments frequently employed in decision research. Orasanu summarizes the state of knowledge in this area in her chapter.

Data from the Chidester et al. (1990) simulation involving personality factors were coded and analyzed to isolate decision-making processes while crews dealt with multiple inflight abnormalities—a jammed stabilizer and low oil pressure on one engine (Mosier, 1991). It was found that the majority of crews utilized a strategy consistent with Thordsen & Klein's (1989) team decision model. Sampling of information and repeated verification of the accuracy of situation assessment continued throughout the decision process. Many crews made preliminary, revocable decisions as soon as they felt they had enough critical data about the problem. The implication of this finding is that, while thorough assessment of the situation is critical, crews make decisions without having all relevant information. Indeed, the best-performing crews collected information pertinent to situation evaluation *after* making a final decision as a means of confirming the decision. In contrast, high-error crews showed a diverse pattern of interactions.

In a field investigation of group formation and interaction processes among three-person airline crews, Ginnett (1987) observed crews from their formation on the ground prior to the first flight of a multi-day trip, and in the cockpit on each flight segment. He found that the quality of the initial briefing was associated with better crew performance throughout the trip. Captains of effective crews communicated the team concept and elaborated or affirmed the rules, norms, and task boundaries that constitute the organizational structure (what Hackman, 1987, has called the "organizational shell") in this first encounter. Leaders of less effective crews showed a variety of interaction patterns. Thus in both studies there was consistency among crews rated as performing well and diversity among the less effective teams. These team issues are discussed in the chapter by Ginnett.

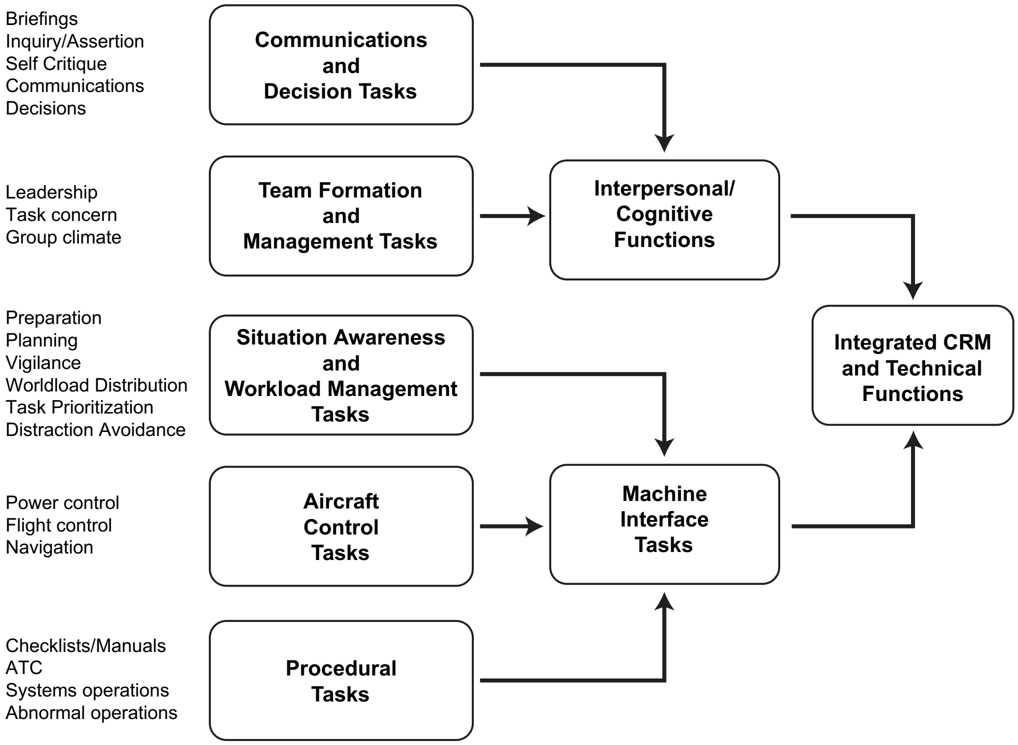
1.4.5. Elaborating Group Process Factors

Building on research with flightcrews and theoretical conceptions of group process mediators of aircrew performance, we should be able to fill in the black box with a more complete description of the processes that influence outcomes. Helmreich, Wilhelm, Kello, Taggart, & Butler (1991) have developed an evaluation system for systematic observation of flightcrews in line operations and simulations. The methodology grew out of findings from small group research and investigations of accidents and incidents. Group processes identified during flight operations fall into two broad categories. One consists of the *interpersonal and cognitive functions.* The second includes *machine interface tasks.* The latter category reflects the technical proficiency of the crew. It is a given that optimal team interactions and decision-making will be of little value if the crew cannot also integrate them with technical execution of maneuvers and procedures needed for safe flight. There is also ample evidence from review of the accidents cited earlier that competence in machine interface tasks alone does not guarantee operational safety.

Figure 1.4 shows the expanded group process model as it flows into outcome factors. In theory, the two categories of group processes containing human factors and technical components must be integrated operationally to produce effective overall performance. Note that the final box in Figure 1.4 is labeled "Integrated CRM and Technical Functions" to emphasize the fact that the two components need to come together in the group process phase, which then flows into desired outcomes of safe and efficient mission completion.

Breaking the subordinate categories down further, die interpersonal and cognitive functions can be classified into three broad clusters of observable behaviors: team formation and management tasks, communications processes and decision tasks, and workload management and situation awareness tasks. The machine interface tasks fall into two clusters, the actual control of the aircraft (either manually or through computer-based flight management systems) and adherence to established procedures for the conduct of flight.

Figure 1.4 Flightcrew performance model: Expanded group process factors



Team formation and management tasks

The first cluster deals with the formation of the crew as an operating team, including cabin as well as flightdeck personnel. As Ginnett's (1987) research has demonstrated, there is a formation process for teams during which patterns of communication and interaction are established. Once established, the process continues and leads to activities that can maintain patterns of effective (or ineffective) group interaction. The process of formation and maintenance can be categorized into two broad areas, *leadership, followership, and task concern;* and *interpersonal relationships and group climate.*

Flightcrews are teams with a designated leader and clear lines of authority and responsibility. Not surprisingly, the captain, as leader, can and should set the tone of the group. Effective leaders use their authority but do not operate without the participation of other team members. As demonstrated in the Chidester et al. (1990) simulation study, captains' attributes such as personality play a role in determining group processes and outcomes. Two negative patterns of leadership have been isolated in the investigation of accidents. One consists of a strong, autocratic leader who chills input from subordinates and conducts operations as if the flightdeck were a single-seat fighter. The "macho pilot" tradition discussed by Foushee & Helmreich (1988) represents the prototype of such a leadership style and is typified by an incident reported by Foushee (1982) in which a co-pilot's attempts to communicate an air traffic control speed restriction were met with an order to "just look out the damn window." Equally destructive are leaders who abdicate responsibility and fail to control activities on the flightdeck. An example of this type of leadership is seen in the crash of a B-727 at Dallas—Fort Worth because the crew was distracted and failed to confirm that flaps were set prior to take-off (NTSB, 1989). In this case, the first officer became involved in a lengthy social conversation with a flight attendant during taxi. Although not participating extensively in the conversation, the captain failed to control the group processes and did not establish work priorities or demonstrate a concern for operational duties.

One of the observable components of group processes is the quality of interpersonal relationships and the resulting group climate. Effective crews maintain a group climate that encourages participation and exchange of information. The group climate does not reflect the crew's concern with effective accomplishment of required tasks, but it is axiomatic that, other things being equal, crews functioning in a positive environment will be more motivated and will participate more fully in team activities.

Communications processes and decision tasks

As data from experimental simulations have shown, the processes of information transfer and decision-making are prime determinants of crew performance, and higher levels of communication are associated with fewer operational errors. Critical elements in this process include *briefings* and the extent to which free and open communications are established and practiced. Briefings need to address team formation issues as well as technical issues anticipated during operations. Although categorized as part of the communications cluster, briefings are one of the demonstrated means of forming effective teams and establishing a positive group climate.

