# MODELS OF THREAT, ERROR, AND CRM IN FLIGHT OPERATIONS

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## ABSTRACT

Issues in Crew Resource Management (CRM) are discussed, including its definition and primary goals of recognizing and managing threat and error. CRM is a component of an organization's safety efforts and must be driven by valid data on operational issues. Data requirements for a safety culture include proactive information on crew behavior. The use of non-jeopardy, Line Operations Safety Audits (LOSA) to document threat, error, and crew behavior in line operations is discussed. Models of threat and error in the aviation system are presented, based on LOSA data from three airlines.

## CRM

Although CRM programs had their origin in efforts to reduce 'pilot error' accidents, over the years understanding of the goals of programs has faded, perhaps in part because of the extension of training into domains other than the cockpit, including the cabin, maintenance, and dispatch (Helmreich & Foushee, 1883; Helmreich, Merritt, & Wilhelm, 1998; Helmreich, Wilhelm, Klinect, & Merritt, in press). For example, CRM has been defined as 'Instructional strategies that seek to improve teamwork in the cockpit.' While effective teamwork is clearly important, it is not the *primary goal* of CRM training. The following is a more accurate representation of CRM. *CRM can broadly be defined as the utilization of all available human, informational, and equipment resources toward the effective performance of a safe and efficient flight. CRM is an active process by crewmembers to identify significant threats to an operation, communicate them to the PIC, and to develop, communicate, and carry out a plan to avoid or mitigate each threat. CRM reflects the application of human factors knowledge to the special case of crews and their interaction.* This definition was taken from the CRM chapter of the FAA's Advisory Circular on the Advanced Qualification Program (AQP), which is in the process of being finalized. The secondary benefits of effective CRM programs are improved morale and enhanced efficiency of operations (Helmreich & Merritt, 1998).

Criticisms of CRM often fail to recognize the variability in programs. Some are carefully designed and reflective of their organization's culture, others are mere exercises in compliance with requirements. Good programs do have a measurable, positive effect on crew performance, and, hence, safety.

Some have argued that CRM training should ultimately disappear, as it becomes fully integrated into technical training. We once supported this notion, but with hindsight we now realize that it is and should be a separate aspect of training. CRM training falls at the interface between safety departments, flight training, and flight operations. CRM programs represent ongoing training driven by objective data reflecting operational issues. CRM is not a one-time intervention, but rather a critical and continuing component of a safety culture.

## CRM SKILLS AS DEFENSE BUILT ON DATA

CRM skills provide a primary line of defense against the threats to safety that abound in the aviation system and against human error and its consequences. Today's CRM training is based on accurate data about the strengths and weaknesses of an organization. Building on detailed knowledge of current safety issues, organizations can take appropriate proactive or remedial actions, which include topics in CRM. There are five critical sources of data, each of which illuminates a different aspect of flight operations. They are: 1) Formal evaluations of performance in training and on the line; 2) Incident reports; 3) Surveys of flightcrew perceptions of safety and human factors; 4) Flight Operations Quality Assurance (FOQA) programs using flight data recorders to provide information on parameters of flight. (It should be noted that FOQA data provide a reliable indication of *what happens* but not *why* things happen.); and 5) Line Operations Safety Audits (LOSA). We focus here on what we have learned from LOSA.

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The nature and value of LOSA. Line Operations Safety Audits are programs that use expert observers to collect data about crew behavior and situational factors on normal flights. They are conducted under strict non-jeopardy conditions, meaning that no crews are at risk for observed actions. Observers code observed threats to safety and how they are addressed, errors and their management, and specific behaviors that have been associated with accidents and incidents (and that form the basis for contemporary CRM training). Data are collected using the University of Texas Line/LOS Checklist (Helmreich, Klinect, Wilhelm, & Jones, 1999). In practice, members of the University of Texas project and trained observers from participating airlines serve as observers. Their presence across all organizations allows us to make valid cross-airline comparisons. Data from LOSA provide a valid picture of system operations that can guide organizational strategy in safety, operations, and training. A particular strength of LOSA is that the process identifies examples of superior performance that can be reinforced and used as models for training. Data collected in LOSA are proactive and can be used immediately to prevent adverse events. The University of Texas project has participated in eight audits with more than 3,500 flights observed. In this paper, data from the three most recent audits, which include threat recognition and error management, are discussed. These three LOSA projects were conducted both in the U.S. and in international operations and involved two U.S. and one non-U.S. carrier.

