THREAT AND ERROR MANAGEMENT: DATA FROM LINE OPERATIONS SAFETY AUDITS

James R. Klinect, John A. Wilhelm, and Robert L. Helmreich
The University of Texas Team Research Project
The University of Texas at Austin
Department of Psychology
Austin, Texas USA

ABSTRACT

Using data collected from Line Operations Safety Audits (LOSA), this paper presents a quantitative view of external threat and flightcrew error in normal flight operations. Results on the different types of threat and error and their management will be presented. These results indicate a substantial amount of variability across error outcomes, phases of flight, and on a larger scale, airlines. Implications and future avenues of research with this type of proactive data are also discussed.

INTRODUCTION

In the paper titled *Models of Threat, Error, and CRM in Fight Operations*, two models of threat and error management were outlined and discussed (Helmreich, Klinect, Wilhelm, this volume). The purpose of this paper is to present data that were collected under the framework of these models in recent Line Operations Safety Audits (LOSA). The discussion that follows will be divided into five sections: LOSA demographics, external threats, threat management, flightcrew errors, and error management.

LOSA DEMOGRAPHICS

Between 1997 and 1998, the University of Texas Team Research Project conducted LOSA's at three airlines with an aggregated sample of 184 flightcrews on 314 segments. Table 1 provides a demographic summary for each airline in the database.

Table 1 – LOSA Demographics by Airline

Airline A	91 flight segments observed Median stage length: 3 hrs. 15 min. Stage length range: 45 min. to 14 hrs.
Airline B	102 flight segments observed Median stage length: 3 hrs. 30 min. Stage length: 45 min. to 12 hrs.
Airline C	121 flight segments observed Median stage length: 1 hr. Stage length: 20 min. to 2 hrs. 35 min.

During a LOSA, trained observers are asked to record three types of data using the most recent version of the Line/LOS Checklist (Helmreich, Wilhelm, Klinect, & Jones, 1999). The observers were asked to (1) document external threats, (2) record flightcrew errors in terms of their type, management response, and outcome, and (3) rate the crew on several CRM behavioral markers. These three types of data provide our proposed framework for threat and error management during normal operations.

EXTERNAL THREATS

In the model of threat and error management, external threats are defined as situations, events, or errors that originate outside of the cockpit (Helmreich, Klinect, and Wilhelm, this volume). Examples include high terrain, poor weather, aircraft system malfunctions, or errors made by other humans in the system such as maintenance or ATC. By categorizing and counting such threats, it allows researchers and airlines to quantify some of the risk that is associated with the flying environment.

In the discussion of external threats, three questions will help organize the presentation of the results. The first question asks about the extent of external threats in normal flight operations. The next question will focus on the phases of flight that are most prone to threats. Finally, the last question asks whether airlines have the same distribution of external threats.

What is the extent of external threats in normal flight operations?

Judging from the aggregated LOSA results, external threats are common in normal flight operations. While this is probably no surprise, the LOSA data in Table 2 roughly quantifies the degree of threat that crews have to face on a daily basis.

Table 2- General External Threat Results

Total external threats	606
Percentage of flight segments with at least one external threat	72%

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Average external threats per flight segment	1.91
Most external threats on one flight	11

Data also show that the number of external threats can vary from flight to flight. As seen in the table above, the number of external threats per flight can be extensive at times. In a flight that we label as the "heavy rain of threat," a flightcrew had to manage eleven different threats. A few of the threats were inconsistent fuel slips, weight restriction on takeoff, smoke in the lavatory, heavy traffic, adverse weather on departure and arrival, and a late runway change. This was no doubt a heavy workload for the crew and one that posed a significant risk to safety.

Future research into external threats will attempt to build an objective metric for operational complexity on the basis of threat type and frequency. By using this metric, our first step will be to validate previous research that has shown flightcrew performance to bifurcate from their baseline performance when operating under complex conditions (Hines, 1998).

In what phase of flight do most external threats occur?

While the number of external threats can vary from flight to flight, they do exhibit some consistency in the sense that some phases of flight are more prone to have threats (Table 3). The highest percentage of external threats were in the descent / approach / landing phase of flight. These tended to be terrain, adverse weather, and ATC command threats such as abnormal routing, poor timing, or slam-dunk clearances.