Inquiry, advocacy, and *assertion* define behaviors meant to ensure that necessary information is available and that required communications are completed at appropriate times (for example, initiating and completing checklists, alerting others to developing problems). The accident literature is replete with examples of crewmembers failing to inquire about actions being taken by others. It is critical to safety and team action that crewmembers request clarification when they are unclear about the current operational situation or planned actions. Paralleling the need to gain operational data is the willingness of crewmembers to advocate effectively courses of action that they feel essential to safe and efficient operations. In cases such as the Air Florida crash in Washington, D.C. (NTSB, 1982). The voice recorder shows that one crewmember is uneasy about the takeoff but fails to express his concern strongly and to advocate an alternative action strategy. Concerns and suggestions for needed actions must be communicated with sufficient assertiveness to ensure that others are aware of their importance. It is noteworthy that the NTSB's first call for something like CRM was in the form of a recommendation for "assertiveness training" for junior crewmembers after investigation of a crash that was caused by fuel exhaustion during a hold to investigate a warning light (NTSB, 1979). In this accident, the second officer repeatedly reported that the fuel state was critical, but without sufficient assertiveness to elicit action on the part of the captain. The willingness of crewmembers to advocate the course of action they feel best, even when it involves disagreements with others, is an essential attribute of an effective team. When crewmembers have differing views of proper courses of action and advocate their preferred course of action, interpersonal conflict may result. The observable behaviors resulting from disagreement are the means used for conflict resolution. Conflict may result in either careful consideration of alternatives, or a polarization of positions and a negative group atmosphere. Effective conflict resolution is focused on *what* is right rather than *who* is right.

Active participation in decision-making processes should be encouraged and practiced, including questioning actions and decisions. When decisions are made, they need to be clearly communicated and acknowledged. *Crew self-critique* is another essential component of effective group processes. Teams need to review their decisions and actions with the goal of optimizing future team activities. Effective critique includes the *product or outcome,* the *process,* and the *people involved*. Critique can and should occur both during and after completion of activities. Critique is not the same as criticism. Indeed, review of effective team performance is a powerful reinforcer.

Situation awareness, workload management tasks

The third grouping of crew effectiveness markers is labeled Workload management and situation awareness. The crew's awareness of operational conditions and contingencies, usually defined as situation awareness, has been implicated as causal in a number of incidents and accidents. However, situation awareness is an outcome rather than a specific set of mission management behaviors. The specific factors that are defined for this cluster are *preparation/planning/vigilance, workload distribution,* and *distraction avoidance.*

Preparation, planning, and vigilance behaviors reflect the extent to which crews anticipate contingencies and actions that may be required. Excellent crews are always ahead of the curve while poor crews continually play catch-up. Vigilant crews devote appropriate attention to required tasks and respond immediately to new information. However, a crew indulging in casual social conversation during periods of low workload is not lacking in vigilance if flight duties are being discharged properly and the operational environment is being monitored; the crew may be using this time for team formation and maintenance.

As the Ruffell Smith (1979) study demonstrated clearly, when abnormal situations arise during a flight, particular crewmembers may become overloaded with multiple tasks and/or become distracted from primary responsibilities. One of the observables of group process is how well crews manage to distribute tasks and avoid overloading individuals. By prioritizing activities, teams can avoid becoming distracted from essential activities, as was the crew whose concentration on a burned-out light bulb kept them from noticing that the autopilot had become disengaged and that the aircraft was descending below the proper flight path (NTSB, 1972).

Machine interface tasks

The flight control and procedural tasks that constitute the machine interface portion of group processes represent the traditional model of flight training and evaluation. The model proposed here, with its inclusion of interpersonal and cognitive processes, in no way downplays the continuing importance of these activities. Rather it reflects the fact that both are essential to safe and efficient operations.

If the proposed model does indeed reflect the major input and process determinants of flightcrew performance, it should provide insights into how training programs can best address the group processes of flight. In the following section we discuss theoretical approaches to maximizing the impact of CRM.

1.5. Theoretical Leveraging of CRM Training

The model indicates that there are multiple determinants of crew effectiveness among both input and process factors. In theory, organizations should achieve the greatest impact on crew performance when they address and optimize as many input and group process factors as possible. In this section we consider how programs can be designed to accomplish this. This discussion is cast in terms of an integrated approach to technical and human factors training.

1.5.1. Optimizing Input Factors

Individual factors

We suggested in an earlier article on crew interaction and performance that the selection of individuals more predisposed toward team activity and crew coordination concepts could provide one means of achieving more effective crew Performance

(Foushee & Helmreich, 1988). Subsequent research has supported this contention as personality factors have been linked to crew performance in experimental simulations (Chidester et al., 1990), to acceptance of CRM training and changes in attitudes regarding flightdeck management (Chidester et al., 1991; Helmreich & Wilhelm, 1989, 1991; Helmreich, Wilhelm, & Jones, 1991), and to fatigue and health complaints in short- and long-haul operations (Chidester, 1990). The chapters by both Hackman and Chidester discuss the need for innovations in this area. Selection represents a long-term strategy, but one that should be entertained. In the short term, however, efforts should concentrate on enhancing training for the existing workforce.

All effective training programs have an information base. In the case of CRM, the goal is to communicate new knowledge about effective team performance and, concurrently, to change or reinforce attitudes regarding appropriate flightdeck management. Changed attitudes, in turn, should be reflected in improvements in group process and ultimately in better crew performance.

Organizational factors

There are a number of issues that organizations can address that should, in theory, increase crew effectiveness. Foremost, of course, is to demonstrate a commitment to developing and implementing training of the highest quality. However, unless the concepts presented in training are consistent with the organization's culture and practices, they are not likely to have a major impact. Several steps are necessary to ensure that the culture and norms are congruent with CRM. One is to stress training using a crew rather than an individualistic model. Another is to make checklists and other cockpit documents consistent with crew concepts (Pan American Airways took this step in the early 1970s in response to a number of crew-induced accidents). An additional step is to address communications issues between flightcrews and other operational units including dispatchers, cabin crews, and the maintenance force. The interface between the cockpit and these elements forms a significant component of group processes and can either support or hinder effective team performance.

An essential means of making organizational culture and norms congruent with CRM concepts is by providing role models who practice and reinforce them. In most organizations, check airmen, instructors, and chief pilots are highly respected and experienced pilots who are looked to as exemplars of the organization's norms and requirements (Helmreich, 1991a, 1991b; Helmreich, Wilhelm, Kello, Taggart, & Butler, 1991). Selection of individuals for these positions should include assessment of interpersonal as well as technical expertise. Special training in evaluating and debriefing group processes can help them establish and maintain norms supportive of good CRM practices.

Regulatory factors

In 1986, following a crash caused by a crew's failure to complete pre-take-off checklists and to extend flaps, then FAA Administrator T. Allen McArtor called a meeting of airline managers to discuss the implementation of human factors training. This resulted in the formation of a government–industry working group that drafted an Advisory Circular (AC) on cockpit resource management (FAA, 1989; in press). The AC defines the concept, suggests curriculum topics, and recognizes that initial CRM training provides only basic awareness of CRM issues. It further points out that awareness must be followed by a practice and feedback phase and a continual reinforcement phase. Full mission simulation training (line-oriented flight training, LOFT) is highly recommended as the most effective means of continual reinforcement. The content of the AC is consistent with generally accepted principles of learning and reinforcement and with the theoretical model of flightcrew performance being discussed here. Although CRM has not been mandated as a requirement for air carriers, the AC clearly encourages U.S. carriers to develop such programs. Efforts are further under way to mandate CRM training for all air transport.

Also growing out of this government–industry collaboration has been a Special Federal Aviation Regulation–Advanced Qualification Program (FAA SFAR 58, AQP) issued in 1990. AQP is described in detail in the chapter by Birnbach & Longridge. It is a voluntary regulation for airlines that allows much more flexibility and innovation in training. In exchange for this flexibility in conducting training, participating airlines are required to provide CRM training, LOFT, and to initiate formal evaluation of crew as well as individual proficiency. Organizations that operate under AQP should find the regulatory environment supportive of CRM training efforts.

1.5.2. Enhancing Group Process Factors

In theory, the point of greatest impact on flightcrew behavior should be the group process itself. This should be accomplished effectively by full mission simulation training (LOFT), where crews have an opportunity to experiment with new interaction strategies and to receive feedback and reinforcement. The FAA supported this approach and issued an Advisory Circular (FAA, 1978) establishing guidelines for the conduct of LOFT. NASA hosted an industry conference on LOFT in 1981 that resulted in two volumes providing a review of techniques and formal guidelines for its conduct (Lauber & Foushee, 1981). The principles espoused include establishing high levels of realism, conducting normal flight operations as well as creating emergency and abnormal situations, and nonintervention by instructors into group processes, decisions, and actions. CRM LOFT is defined as training rather than formal evaluation, with the goal of allowing crews to explore the impact of new behaviors without jeopardizing their certification as crewmembers.