## THE MODEL OF THREAT AND ERROR MANAGEMENT

Data are most valuable when they fit within a theoretical or conceptual framework. Our research group has developed a general model of threat and error in aviation that is shown below in Figure 1. As the model indicates, risk comes from both expected and unexpected threats. Expected threats include such factors as terrain, predicted weather, and airport conditions while those unexpected include ATC commands, system malfunctions, and operational pressures. Risk can also be increased by errors made outside the cockpit, for example, by ATC, maintenance, and dispatch. External threats are countered by the defenses provided by CRM behaviors. When successful, these lead to a safe flight.

The response by the crew to recognized external threat or error might be an error, leading to a cycle of error detection and response. In addition, crews themselves may err in the absence of any external precipitating factor. Again CRM behaviors stand as the last line of defense. If the defenses are successful, error is managed and there is recovery to a safe flight. If the defenses are breached, they may result in additional error or an accident or incident.

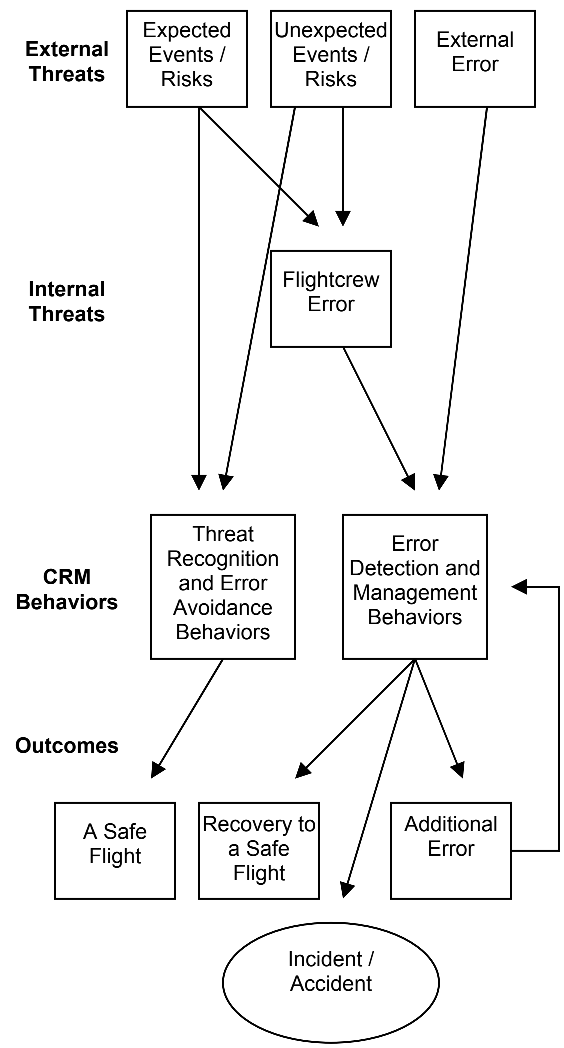



Figure 1. The model of flightcrew error management.