Table 3 – External Threats by Phase of Flight

Phase of Flight	Percentage of External Threats
Preflight / Taxi	22%
Takeoff / Climb	28%
Cruise	10%
Descent / Approach / Land	39%
Taxi / Park	1%

It was surprising to note that 22% of the external threats occurred before the aircraft left the ground in the preflight / taxi phase of flight. These threats were mostly associated with aircraft system abnormals, ground operation events, and operational pressures such as delays, late aircraft arrival, or other irregular operations. The nature of the typical preflight / taxi threats were substantially different from those that occur when airborne. Therefore, future research will investigate whether flightcrews use a different set of threat management strategies in certain phases of flight.

Are all airlines exposed to the same distribution of external threats?

For the number of threats per flight segment, the results indicate that the three airlines in the database were not exposed to the same distribution of external threats (Table 4). At a more specific level, the results also show significant differences in the types of external threats.[1] These included terrain, adverse weather, aircraft malfunction, ground operation events, and external errors.

Table 4 – External Threat Variability by Airline

	Airline A	Airline B	Airline C
Average number of external threats per flight segment	3.3	2.5	.4

This type of threat data is useful for airlines because it allows them to target areas of external risk in a systematic fashion. In other words, it allows the operational complexity for an entire airline to be profiled. For example, Airline A operated in an environment with proportionally more aircraft system malfunctions, terrain threats, and adverse weather threats. In contrast, Airline B operated in an environment that had significantly more external errors, ATC threats, and ground events than Airlines A and C. Airline C, which flew into a relatively benign environment, had the fewest overall external threats per flight segment. These data could also be used to profile threats for particular geographic locations, airports, or fleets.

THREAT MANAGEMENT

Threat management is the act of minimizing the potential consequences of threats on flight safety. To explore the data on threat management in normal flight operations, two questions will be addressed. The first concerns external threats with which flightcrews have the most difficulty in managing. The second question covers the type of crew behaviors that were observed to be the most important in threat management.

[1] Chi squares were significant at the .05 level.

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Which external threats do flightcrews have the most difficulty managing?

One of the potential consequences of an external threat can be the propagation of flightcrew error. While the linkage between threats and errors are sometimes not perfectly causal in nature, we do believe that we can determine if an error would have occurred without the presence of a threat. The results show that only 7% of the threats in the database influenced flightcrews to commit an error. Among this small number of linkages, an interesting finding did come about. More than half of the linkages were associations between unusual ATC command threats, such as late runway changes or slam-dunk clearances, to flightcrew decision errors that resulted in an unnecessary acceptance of risky ATC instructions.

What flightcrew behaviors were observed to be the most important in threat management?

For the past three line audits, we have asked our observers to list flightcrew behaviors that either led to effective or ineffective threat management. The results show that the most frequently mentioned behaviors were strong leadership through the coordination of flight deck activities, active preparation for contingency situations, flightcrew vigilance, quality and content of briefings, and crew members that asked questions or spoke up with pertinent information.

FLIGHTCREW ERRORS

Flightcrew errors are defined as *a crew action or inaction that leads to a deviation from crew or organizaitonal intentions or expectations* (Helmreich, Klinect, Wilhelm, this volume). Again, using the models of threat and error management as conceptual foundations, the LOSA data allows us to examine flightcrew error in normal flight operations.

In this section, four questions will lead the discussion of the flightcrew error results. The first question asks about the extent of flightcrew errors. The second centers on the phases of flight that were most prone to error. The third question queries about the most frequent types of error and their consequences. Finally, the last question asks whether airlines are subjected to the same distribution of error.

What is the extent of flightcrew errors in normal flight operations?

It has long been argued that pilot error is an everyday occurrence but to what degree? The LOSA results presented in Table 5 offer some initial insight.

Table 5 - General Flightcrew Error Results

Total errors	578
Percentage of flightcrews with at least one error	68%
Percentage of flight segments with at least one error	64%
Average errors per flight segment	1.84
Most errors on one flight segment	14

These data show that flightcrew errors were just as pervasive as external threats. Over 60% of the flightcrews and segments in the database contained errors. There was also a substantial degree of variability across flightcrews with errors.

In what phase of flight do most errors occur?

The phases of flight most prone to external threats was also most likely to contain flightcrew errors – the descent / approach / landing phase of flight. (Table 6). Typical errors in this phase were associated with checklist usage, automation, and proficiency. Interestingly this phase also contained the most errors linked to consequential outcomes.[2] This is further evidence that this phase of flight is by far the riskiest for flightcrews to manage.