LOFT should influence subsequent behavior most strongly when scenarios are crafted to require team decision-making and coordinated actions to resolve in-flight situations. The debriefing of LOFT is also a critical element in achieving impact. Skilled instructors should guide crews to self-realization rather than lecture them on observed deficiencies. Instances of effective team behavior should be strongly reinforced. The use of videotapes of the simulation can provide crews with the opportunity to examine their own behavior with the detachment of observers (Helmreich, 1987). Butler discusses the status of contemporary LOFT programs in his chapter and Wiener discusses the peculiarities of LOFT in the high-technology cockpit in his chapter.

In addition to the practice and reinforcement provided later by LOFT, initial CRM training, usually conducted in a seminar setting, should allow participants to observe and experiment with behavioral strategies and to receive individual and group feedback. Instruction that allows participants to experience processes is more meaningful than lectures where ideas are presented to a passive audience. Introductory training in CRM provides the conceptual framework needed to understand the processes that will later be encountered in LOFT.

It is also necessary to identify and reinforce effective group processes in normal line operations as well as in the training environment. We earlier identified check airmen as key agents and role models. To help transfer concepts from training to the line, check airmen should address not only technical performance but also interpersonal and cognitive issues in their conduct of periodic evaluations of crew performance line operations (line checks).

As we pointed out in describing Figure 1.4, process factors from both the interpersonal and machine interface components need to be integrated as the team performs its duties. The corollary of this is that the most effective training should bring together technical and human factors aspects of each maneuver taught, so crewmembers can recognize that every technical activity has team-level components essential to its successful completion. For example, the V_1 cut[3] is a maneuver in which crews are required to demonstrate proficiency. It involves the loss of power at a point when it is too late to abort the take-off. Crews are required to climb out, reconfigure the aircraft,

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[3] V_1 is the decision speed for take-off. When an aircraft reaches V_1 the crew is committed to take-off. It is a function of runway length and condition, aircraft weight, temperature, etc. We are indebted to Captain Kevin Smith for his analysis of actions required during the maneuver.

communicate with the tower, and return for landing. While this is often seen as primarily a technical exercise, in fact it requires concerted activity by the full crew along with rapid, accurate information transfer within the cockpit and between cockpit and cabin and cockpit and ground. If training in basic flight maneuvers stresses the human factors as well as technical components, the likelihood that crews will demonstrate effective, integrated group processes should be increased.

In a similar vein, the specificity of concepts communicated and reinforced should determine their acceptance and adoption. Individuals may accept, in principle, abstract ideas of open and complete communication, team formation, situation awareness, and workload management, but may find it difficult to translate them into concrete behaviors on the flightdeck. In theory, individuals who understand both the conceptual bases of effective crew coordination and their specific behavioral manifestations should be able to put them into practice readily and should be able to evaluate their success in accomplishing them.

As part of a research effort to evaluate the impact of CRM training and to train observers to judge crew effectiveness, Helmreich, Wilhelm, Kello, Taggart, and Butler (1991) have attempted to define behavioral markers of the three clusters of interpersonal and cognitive tasks. These are observable behaviors that reflect the concepts central to CRM training. Forty discrete markers have been isolated and utilized in observations of line operations and LOFT (Clothier, 1991a). The data suggest that these behaviors can be reliably measured. Figure 1.5 shows the ten markers associated with the Situation Awareness/Workload Management cluster. It can be argued that programs that employ concrete, behavioral examples should have a greater impact on crew processes and outcomes than those that deal with abstract concepts.

Figure 1.5 Behavioral markers for workload distribution/situational awareness

- Avoids “tunnel vision”, being aware of factors such as stress that can reduce vigilance
- Actively monitors weather, aircraft systems, instruments, and ATC, sharing relevant information
- Stays “ahead of curve” in preparing for expected or contingency situations
- Verbally insures that cockpit and cabin crew are aware of plans
- Workload distribution is clearly communicated and acknowledged
- Ensures that secondary operational tasks are prioritized
- Recognizes and reports work overloads in self and others
- Plans for sufficient time prior ro maneuvers for programming of automation
- Ensures that all crewmembers are aware of status and changes in automation
- Recognizes potential distractions caused by automation and takes appropriate preventive action

In this section we have tried to derive approaches to CRM training that should theoretically have the greatest leverage on crew performance. This analysis suggests that programs need to attack a number of areas in concert if they are to achieve maximum influence on behaviors and attitudes. In the following section we discuss efforts to achieve these goals and describe some of the major developments in CRM training over the last decade.

1.6. The Evolution of CRM Training

Formal training in human factors aspects of crew operations was beginning to take root by the 1970s. For example, the late Frank Hawkins (1984) had initiated a human factors training program at KLM, Royal Dutch Airlines, based on Edwards' (1972, 1975) SHEL model and trans-cockpit authority gradient. Operational and theoretical concerns with human factors aspects of flight came together in a NASA/Industry workshop held in 1979. At this gathering, managers from worldwide aviation met with the members of the academic and government research community concerned with human performance. Research into the human factors aspects of accidents was reviewed (e.g., Cooper, White, & Lauber, 1980) along with the seminal findings from the Ruffell Smith (1979) study. Many of the participants left the meeting committed to developing formal training in crew coordination.

A number of different CRM courses began to emerge in the early 1980s. The focus of most early training was on input factors, especially in the areas of knowledge and attitudes. Much of the emphasis was on the review of human factors aspects of accidents, with the goal of changing attitudes regarding appropriate flightdeck management. Many of these courses were presented in a lecture format, and some consisted only of videotaped presentations. Other training, growing out of management development programs, included tests and exercises designed to provide self-awareness and to demonstrate general concepts of group processes. What was not present in early efforts was a focus on organizational issues and flightcrew group processes, including reinforcement of effective process behavior. Many early CRM courses faced considerable resistance from crewmembers who expressed concerns about both the motivation for and possible outcomes of the training. Some saw it as unwarranted psychological meddling, equating the training with clinical psychology or psychotherapy. Others feared that captains' authority would be eroded by a kind of Dale Carnegie charm school approach to developing harmonious interpersonal relations, without regard for operational effectiveness.

The first CRM course integrated with LOFT was developed by United Airlines following the NASA workshop. The course, called Command, Leadership, and

Resource Management, was the result of a collaboration among United flight training personnel, members of the Air Line Pilots' Association, and Drs. Robert Blake and Jane Mouton. Blake and Mouton were social psychologists who had developed training programs aimed at improving managerial effectiveness for a number of major corporations. The centerpiece of their training approach is providing participants with insights into their personal managerial styles (an individual input factor) using the managerial grid (Blake and Mouton, 1964) as a means of classifying managers along independent dimensions of task and interpersonal orientations. The multi-day training program that emerged is intensive and interactive, requiring participants to assess their own behaviors and those of peers. Operational concepts stressed in the training include process factors such as inquiry, seeking of relevant operational information; advocacy, communicating proposed actions; and conflict resolution, decision-making, and critique, reviewing actions taken and decisions reached. The unique aspect of the United approach was that the initial training was followed by recurrent review of CRM concepts. The program also demonstrated a major commitment to group process factors by providing annual CRM LOFT sessions. These allow crews to practice the human factors concepts covered in the seminar and recurrent training. One of the major innovations in United's LOFT was the use of a video camera in the simulator to record crew interactions. By replaying the tape of their LOFT, crews gain the ability to review their actions and decisions and to obtain insights into their behavior, guided by the LOFT instructor.[4] This program represents the first integration of multiple input and group process factors that also recognized the need for continuing practice and reinforcement.

NASA and the Military Airlift Command of the U.S. Air Force jointly sponsored a workshop on developments in CRM training in May, 1986 (Orlady & Foushee, 1987). This conference demonstrated the striking spread of CRM training throughout the world since the first workshop in 1979. Reports were presented on the implementation of CRM courses at United Airlines (Carroll & Taggart, 1987), Pan American World Airways (Butler, 1987), People Express Airlines (Bruce & Jensen, 1987), Continental Airlines (Christian & Morgan, 1987), Japan Air Lines (Yamamori, 1987), Trans Australia Airlines (Davidson, 1987), in units of the Military Airlift Command (Cavanagh & Williams, 1987: Halliday, Biegelski, & Inzana, 1987), and in corporate and regional operations (Mudge, 1987; Schwartz, 1987; Yocum & Monan, 1987).