## THE MODEL OF FLIGHTCREW ERROR MANAGEMENT

Errors made within the cockpit have received the most attention from safety investigations and has been implicated in around two-thirds of air crashes (Helmreich & Foushee, 1993).[2] Our analyses of error

[2] Early investigations tended to focus on the crew as the sole causal factor. Today, of course, we realize that almost all accidents are

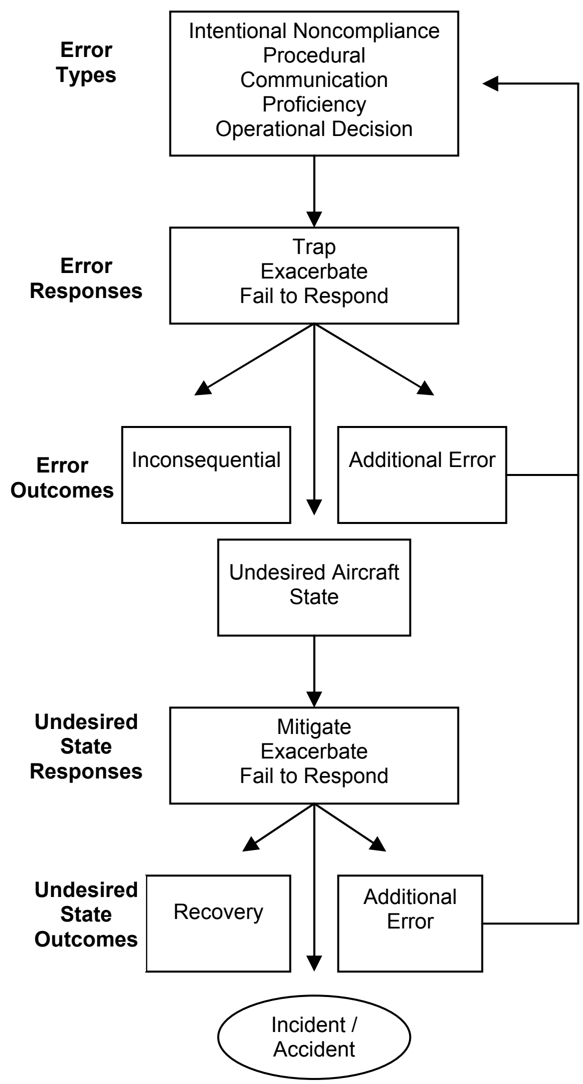
have led us to reclassify and redefine error in the aviation context. Operationally, flightcrew error is defined as *crew action or inaction that leads to deviation from crew or organizational intentions or expectations*. Our definition classifies five types of error: **1) Intentional noncompliance errors** are conscious violations of SOPs or regulations. Examples include omitting required briefings or checklists; **2) Procedural errors** include slips, lapses, or mistakes in the execution of regulations or procedure. The intention is correct but the execution flawed; **3) Communication errors** occur when information is incorrectly transmitted or interpreted within the cockpit crew or between the cockpit crew and external sources such as ATC; **4) Proficiency errors** indicate a lack of knowledge or stick and rudder skill; and **5) Operational decision errors** are discretionary decisions not covered by regulation and procedure that unnecessarily increases risk. Examples include extreme maneuvers on approach, choosing to fly into adverse weather, or over-reliance on automation.

<u>Crew response to error and error outcomes</u>. Three responses to crew error are identified: **1) Trap** – the error is detected and managed before it becomes consequential; **2) Exacerbate** – the error is detected but the crew's action or inaction leads to a negative outcome; **3) Fail to respond** – the crew fails to react to the error either because it is undetected or ignored.

Definition and classification of errors and crew responses to them are based on the observable process without consideration of the *outcome*. There are three possible outcomes: **1) Inconsequential** – the error has no effect on the safe completion of the flight, or was made irrelevant by successful cockpit crew error management. This is the modal outcome, a fact that is illustrative of the robust nature of the aviation system; **2) Undesired aircraft state** – the error results in the aircraft being unnecessarily placed in a condition that increases risk. This includes incorrect vertical or lateral navigation, unstable approaches, low fuel state, and hard or otherwise improper landings. A landing on the wrong runway, at the wrong airport, or in the wrong country would be classified as an undesired aircraft state; **3) Additional error** – the response to error can result in an additional error that again initiates the cycle of response.

