An Exploratory Study of Error Detection Processes During Normal Line Operations

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Introduction

The fact that human error is implicated in 70% to 80% of all aviation accidents is a frequently quoted yet often misunderstood statistic. While human error has obvious implications for safety, it is also a natural part of normal human performance, occurring both spontaneously or triggered by a variety of environmental and personal factors. As Helmreich (2000) suggests, given the ubiquity of human error, an essential element of operational safety is the effective management of error events by operational personnel. Furthermore, operational personnel act as the last line of defence in complex operational systems, and must deal with both the inherent flaws in the system, as well as their own propensity to naturally create error (Reason, 1997). Accordingly, the new focus of Threat and Error Management describes both individual and organisational approaches to the maintenance of safety within such inherently flawed socio-technical systems (Helmreich, Wilhelm, Klinect, & Merritt, 2001).

A wide range of error management strategies have been discussed in the literature, and typically a range of non-technical skills have been identified as essential error countermeasures (Helmreich & Merritt, 2000; Thomas, 2004). However, before operational personnel can undertake any effective management of error, the error must first be detected. Error detection is a significant issue for safety-critical systems and a growing body of research indicates that a considerable number of errors are never detected (Sarter & Alexander, 2000).

In relation to the development of a sound business-case for aviation psychology intervention, recent research suggests that improvements in error detection rates should provide a reduction in the number of errors that have safety-related outcomes. Indeed, as the notions of data-driven intervention and scientifically defensible investment of safety-related resources gather strength, the area of error detection stands-out as an appropriate focus for safety-change.

However, still too little is understood about the error detection mechanisms that are employed in the critical environment of normal line operations. There is currently a deficit of published research which employs naturalistic observation and analysis of error detection behaviours during normal line operations at a level of resolution that can reliably inform safety-related intervention.

Accordingly, this paper provides a systematic analysis of error detection processes during normal flight operations in the commercial aviation environment. The paper discusses the relative role of scanning, monitoring, cross-checking and checklist-based approaches to error detection and emphasises the important role of the ongoing monitoring of each crew-member's actions in the multi-crew environment.

Method

Participants. This study adopted an observational approach to the analysis and coding of error events during normal flight operations within the commercial aviation setting. Data were collected by trained observers from a sample of 102 sectors of normal line operations, within a single-aisle jet fleet of an airline operating largely short-haul operations.

Design and Procedure. The primary framework for the observational data collection and analysis was the Threat and Error Management Model developed by the University of Texas for the analysis of threat and error events during normal flight operations (Helmreich, Klinect, & Wilhelm, 1999; Klinect, Wilhelm, & Helmreich, 1999). This model informs a highly structured approach to the analysis of flight crews' threat and error management behaviours during normal line operations, and forms the foundation of the Line Operations Safety Audit (LOSA) methodology.

Observers received two days of training in the observational methodology, along with a period of practice observations. The training process focused on the calibration of the observer team and reliability in the observers' detection and analysis of error events.

Measures. The observational methodology provided both qualitative and quantitative data. Observers provided a written narrative of each error event, and also utilised a structured coding technique that enabled quantitative analysis of a range of error-related variables. The original coding framework used by the observers was subsequently expanded through *post hoc* analysis of the written narratives of each error event. The following key error-related variables were then utilised in the analysis:

Table One: Variables coding error occurrence and management during normal operations.

ERROR OCCURRENCE	ERROR MANAGEMENT
• Error Origin	• Error Detection
• Error Type	• Error Detection Process
• Phase of Flight	• Error Response
• Operational Risk	• Error Outcome

Results

During the 102 sectors of normal flight operations observed in this study, a total of 246 errors were recorded, representing a mean error rate of 2.41 errors per flight. Errors were distributed across both crew members and between Pilot Flying (PF) and Pilot Not Flying (PNF), with no significant difference in error rates between the Captain and the First Officer.

Errors were most frequent during the descent-approach-landing phase of flight (42.7%), and the most common type of error involved unintentional deviations from normal operating procedures (68.7%). These findings are in line with a range of published data from normal line operations (Klinect et al., 1999). A summary of error occurrence is provided in Table Two.

Table Two: A summary of error occurrence during normal operations.

ERROR OCCURRENCE			
Error Origin	Frequency	**Phase of Flight**	Frequency
Captain	41.1	Pre-departure	13.4
First Officer	45.5	Take-off and Climb	18.7
Both Crew	13.4	Cruise	16.3
		Descent – Approach - Landing	42.7
Error Type	Frequency	Taxi-in	8.9
Intentional Non-Compliance	8.1		
Procedural	68.7	**Operational Risk**	Frequency
Communication	7.7	None	4.1
Proficiency	11.0	Low	23.6
Decision-Making	4.5	Medium	43.9
		High	28.5

Frequency expressed as a percentage of errors observed (n = 246).