In the late 1980s a second generation of CRM training began to emerge in the United States. Pan American World Airways and Delta Airlines both initiated CRM

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[4] The videotape is always erased following the LOFT debriefing to preserve the confidentiality of the training and behaviors observed.

courses that included recurrent classroom training and LOFT. In addition, these programs addressed organizational input factors by providing additional training for check airmen and instructors with the goal of increasing impact on group process factors through reinforcement of effective behaviors both in LOFT and in line operations. Black and Byrnes discuss the implementation of the Delta program in their chapter.

Although there has been a great proliferation of CRM courses, there has not been a parallel growth in the use of CRM/LOFT to provide practice and reinforcement. At the time this is written, in the United States only United, Horizon Airlines, Delta, Continental, and units of military aviation have integrated CRM/LOFT programs, although a number of other organizations including Northwest Airlines, US Air, and Comair are in the process of implementing them. There are a number of reasons why more comprehensive programs have been slow in emerging. One is certainly economic. As Chidester points out in his chapter, at a time of great financial distress in the industry, innovative and relatively expensive programs that are not formally mandated by regulations must compete with other operational needs for scarce resources. Indeed, regulations in the U.S. have tended to operate against the adoption of LOFT because it is necessary to meet many formal, technical requirements each year and because requirements for recurrent training for captains are semi-annual but annual for first officers and flight engineers, making it difficult to schedule complete crews for LOFT.[5] The previously mentioned Advanced Qualification Program both removes some of the regulatory barriers to comprehensive CRM/LOFT and provides incentives for their adoption. Additional resistance to changes in training may also come from awareness that the aviation system has an excellent safety record when compared with all other forms of transportation and from the fact that empirical evidence for increased safety of flight as a result of CRM training has been lacking until very recently.

At the present time a third generation of CRM training is emerging. This approach continues the practices of integrating CRM with LOFT but also takes a systems approach to multiple input factors including organizational cultures and group and individual factors. Evaluation and reinforcement in line operations are also cornerstones of this approach. In addition, new programs are becoming more specific in focus and are defining and directly addressing optimal behaviors (e.g., behavioral markers). Efforts are underway in several organizations (stimulated in part by requirements of AQP) to remove the distinction between technical training and evaluation and CRM, with the

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[5] United Airlines, Pan American Airlines, and Delta Airlines have received exemptions from some training requirements to facilitate training complete crews on an annual basis in exchange for implementation of integrated CRM/LOFT programs.

goal of implementing a training philosophy where both components are addressed in every aspect of pilot qualification.

An additional characteristic of evolving programs is the extension of CRM training beyond the cockpit to other operational areas. Joint training for cabin and cockpit crews has been initiated at America West Airlines, and programs are being developed at a number of other carriers. American Airlines is including dispatchers in CRM training in recognition of common concerns and responsibilities and the need for effective, open communication. Pan American and later Continental Airlines developed CRM programs for maintenance personnel. Efforts are also underway to implement similar training within the FAA for Air Traffic Control personnel who also operate in a team environment but have historically received little or no formal instruction in human factors issues relating to their jobs.

Looking at the growth and evolution of CRM training, one is struck by the willingness of very disparate organizations to embrace a training concept that counters many of the traditions of an industry. In the following section we consider factors that may have facilitated this acceptance.

1.7. CRM and Traditional Management Development Training

From an observer's perspective, the philosophical and pragmatic bases of CRM are consistent with programs that have been used in management development training for several decades. Concerns with self-assessment, managerial styles, interpersonal communications, and organizational influences on behavior have academic roots in social, industrial, and clinical psychology, sociology, and schools of business. Programs to translate empirical and theoretical knowledge about groups into practical training have been employed with differential acceptance in many segments of industry and government. Indeed, many of the initial CRM programs, such as that at United Airlines, were adaptations of existing management training courses. What is striking about CRM is the rapidity of its spread and the enthusiasm with which it has been accepted. What is unique about its implementation in this setting? What can convince fiscally conservative managers to commit scarce resources and highly experienced crewmembers to re-evaluate their approach to a highly structured task?

Part of the answer rests in the nature of the flight environment. Operating an aircraft with a multi-person crew is a structured and bounded endeavor with clear lines of authority and responsibility. The inherent activities involved in taking an aircraft from one point to another are similar in organizations throughout the world. Although aircraft differ in design and sophistication and in number of crewmembers required for operation, the basic tasks are generic. One implication of this is that the types of problems in flightdeck management found in one organization or flightcrew have a high probability of occurring in others. Findings regarding crew contributions to accidents can be easily recognized as generic rather than as unique occurrences in unique organizational cultures and operating environments. It can be inferred that similar approaches to improving crew effectiveness should work throughout the industry despite differences in the culture, history and health of organizations. The chapters by Johnston; Yamamori & Mito: and Helmreich, Wiener, & Kanki provide additional perspectives on cross-national issues in human factors.

In aviation the results of breakdowns in flightcrew group processes are dramatic and highly visible and provide an unequivocal outcome criterion. In contrast, outcome criteria in industry such as profits or productivity are relatively diffuse and subject to qualification by industry-specific and organization-specific factors. Given an overall performance criterion that represents a common, desired outcome, it is understandable that a similar approach would be recognized and embraced.

Again, in contrast to the diversity found outside aviation, the range of decisions and behaviors that faces flightcrews is constrained and can be incorporated in a fairly simple model. Because of this behavioral specificity, training can be more sharply focused than it normally is in courses developed for generic managers. This clearer definition of issues and processes should lead both to greater acceptance by participants and to more tangible, positive outcomes.

Another distinctive feature of the aviation environment is the ability to use highly realistic simulation to practice behaviors and receive feedback and reinforcement. Unlike many of the exercises that are used in general management training, LOFT provides a valid representation of the actual task setting with measurable outcomes. This allows crews to observe the discrete components of group processes as they flow into outcomes. LOFT provides compelling evidence of the validity of the concepts being trained.

The ultimate question, of course, is how well the training achieves its stated goals. In the following section we review preliminary results from evaluation of CRM courses in a number of organizations.

1.8. Research Findings

Although the process of research is necessarily slow and incremental, a number of consistent findings have emerged regarding the effects of CRM programs. Our goal is to provide a brief overview of what research has told us about the impact of CRM and to point out some of the gaps in current knowledge. It should be noted that the research to be discussed regarding the effectiveness of CRM training comes from evaluation of intensive programs integrated with LOFT and not from brief lecture or discussion sessions called CRM that may be included in crew training. Strategies for the investigation of CRM-related behaviors and concepts are discussed further in Helmreich (1991b).

1. *Crewmembers find CRM and LOFT* to *be highly effective training.* Survey data from more than 20,000 flight crewmembers in civilian and military organizations in the United States and abroad show overwhelming acceptance of the training. The vast majority of crewmembers find the training both relevant and useful (Helmreich & Wilhelm, 1991). Figure 1.6 shows the distribution of responses in five airlines to a post-training survey question regarding the utility of the training.

   A similar pattern of endorsement is found in evaluations of the value of LOFT. Wilhelm (1991) has analyzed reactions to LOFT from more than 8,000 participants in the training at four organizations. Crewmembers overwhelmingly feel that it is important and useful training and that it has value on the technical as well as the human factors dimensions. Figure 1.7 shows the distribution of mean ratings of the usefulness of LOFT in four airlines, broken down by crew position.