Table 6 – Distribution of Flightcrew Errors by Phase of Flight

Phase of flight	Percentage of errors	Percentage that were consequential
Preflight / Taxi	23%	7%
Takeoff / Climb	24%	12%
Cruise	12%	12%
Descent / Approach / Landing	39%	21%
Taxi / Park	2%	Insufficient data

[2] The definition for a consequential outcome is a flightcrew error either linked to undesired aircraft state or another error. An undesired aircraft state is defined as an outcome in which an aircraft is placed in a compromising situation that poses an increased risk to safety. These can include altitude deviations, unstable approaches, and heading deviations.

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There was also a large number of errors in the preflight / taxi phase. These were typically associated with checklist usage, documentation, and incorrect switch and lever settings. In addition, error management during this phase was substantially better than the descent / approach / landing phase with 7% of the errors becoming consequential.

What are the most frequent types of errors and which are the most consequential?

As specified in the model of flightcrew error management, there are five types of error: (1) intentional noncompliance (otherwise known as willful violations), (2) procedural, (3) communication,[3] (4) proficiency, and (5) operational decision errors (Helmreich, Klinect, and Wilhelm, this volume). A distribution of error types and the percentage that were linked to consequential outcomes are presented in Table 7.

Table 7 – Distribution of Error Types and Consequential Outcomes

Error type	Percentage of errors	Percentage that were consequential
Intentional Noncompliance	54%	2%
Procedural	29%	23%
Communication	6%	13%
Proficiency	5%	69%
Operational Decision	6%	43%

The most frequent type of error, intentional noncompliance, was also the least consequential. The two percent that were consequential were intentional violations of checklist procedures, such as performing a checklist from memory. All of these willful checklist errors were linked to incorrect lever and switch settings. This concurs with previous research that states that violations are only of consequence when they are paired with an unintentional error (Free, 1994; Hudson, 1998).

While proficiency and operational decision errors were the least often observed, results indicate that they were also the most difficult for flightcrews to manage. When both of these types were combined into one category, they were linked to consequential outcomes over 70% of the time. Future research will investigate further into these types of error in the hope of learning what flightcrews do in their mismanagement.

In order to elicit more detail from flightcrew errors, content domains were derived across the five error types.[4] These results show that 31% of the 578 errors in the LOSA database were associated with automation (MCP and/or FMC errors). This was closely followed by checklist errors (24%), sterile cockpit errors (13%), ATC related errors (8%) and briefing errors (6%).

Of the 179 automation errors, 21% were associated with incorrect switch settings or execution of modes. These can be considered typical slips or lapses with automation (Reason, 1997). However, the majority of automation errors (65%) were associated with a failure to cross-verify settings. As a whole, 11% of the automation errors were linked to consequential outcomes.

In the checklist error domain, 7% of the 139 errors were linked to an additional error or undesired aircraft state. The most frequent checklist error was the performance of a checklist from memory (37% of the total). Others included the lack of challenge and response to a checklist (26%), checklist completed but not called "complete" (22%), and omitting or performing the wrong checklist (8%). The remaining 7% were slips and lapses at the item level (e.g., missed item).

Do all airlines have the same distribution of errors?

Similar to external threats, there were significant differences between airlines in the number of errors committed and the percentage of errors that became consequential (Table 8).[5]

Table 8 – Error Variability by Airline

	Airline A	Airline B	Airline C
Average errors per flight segment	.86	1.9	2.5
Percentage of errors that were consequential	18%	25%	7%

There were also differences in the types of error committed across airlines. For example, Airline C had

[3] Current research is integrating models of threat and error management with content coding and linguistic analyses, in an investigation of cockpit communication processes (Sexton & Helmreich, this volume).

[4] Error content domains are in the appendix (Table 11).

[5] Chi squares were significant at .05 level.

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a significantly higher proportion of intentional noncompliance errors. If we were to interpret this result as an organizational diagnostic, the high number of intentional noncompliance errors might indicate the need for Airline C to evaluate procedures, manuals, or the check airman program to ensure greater compliance.

ERROR MANAGEMENT

The notion of error management has steadily gained momentum in the world of pilot training. In the simplest form, error management consists of an error, flightcrew response, and outcome. Using this logic, a number of questions will be addressed in the discussion of the error management results. The first two questions ask about the typical responses and outcomes to error. The next question touches on the extent of undesired aircraft states and how they are managed during flight. Lastly, the final question asks about CRM behaviors that were cited as the most important in error management.