Undesired states can be **1) Mitigated**, *2)* **exacerbated**, or **3) Fail to respond**. For example, recognizing an unstable approach and going-around would mitigate the situation. Crew actions may exacerbate the situation, increasing the severity of the state and the level of risk. Just as with error response, there can also be a failure to respond to the situation. There are three possible resolutions of the undesired aircraft state: **1) Recovery** is an outcome that indicates the risk has been eliminated; **2) Additional error** - the actions initiate a new cycle of error and management; and **3) crew-based incident or accident.**

The model can facilitate analysis of all aspects of error, response, and outcome. The failure or success of defenses such as CRM behaviors can also be evaluated. Errors thus classified can be used not only to guide organizational response but also as scenarios for training, either in classroom or LOFT. The full error management model is shown graphically in Figure 2.




system accidents as discussed by Helmreich & Foushee (1993) and Reason (1997).

Figure 2. A model of flightcrew error.

Major findings from LOSA conducted in three airlines are presented in subsequent papers (Klinect & Wilhelm, this volume). It is critical to note that the data show very large and significant differences between airlines and between fleets within airlines. This is illustrated in Figures 3 and 4 following.

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

Figure 3. Threats and errors in three airlines**.**

| Aircraft | Intentional noncompliance | Procedural |
|---|---|---|
| Advanced Tech. Fleet #1 | 40% | 31% |
| Advanced Tech. Fleet #2 | 30% | 44% |
| Conventional Tech. Fleet #1 – 3 person crew | 17% | 55% |
| Conventional Tech. Fleet #2 – 2 person crew | 53% | 20% |

Figure 4. Percentages of error types within fleets in one airline.

## IMPLICATIONS OF LOSA DATA AND MODELS

Unlike incident and accident investigations that provide information after a potentially catastrophic or near-catastrophic event, LOSA data provide a picture of normal operations and allow estimation within organizations of the degree of risk associated with certain environments, fleets, or types of maneuvers. LOSA data in organizations that have established a credible safety culture provide a valid report card on the operation. They show areas of strength and those in need of intervention. The between organization and between fleet differences demonstrated have several important implications. The first is that organizations cannot assume that their operation will correspond to normative data from the industry. The high degree of variability observed corresponds to differences in the operating environment and, most importantly, demonstrates the power of organizational cultures and subcultures (Reason, 1997). Even in the same organization, fleets engaged in comparable operations can differ widely, manifesting their own subcultures. While the LOSA database assembled by the University of Texas project cannot be used to represent industry norms because of this variability, the data do point to general problems and capture the extent of variation.

The value of data showing operational areas of strength must be recognized. Training based on positive examples is superior to that based on negatives. It is important for organizations to recognize those things they do particularly well and to reinforce them.

The two models presented can provide a useful framework for training by illustrating concretely the sources of risk and the process of risk avoidance and error management. The model and the data also demonstrate clearly how the core behaviors of CRM serve in risk avoidance and error management. By engaging the models and real data in the training process, the acceptance and impact of training should be increased. Training must recognize the inevitability of error. It should concentrate on the management of threat and error. It also needs to focus on strategies to reduce the consequences of errors and to mitigate undesired states. As one airline has recognized, the data can be used to improve LOFT training to ensure that crews encounter the kinds of threats in the simulated environment that are most prevalent in line operations. It has been our view that the operational impact of LOFT should be enhanced, and LOSA data can help strengthen this training.

Intentional non-compliance errors should signal the need for action since no organization can function safely with widespread disregard for its rules and procedures. One implication of violations is a culture of complacency and disregard for rules, which calls for strong leadership and positive role models. Another possibility is that procedures themselves are poorly designed and inappropriate, which signals the need for review and revision. More likely, both conditions prevail and require multiple solutions. One carrier participating in LOSA has addressed both with considerable success.