   Clearly, acceptance of training is a necessary but not sufficient indicator of its effectiveness. If crews do not perceive training as useful, it is unlikely that it will

Figure 1.6 Responses to the question, "Overall, how useful did you find the CRM training?" in five organizations (A, B, C, D, E)

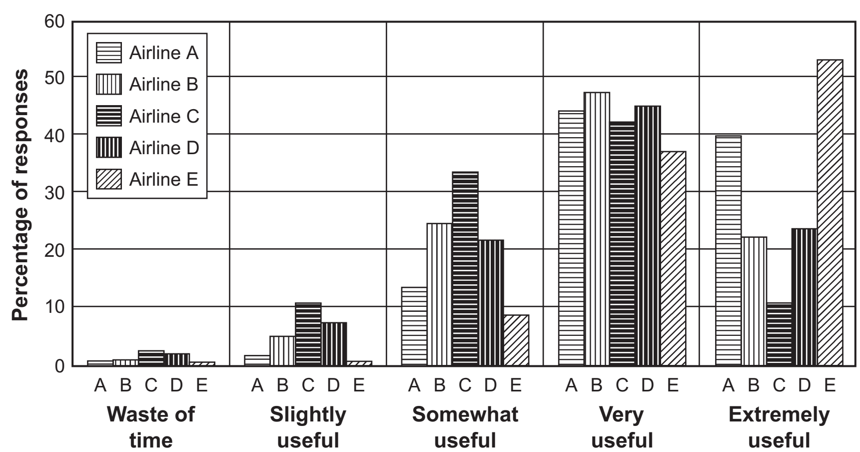
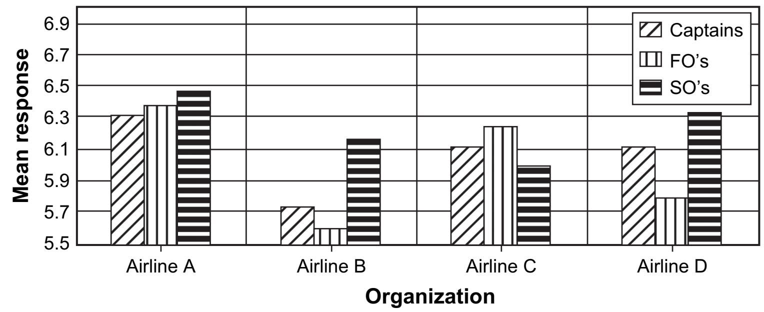


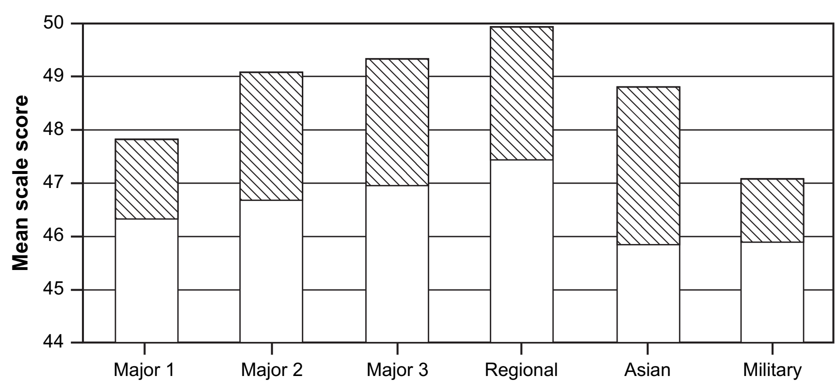
Figure 1.7 Average ratings for the item, "Overall, LOFT is an extremely useful training technique," in four organizations (A, B, C, D). Scale: 1, strongly disagree: 4, neutral: 7, strongly agree



induce behavioral change. On the other hand, the training may be perceived as useful, but because behavioral tools are not provided to help participants apply the concepts, the result may be increased awareness of CRM concepts but little change in observable behavior.

2. *There are measurable, positive changes in attitudes and behavior following the introduction of CRM and LOFT,* Changes in attitudes regarding flightdeck management measured by the *CMAQ* (Helmreich, 1984) can be used as a measure of training impact. Typically, attitudes show significant positive shifts on the three scales of the *CMAQ,* Communications and Coordination, Command Responsibility, and Recognition of Stressor Effects (Helmreich & Wilhelm, 1991). As Figure 1.8 illustrates for the Communications and Coordination scale in six

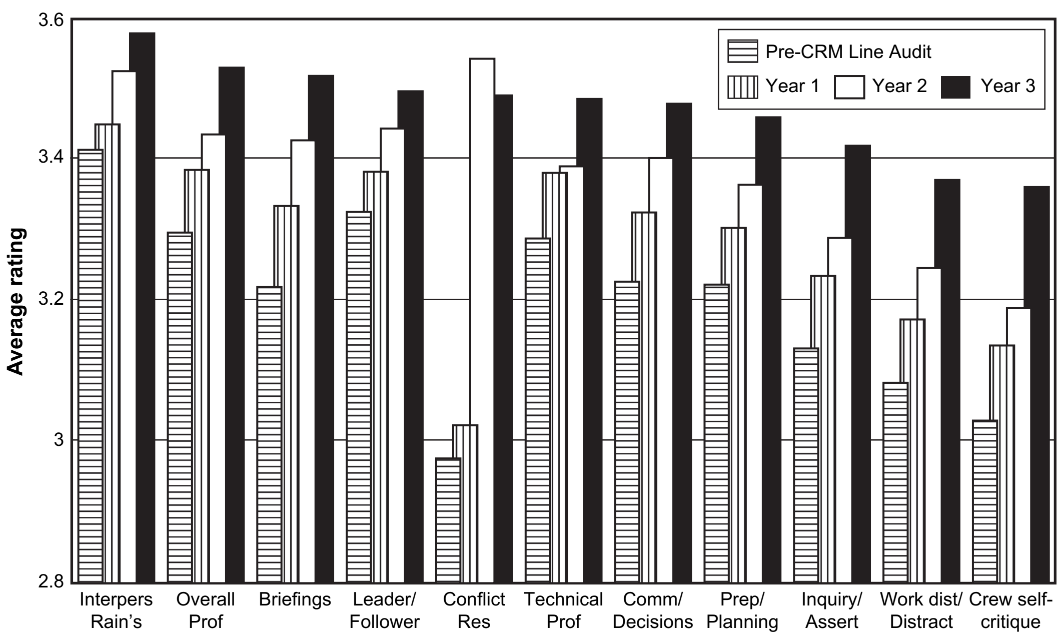
Figure 1.8 Pre-test (unshaded) and post-training (shaded) attitudes on the CMAQ Communications and Coordination scale. All differences significant ($p < .01$): scale range, 11—55



organizations, there is a consistent increase in the positivity of reactions, although the magnitude of change (along with the baseline attitudes) varies between organizations. The *CMAQ* findings suggest that participants do relate the concepts being taught to specific attitudes regarding the conduct of flight operations.

Because the linkage between attitudes and behavior is less than perfect (e.g., Abelson, 1972), it is critical to the validation of CRM training effectiveness that there be observable changes in crewmembers' behaviors on the flightdeck. Data have been gathered both by independent observers and by check airmen and instructors given special training in observational methodology (e.g., Clothier, 1991b). Data collected across time show changes in behavior in the desired direction. Figure 1.9, for example, shows shifts in observed behavior during line operations over a 3-year period on 14 observed categories of process behavior following the introduction of CRM and LOFT in one major airline. All mean differences are statistically significant. It can be noted that the behavioral effects continue to grow across time. A reasonable interpretation of this trend is that, as concepts become more widely accepted, organizational norms shift and exert pressure on crewmembers to conform to the new standards of behavior.