What are the typical responses to error?

When an error is committed, there are three types of responses: trap, exacerbate, and no response. For a trap response, the error is detected by the flightcrew and actively managed to an inconsequential outcome. On the other hand, an exacerbated error is one that is detected, but mismanaged in a way such that it induces additional errors or undesired states. The final response is a failure to respond to an error. The outcomes for these types of errors can either be inconsequential or linked to undesired aircraft states and additional errors. To get a more accurate picture of error management, the following analysis is only going to look at flightcrew responses to procedural, communication, proficiency, and operational decision errors. This is done because these types of error are unintentional and thus more likely to elicit an active error management response (Table 9).

Table 9 - Distribution of Flightcrew Responses to Unintentional Errors

Error response	Percentage of unintentional errors
Trap	36%
Exacerbate	11%
No Response	53%

The majority of the error responses were a failure to respond. Interestingly, 36% of these errors were linked to undesired aircraft states. When an undesired aircraft state occurs, the flightcrew no longer manages the error. Instead, they are managing against the potential consequences of an undesired state. This subtle difference may lead flightcrews to utilize distinct sets of behaviors and management strategies.

What are the typical outcomes of error?

The results show that 85% of the flightcrew errors were inconsequential. However, 15% of the errors observed were linked to an additional error or undesired state (Table 10).

Table 10 - Distribution of Flightcrew Error Outcomes

Error Outcome	Percentage of Outcomes
Inconsequential	85%
Undesired Aircraft State	12%
Additional Error	3%

What is the extent of undesired aircraft states and how are they managed?

Undesired aircraft states are theorized to be at the cusp of an incident or accident. Out of the 314 flight segments, 67 undesired states were observed. The most frequently observed were vertical deviations from the assigned altitude (16% of the undesired states), aircraft speed above limits (12%), and unstable approaches (10%).

As for flightcrew responses to undesired aircraft states, 79% were mitigated. An example of a mitigated response is when a flightcrew violates an altitude and immediately flies back to the assigned altitude. However, not all undesired aircraft states are effectively managed. Approximately nine percent were exacerbated into flightcrew errors. The remaining 12% were states in which the flightcrew did not respond and allowed the state to resolve itself. Examples include long landings and landings outside of the touchdown zone.

What behaviors were observed to be the most important in error management?

Expert observers were asked to list behaviors that they thought were important in the flightcrew management of error. The most frequent behaviors listed were vigilance, crewmembers speaking up and stating pertinent information, and crewmembers asking questions regarding crew actions and decisions.

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SUMMARY

This paper presented a unique perspective on threat and error management. This insight into normal flight operations allowed us to learn the following points.

- External threats and flightcrew errors are pervasive in normal flight operations but can differ in their frequency and type across airlines
- The descent / approach / landing phase of flight contained the most threats, errors, and consequential outcomes.
- Intentional noncompliance errors were the most frequently committed and also the least consequential. Proficiency and operational decision errors were the most difficult for flightcrews to manage.
- The most common errors committed were associated with automation and checklists. The majority of these errors were not typical slips, but a failure to cross-verify settings or incorrect usage.
- For the most part, flightcrews failed to respond to errors after they were committed. Most of the time they were inconsequential but there was a significant amount that turned into undesired aircraft states in which flightcrews were very successful in mitigating their consequences.
- Many CRM behaviors were cited in effective / ineffective threat and error management. These included leadership, vigilance, stating important information, asking questions, and contingency planning.

These summary points are only a start in our understanding of threat and error in normal operations. Future research will test theories across aircraft types (automated vs. conventional), crew positions, and other demographics like crew experience. In addition, the linkage between CRM behaviors and threat and error management will be further established. By presenting these results, it was our hope to stimulate new forms of thought on how we view aviation safety.

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APPENDIX

Table 11 - Content Error Domains

Sterile cockpit errors	Lever or switch errors (not automation)
Callout errors	Radio errors
ATC related errors	Documentation errors
Checklist errors	Air and ground navigation errors
FMC/MCP errors	Crew to crew communication errors
Hard warning errors	Miscellaneous errors
Briefing errors	
Proficiency errors	
Decision errors	