Procedural errors may reflect inadequately designed SOPs or the failure to employ basic CRM behaviors such as monitoring and cross checking as countermeasures against error. The data themselves can help make the case for the value of CRM. Similarly, many communications errors can be traced to inadequate practice of CRM, for example in failing to share mental models or to verify information exchanged.

Proficiency errors can indicate the need for more extensive training before pilots are released to the line. LOSA thus provides another checkpoint for the training department in calibrating its programs by showing issues that may not have generalized from the training setting to the line.

Operational decision errors also signal inadequate CRM as crews may have failed to exchange and evaluate perceptions of threat in the operating environment. They may also be a result of the failure to revisit and review decisions made.

Organizations nurturing a safety culture must deal with those issues identified by LOSA and other data sources, interventions may include revising procedures, changing the nature and scope of technical training, changing scheduling and rostering practices, establishing or enhancing a safety department, and a variety of other actions. The LOSA data set can be used by management to set priorities based on threats that crews face and how effectively they respond to those threats. At the organizational level, we have seen positive examples of the use of both threat and error LOSA data. Some examples of proactive responses include: changing SOPs regarding approaches resulting in a 70% reduction in unstable approaches; developing special training in captaincy in response to evidence of weak leadership regarding SOPs and procedures, require special airport qualifications for certain foreign destinations after noting the density of threats. Several organizations have provided wide dissemination of LOSA data to raise the awareness of crews regarding threat and error. One, for example, placed a summary of their LOSA data in all aircraft and bases for crews to examine in detail.

One of the most important actions that organizations can provide through LOSA is to communicate a non-punitive attitude toward error (but not toward intentional non-compliance). LOSA, in conjunction with non-punitive incident reporting systems, can provide the data needed for development of truly effective safety cultures. One of the research challenges that remains is to develop analytic strategies to integrate LOSA data with those from incident reports. We can recognize the fact that undesired states in our model represent incidents that have been mitigated. One step in this direction is the development of an incident reporting system that addresses human factors issues in self-reports using the same conceptual model of threat and error employed in LOSA (Jones & Tesmer, this volume). In addition, the results from FOQA, surveys, and training should be considered as part of the same model. The ultimate goal is an accurate multivariate representation of a complex operating environment.

The threat and error management models can also serve a useful function in the analysis of accidents by providing a template for capturing contextual factors and countermeasures in a systematic manner. Results of these analyses can assist both safety investigations and the development of management interventions and training.

One of the major challenges for research will be to understand the complex relationships between threats and errors and between errors and responses. We know that high threat does not lead inexorably to error. This is certainly due in part to the fact that both crew and system defenses moderate the relationship. One of the uses of the data should be to prioritize the deployment of resources for safety.

## SUMMARY

There are basic steps that every organization needs to follow to establish a proactive safety culture that is guided by the best possible data on its operations. These include the following:

- Establish trust
- Adopt a credible, non-punitive policy toward error (not violation)
- Demonstrate commitment to taking action to reduce error-inducing conditions
- Collect ongoing data that show the nature and types of errors occurring
- Provide training in threat and error management strategies for crews
- Provide training in evaluating and reinforcing threat and error management for instructors and evaluators

Trust is a critical element of a safety culture, since it is the lubricant that enables free communication. It is gained by demonstrating a non-punitive attitude toward error and showing in practice that safety concerns are addressed. Data collection to support the safety culture must be ongoing and findings must be widely disseminated. CRM training must make clear the penultimate goals of threat and error management. Ancillary benefits such as improved teamwork and morale are splendid, but not the driving force. Finally, instructors and check airmen need special training in both evaluating and reinforcing the concepts and in relating them to specific behaviors.

If all of the needed steps are followed and management's credibility is established, a true safety culture will emerge and the contribution of CRM to safety will be recognized.

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