Figure 1.9 Average crew performance ratings in one organization across time. Scale: 1, poor; 5, excellent

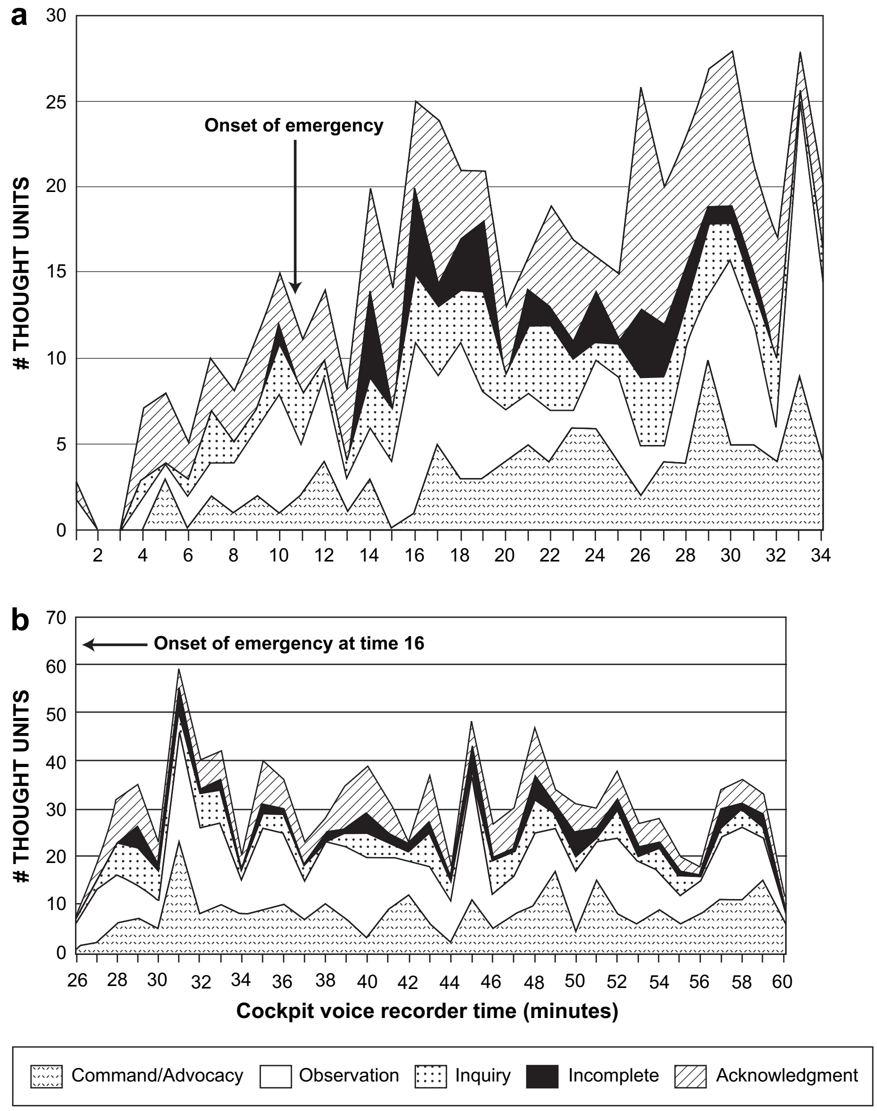


Significant differences have also been found when crew behavior is aggregated and contrasted in terms of the level of flightdeck automation (Butler, 1991: Clothier, 1991a). Crews observed in advanced technology aircraft are rated as more effective in LOFT than those flying conventional aircraft on a number of human factors dimensions. The causes and extent of these differences remain for further research to clarify. Issues surrounding cockpit automation, crew coordination, and LOFT are discussed in the chapter by Wiener.

As we have noted, the number of accidents involving crews with formal training in CRM and LOFT is too small to draw any statistical inferences regarding the role of these experiences in helping crews cope with serious emergency situations. There are, however, a growing number of anecdotal reports that the training does provide valuable resources for crews faced with major inflight emergencies. Two recent accidents have involved United Airlines crews with both CRM and LOFT experience. In one, a cargo door blew off in flight on Flight 811, a Boeing 747, causing considerable structural damage and the loss of two engines. In the other, the catastrophic failure of the center engine on a McDonnell Douglas DC-10, Flight 232, resulted in the loss of all hydraulic systems and flight controls. Both crews were able to minimize loss of life by coping effectively with the problems, and both acknowledged the role of CRM in enabling them to cope with their novel emergencies. Crew communications taken from the cockpit voice recorder transcripts have been coded in terms of content and frequency and analyzed by Steven Predmore (1991). The coding system classifies communications in terms of CRM concepts including inquiry, command and advocacy, reply and acknowledgment, and observation (communication of operational information). Both crews maintained a high level of communication and verification of information throughout the emergencies. Figure 1.10 shows the pattern of communications over time in both accidents.

3. *Management, check airmen, and instructors play a critical role in determining the effectiveness of CRM training.* Hackman's (1987) delineation of the "organizational shell" as a critical determinant of the success of CRM training has been borne out by operational experience and research. Organizations where senior management has demonstrated a real commitment to the concepts of CRM and its importance for safety and crew effectiveness by providing intensive and recurrent training have found greater acceptance than those which have simply provided a brief introduction to the concepts. Indeed, several organizations in which flight operations management made a concerted effort to communicate

Figure 1.10 Crew communications, by category, during two United Airlines inflight emergencies, (a), Flight 811: (b), Flight 232



the nature of CRM training and the organization's dedication have noted significant improvement in cockpit management attitudes even before formal training was instituted.

The pivotal position of check airmen and instructors as primary role models and agents of reinforcement has also become increasingly recognized

(Helmreich, 1987: Helmreich, Wilhelm, Kello, Taggart, & Butler, 1991). Consistent with the theoretical model, the extent to which these key individuals endorse, practice, and emphasize CRM concepts both in the training and checking environment seems largely to determine program acceptance.

4. *Without reinforcement, the impact of CRM training decays.* Data indicate that even intensive, initial CRM training constitutes only an awareness phase and introduction to the concepts, and that continuing reinforcement is essential to produce long-term change in human factors practices. Some of the most compelling evidence of the need for ongoing emphasis on CRM comes from revisiting organizations where well-received initial CRM training has not been accompanied by an organizational commitment to continuing the effort (Helmreich, 1991a). In one organization, when the *CMAQ* was re-administered more than a year after the completion of initial training, attitudes had reverted to near their baseline, pre-CRM levels. In this organization many open-ended comments written by respondents expressed concern over the fact that some outspoken opponents of CRM concepts continued management styles antithetical to good human factors practice. In another organization, recurrent CRM and LOFT were provided, but management support was weak, there was high turnover in training and checking personnel, no formal human factors training for new check airmen and instructors, and limited efforts to revise and update LOFT scenarios. When attitudes regarding the value of CRM training and LOFT were assessed more than two years later, they had become significantly less positive than in the first year. These longitudinal findings have major operational significance as they reinforce the notion that organizations desiring to maintain the momentum provided by initial CRM training must make a formal commitment to provide the resources necessary for continuing training and reinforcement.

5. *A small but significant percentage of participants "boomerang" or reject CRM training.* Although the self-report reactions and attitude change findings discussed above show the overall positive impact of initial CRM training, some participants fail to see its value and some even show attitude change in a direction opposite to that intended. These individuals have been described as showing a "boomerang effect" (Helmreich & Wilhelm, 1989). Similarly, some crews observed in line operations following initial CRM seminars do not practice the concepts espoused in training. The fact that reactions to CRM are not uniformly positive does not negate the value of the training, but this undesired outcome is reason for some concern.

Research has shown that there are multiple determinants of the boomerang effect (Helmreich & Wilhelm, 1989). Some resistance to the training is rooted in individual personality characteristics. Crewmembers who are lacking in traits associated with both achievement motivation and interpersonal skills are initially more prone to reject CRM concepts. In addition, the group dynamics of particular seminars also appear to influence reactions. The presence of a charismatic participant who openly rejects the training can influence the level of acceptance by other crewmembers and poses a major challenge to those conducting the training.

1.9. Open Issues for Research

There are a number of open questions that require sustained research efforts to assist CRM training in reaching its full potential. One is to determine the long-term impact of the training on crew behavior and system safety. Many of the measures employed to evaluate crew performance and attitudes are still under development and require refinement through research (see the chapter by Gregorich & Wilhelm). Part of the measurement effort has been directed toward the development of consistent classification strategies for human factors aspects of aviation incidents and accidents. These can generate extremely important research databases, and investigations supporting this effort are much needed.

Chidester describes many of the critical issues facing those trying to develop effective CRM programs in his chapter. All of these can be addressed more effectively with continuing research into the impact of programs and careful assessment of participant reactions. Such data should facilitate continual refinement of programs and will take into account changes in the aviation system itself (for example, the development of more digital data links between aircraft and Air Traffic Control).

Another urgent need is to learn how to maximize the role of LOFT in reinforcing and extending human factors training. Recent data suggest that there are great differences in the perceived value of different scenarios and in the quality of their implementation (Wilhelm, 1991). The chapter by Butler discusses critical research issues that need to be addressed in LOFT design and execution.

Several critical topics need much additional research before they can be translated into basic CRM training. Research into fundamental aspects of interpersonal communications, such as that described in the chapter by Kanki & Palmer, has much to offer those developing CRM programs, but the knowledge base remains relatively undeveloped. Another critical area is decision-making. As Orasanu points out in her chapter, substantial progress has been made toward understanding decision-making in natural situations, but much remains to be done before full operational benefits can be gained. In particular, additional research into individual and group decision-making under highly stressful conditions (such as high time pressure, fatigue, life stresses, and life-threatening emergencies) should have high priority. Indeed, the whole topic of psychological stress and its behavioral impact has languished in the research community and needs renewed attention. Not until the research base is extended will we be able to mount effective programs of stress management and evaluate their operational impact.[6]

Given the lack of empirical data on the impact of system automation on crew coordination, it is also difficult to specify how best to train crewmembers to interact most effectively with "electronic crewmembers." The chapter by Wiener provides a summary of the state of our knowledge about behavioral effects of automation, and Byrnes & Black describe the first course attempting to integrate automation issues with CRM training in their chapter. Clearly this effort will be enhanced by further research.

We also need to know whether the boomerang reaction to CRM training is transitory or enduring. It is characteristic of human nature to question new and alien concepts on first encounter. Some exposed to CRM for the first time may show initial hostility to the concepts but may, after time and with peer pressure, later become enthusiastic advocates of CRM concepts. Only longitudinal research strategies that revisit and reassess individual reactions across time can determine the long-term reactions of the "boomerang" group. An associated question is whether different training strategies or interventions may be needed to gain acceptance from this subset of individuals.

Human factors concepts and training need to be further integrated with traditional technical training. To a considerable extent, CRM has developed outside the boundaries of the traditional training and evaluation of technical proficiency. As CRM has matured and become a part of organizational cultures, awareness of the fact that there are vital human factors components of all aspects of flight training has grown. As the theoretical model suggests, the effectiveness of both CRM and technical training should be enhanced when trainers stress the human factors components of every aspect of flight. Only basic research and operational evaluation can optimize these efforts. In the same vein, such research should provide guidance for incorporating human factors training into initial pilot training as well as training for experienced crewmembers.

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[6] A related question is what level of stress needs to be imposed on training to maximize the probability that human factors concepts will generalize to operational emergencies. See the chapter by Butler for further discussion of this topic with regard to LOFT.

1.10. Conclusions

Recognizing the critical role of human factors in determining the effectiveness of technically proficient flightcrews in both normal and emergency situations, the aviation community has embraced the concept of CRM training. The spread of CRM programs has proceeded faster than the accumulation of knowledge regarding their operational impact, reflecting the perceived importance of the issues. However, research findings to date suggest that this faith has not been misplaced. Crewmembers value the training, and available data suggest that it does have a positive impact on crew behavior and, by inference, on the safety of the aviation system.

The theoretical model of flightcrew group processes suggests that the most effective CRM courses will simultaneously address multiple input and group process factors and will be developed with awareness of the particular cultures in which they are embedded. Impact should also be enhanced when participants are not forced to make large generalizations from abstract concepts to their normal work setting, but rather receive training that communicates psychological concepts in terms of shared everyday experiences and clearly defined behaviors. Successful programs appear to provide not only basic psychological concepts, but their translation into operational terms.

It seems likely that if research and evaluation proceed in tandem with the implementation of continuing human factors training, courses of the future will evolve continually and make today's efforts look as antiquated as the Link Trainers of World War II. The open exchange of information that has developed surrounding CRM training has provided an environment conducive to rapid evolution.

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CRM/LOFT and the collection of data to assess the process. Captain Milt Painter and the CRM team at Southwest Airlines contributed their time and talent to the development of LOFT videos for calibrating evaluators. John A. Wilhelm has been a close collaborator for many years and remains master of the data, while William R. Taggart has provided invaluable counsel and assistance in the design and delivery of training for evaluation of crew performance. Finally, current and former graduate students at the University of Texas have been instrumental in all stages of the project. This group includes Cathy Clothier, Thomas R. Chidester, Steven E. Gregorich, Cheryl Irwin, Sharon Jones, Randolph Law, Terry McFadden, Ashleigh Merritt, Steven Predmore, and Paul Sherman.

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1.11. CRM Redux

Revisiting words written 15 years ago was a chastening experience for me. While the superordinate goals of CRM training—safe and efficient flight—are the same, its scope and practice have changed dramatically. Developments in CRM training and guidance for its delivery are provided in an updated Advisory Circular (120.51) of the US Federal Aviation Administration (Federal Aviation Administration, 2004). The aviation system has also undergone massive upheaval: a faltering economy has resulted in bankruptcies and mergers, airline fleets have been reduced in size, and operations have been shifted to more efficient, highly automated aircraft flown by two-person crews. Extremely long-haul flights, for example Houston to Tokyo, have also been established.

On very long flights a full relief flight crew (captain and first officer) is required, raising issues of command and leadership in the event of an in-flight emergency.

One of the factors we did not recognize in 1993 was the powerful influence of national culture on flight crew behaviors and the diverse approaches needed for delivery and acceptance of CRM programs in different cultures (Helmreich & Merritt, 1998; Merritt & Helmreich, 1996c). Another growing realization has been that CRM is not for the cockpit alone. (I must confess that as the first edition was going to press there was heated debate among the editors about whether the title of the volume should be *Crew* or *Cockpit* Resource Management. The three of us, Earl Wiener, Barb Kanki and myself, ultimately agreed that it should have been *Crew Resource Management.*

1.11.1. Culture

I observed a wide range of cockpit behaviors from the jumpseat (despite assurances from managers and check airmen that pilot behavior was highly standardized in their airline). To explore this rather startling finding, I designed and administered a survey of pilot attitudes, the *Cockpit Management Attitudes Questionnaire* (CMAQ: Helmreich, 1984). The CMAQ was completed by pilots from a number of countries. It queried them about their beliefs regarding appropriate cockpit leadership and management of the flight deck. Analyzing the data, I was struck by highly significant differences in response as a function of aircraft fleet, pilot background and, especially, national culture. It remained for my former student and colleague Ashleigh Merritt to develop a new survey, the *Flight Management Attitudes Questionnaire* based on the CMAQ (FMAQ: Helmreich & Merritt, 1998). The FMAQ draws on the multi-dimensional conceptualization of culture developed by the Dutch psychologist Geert Hofstede (Hofstede, 2001). The FMAQ has been administered to flight crews in more than 30 countries. Examining the cross-national data, the most diagnostic of Hofstede's dimensions has proved to be power distance (PD). In high PD cultures it is accepted and expected that leaders behave in an autocratic manner and it is unacceptable for co-pilots and other junior crew to question the captain's decisions and acts (Helmreich et al., 2001). Asian and Latin American cultures tend to be high in PD with Australia anchoring the egalitarian pole and the US falling in an intermediate position. One first officer from a high PD culture said to me, "I would rather die than challenge the captain's actions." Sadly, this statement has been borne out in more than one accident (Helmreich, 1994).

After administering the FMAQ to pilots from an airline in an extremely high PD culture, I presented the survey results through a translator to a meeting of senior managers and chief pilots. As always I stressed the importance of the first officer speaking up when the situation is deteriorating and the aircraft is standing into danger.

I was informed later by a bilingual, expatriate pilot at the meeting that while I was talking a senior manager announced to all present that they should disregard everything I said.

In the most egalitarian cultures, however, status inequalities are prevalent. In one airline from a very low PD culture, organizational rules require that on overnight stops the captain must always have a room on a higher floor than the rest of the crew.

Even without managerial sabotage, gaining acceptance of CRM concepts that run counter to culture is a daunting enterprise—especially in cultures where juniors should not question or contradict their seniors. I was astonished and delighted to hear how a senior captain, head of the CRM program in one Asian carrier, got the CRM message across. His admonition to junior pilots was "Think of yourself as the eldest son in a traditional family. Your task is to protect your father from harm. Thus it is essential that you speak up and warn him if his actions are leading the flight into danger."

Clay Foushee and I described CRM as being in its third generation in our chapter in the first edition. In the following 15 years another three generations can be identified (Helmreich et al., 1999). The fourth generation stressed the definition of procedures that include the behaviors exemplifying effective cockpit resource management. The fifth generation, known as error management, was short-lived and unpopular. As one captain remarked to me, "I feel insulted being labeled as an 'error manager'—it implies that my job is to screw up and then correct my mistakes."

Under the leadership of Captains Bruce Tesmer and Don Gunther of Continental Airlines, a sixth generation of CRM emerged, known as *threat and error management* or TEM. TEM is defined and described in the Line Operations Safety Audit (LOSA) Advisory Circular 120.70 of the US Federal Aviation Administration (Federal Aviation Administration, 2006). TEM gained immediate acceptance from pilots, managers and regulators (Helmreich, 1997). TEM accurately depicts the role of flight crews—piloting and navigating the aircraft from point A to point B while coping with threats to safety in the system and managing errors originating in the cockpit. External threats include air traffic controller errors, severe weather, terrain, and a host of others. The TEM concept can be applied in all components of an organization—maintenance, dispatch, ramp operations, etc. Threat and error management has also proved to be a valuable framework for the analysis of CRM-related behaviors in the investigation of air crashes (Helmreich, 1994).

One of the critical issues facing airlines, given the cost of developing and delivering training to highly paid staff who expect to be paid for their participation, was whether CRM programs change pilot behavior and increase system safety. After experiencing a series of embarrassing incidents (including landing at the wrong airport and shutting down the good engine after failure of the other), Delta Airlines developed and conducted an intensive three-day CRM course for all its pilots. The course led to significant, positive changes in attitudes about CRM but Delta management wanted to know if the training also led pilots to change their behavior in normal operations. The University of Texas Human Factors Research Project was asked to determine how well crews practiced CRM during normal line flights. With my colleague John Wilhelm, retired Pan American World Airways captain Roy Butler, and a team of trained observers, we collected data on crew behavior during regularly scheduled flights. To code observations we adapted the systematic observational methodology that I had employed studying the behavior and performance of aquanauts living in a habitat on the ocean floor in Project Sealab (Radloff & Helmreich, 1968) and that John Wilhelm and I had used in observing the behavior of aquanauts living on the bottom of the Caribbean in Project Tektite (Helmreich, 1972, 1973). We observed 291 Delta domestic and international flights. The results were most reassuring: Delta crews were practicing CRM on normal flights as evidenced by their effective use of the behavioral indicators of good CRM.

The observational methodology we employed evolved into the *Line Operations Safety Audit* (LOSA) under the guidance of James Klinect, PhD, a graduate of our program and principal of the LOSA Collaborative. CRM is an essential component of LOSA. LOSA's strength is in the use of expert observers riding the cockpit jumpseat with total assurance of confidentiality to capture not only real time behaviors including task performance and CRM practices of crews but also the context of behavior and the outcomes—errors committed or managed and threats managed or mismanaged. LOSA and CRM have been mandated by the International Civil Aviation Organization for all the world's airlines (ICAO, 1998, 2002).

LOSA in the USA was nearly sabotaged by the terrorist attacks on the World Trade Center in 2001 following which an FAA edict specified that only crewmembers could have access to the cockpit during flight. Continental Airlines responded to this situation by giving me an ID showing me in full captain's uniform, although they were wise enough not to let me fly one of their aircraft.

CRM rapidly infiltrated other components of the aviation system—soon we had Dispatch Resource Management and Maintenance Resource Management addressing team and inter-group issues. CRM training for air traffic controllers also emerged.

After Southwest Airlines had completed initial CRM training for its pilots, I presented the results (observations and attitude change) to management. Southwest CEO Herb Kelleher attended and rose to speak after presentations by me and the managers and instructors of the CRM program. Herb said that it was not fair for pilots to be the only beneficiaries of such training—thus was born Management Resource Management at Southwest Airlines.

1.11.2. Acquiring and Using Safety Data

Any successful program designed to improve CRM attitudes and behaviors needs to be based on valid data. As we have noted, the CMAQ and later the FMAQ provide reliable baseline information on the cognitive acceptance of CRM. LOSA, with guarantees of anonymity for those observed, provides a real-time snapshot of actual behavior. Another source of data also yields unique insights into organizational practices and CRM—confidential incident reporting systems. The Aviation Safety Reporting System (ASRS) managed by NASA has been in existence for more than 30 years and has amassed an enormous national database of events, but ASRS reports lack organizational specificity and don't give airlines useful information on conditions in their own organization. American Airlines, under the leadership of Dr Thomas Chidester, then at American and now at the FAA, helped institute a local reporting system, the Aviation Safety Action Program (ASAP: AC 120-66, Federal Aviation Administration, 2002), which provides protection from disciplinary action for those reporting threats to safety and errors to their own organization. These reports are processed at the organizational level and provide useful insights into local issues. An ASAP committee including management and pilots' association members reviews each report and develops a strategy to deal with the issues raised. A high percentage of ASAP narratives deals with CRM issues. Data from these sources combined with data-driven CRM training contribute to the development of an organization's safety management system and safety culture (Helmreich & Merritt, 2000).

1.11.3. Expansion of CRM into New Domains

Medicine

In 1994 I met an anesthesiologist, Hans-Gerhard Schaefer, from the University of Basel/Kantonsspital in Switzerland. Hans had heard of CRM and decided that it might be just the thing to improve teamwork in the operating theaters of Basel. Hans traveled to Austin and spent a year in our lab at the University of Texas. During his stay in Texas he observed all aspects of teamwork and team training in aviation. Following his return to Switzerland, I was invited to spend a year as a visiting professor in Basel where, assisted by Bryan Sexton, a student of mine from the University of Texas, we observed physician and staff behavior in operating theaters during surgeries. We also participated in development of a Critical Incident Reporting System (CIRS) to allow professionals to share information on safety-related issues—especially CRM issues surrounding the interfaces between surgeons, anesthesiologists and nurses.

A few years later the United States Institute of Medicine (IOM) issued a highly influential report documenting the scope of preventable medical error. The IOM report concluded that more than 90,000 people a year may die needlessly in the USA from preventable medical error (Institute of Medicine, 1999). Comparing medicine and aviation, I discovered many similarities between the two professions. Stunned by the implications of the data, a number of medical organizations began to realize that they might benefit from adopting aviation's approaches to safety (Helmreich, 1997). The *British Medical Journal*, one of the most prestigious medical publications, placed a crashed aircraft on the cover of its issue containing articles by me and others about adapting aviation safety approaches to healthcare (Helmreich, 2000). Contrasting death rates from errors in the two professions, it is apparent that your doctor is more likely to kill you than your pilot. The data also suggest that significant improvement may come from embracing aviation's safety strategies including CRM (Helmreich & Sexton, 2004a, 2004b; Thomas & Helmreich, 2002a, 2002b).

Facing the reality of becoming an increasing consumer (and potential victim) of the healthcare system as I age, I became more involved in patient safety issues and in designing appropriate CRM training for healthcare professionals. In the USA, one of the barriers to the effective information exchange needed to optimize CRM in medicine is that, unlike aviation, there is no immunity from punishment or malpractice lawsuits for those who report and acknowledge their errors. Indeed, in Texas until recently a nurse who committed an error, even the administration of the wrong medication because of an error in the pharmacy, faced potential loss of license. The workaround for lack of protection for those who disclose errors has been to limit reports submitted to threat and error databases to near misses with no adverse impact on patients. I do not see this as a critical problem because near miss data usually have as much diagnostic value as information from events with less happy outcomes. In the absence of a more coherent healthcare system, it remains to be seen how useful these data will prove to be and if medical CRM training enhances safety significantly.

Firefighting

Of all the professions in the USA firefighting has the second highest incidence of line of duty death (behind mining) with 114 fatalities in 2008. CRM training has been provided for firefighters to help them cope as individuals and teams with complex, dangerous and frequently changing situations where information is often incomplete. I had the privilege of working with the International Association of Fire Chiefs as they developed and implemented a national, internet-based close-call reporting system (www.firefighternearmiss.com). Their firefighter reporting system asks respondents to identify multiple causal and contributing factors and to provide a narrative describing the event. Contributing and causal factors in the reports provide insights into team coordination issues and decision making. In larger fires there are frequently multiple units from different stations on the scene. This type of situation requires effective leadership as well as inter- and intra-team coordination.

1.11.4. The Future

I have been amazed and delighted at the proliferation of CRM in extremely diverse professions. The basic concepts of CRM clearly address critical safety issues. Cooke and Durso (2007), in their assessment of failures and successes, apply psychology to settings as different as minefields, the operating room, and the performance of elderly drivers. I feel confident that, in its threat and error management identity, CRM will continue to play a significant role in the training of professionals who work in areas where teams must interact successfully for safe and efficient task performance.

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