It was found that less than half the errors committed by crews were actually detected, with a total of 56.9% of all errors remaining undetected by the crew. This finding suggests that error detection does in fact form a significant weakness in error management strategies during normal flight operations. A summary of Error Management strategies, and in particular Error Detection Processes is provided in Table Three.

Table Three: A summary of error management during normal operations.

ERROR MANAGEMENT			
Error Detection	Frequency	**Error Detection Process**	Frequency
Captain	26.0	Aircraft Warning System	4.5
First Officer	10.2	Aircraft Status or Performance	2.4
Other	6.9	Cross-Check (monitoring other crew)	23.6
Nobody	56.9	Scan (self-monitoring)	9.3
		Checklist	0.8
Error Response	Frequency	Other	2.4
Detect + Manage	38.6	None	56.9
Detect + Mismanage	2.4	**Error Outcome**	Frequency
Detect + Ignore	2.0	Inconsequential	94.7
Fail to Detect	56.9	Undesired Aircraft State	2.0
		Additional Error	3.3

Frequency expressed as a percentage of errors observed (n = 246).

As illustrated in Table Three, Captains were more effective in error detection than First-Officers, detecting on average twice as many errors. This finding highlights the potential role of experience in effective error detection, and suggests an essential component of the command role relates to error detection processes. Also of note is the relatively low frequency with which errors were seen as having potential safety-related consequence. Only 3.3% of errors led to an additional error, and only 2.0% of errors led to an undesired aircraft state. This highlights the overall frequency of relatively minor and inconsequential error occurrence during normal line operations.

Further analysis of the error detection processes revealed that significant differences existed between the various error detection processes at play in normal flight operations, $\chi^2(6, N=246) = 428.11$, $p < .001$. Cross-checking and monitoring of the other crew-member's actions was the most frequently observed error detection process. This finding supports previous, largely anecdotal, evidence that the inter-person monitoring function is a core component of successful error management. However, while 38.4% of the errors committed by First Officers were detected by the monitoring activities of Captains, only

14.9% of Captains' errors were detected by monitoring activities of First Officers. This difference in the relative influence of error detection through monitoring function might be accounted for by the relative influence of expertise and authority on the flight deck, with First Officers potentially less inclined to alert more senior crew-members to their errors.

In contrast to the relatively high rates of error detection through monitoring and cross-checking functions, the detection of error by the pilot who committed the error occurred in less than one tenth of all instances of error. This finding reveals an inherent weakness in the naturalistic error management processes utilised during normal flight operations, and highlights an area that should benefit from safety-related intervention. On further analysis, it was evident that Captains out-performed First Officers in relation to the detection of their own errors, with Captains detection 15.8% of their own errors, compared to First Officers detecting only 6.3% of their own errors.

Of the other components of error detection, relatively few errors were detected by systemic defences such as aircraft warning systems (4.5% of errors), and checklists (0.8% of errors). This finding however does not reflect negatively on the role of such systemic defences in the overall of the high-risk system of commercial aviation. Rather, this finding indicates that these systems operate as important defences against a small set of significant errors, whereas the remainder rely on human detection mechanisms.

Discussion and Conclusions

This study has provided a systematic analysis of error detection processes in normal flight operations within the commercial aviation setting. The results of this study reinforce the perspective that a significant proportion of errors remain undetected during normal operations and emphasises the area of *error detection* as an ongoing weakness in the defences provided by error management.

With reference to the errors that were detected, the result of this study suggest that error detection is more easily accomplished by the crew-member who was not responsible for the error. Accordingly, this study emphasises the importance of crew cooperation in the multi-crew environment and highlights the essential role of monitoring and cross-checking in maintaining safety. The study highlights also that while only a small proportion of errors were first detected by Aircraft Warning Systems and through the use of Checklists, these mechanisms still must play an important final system defence against undetected errors.

The results presented in this study provide an important empirical dimension to the development of error management training programs, and emphasise areas for training intervention. The results of this study indicate that error management training programs should work to strengthen error detection strategies involving the monitoring and cross-checking of the other crew-member's actions in the multi-crew environment. Moreover, the further analysis and development of self-monitoring strategies in order to increase the proportion of errors detected by the individual operator who created the error should be investigated. It is suggested that training interventions which emphasise a range of metacognitive strategies for error detection are developed and empirically evaluated.

Metacogniton coordinates the processes underlying cognitive monitoring and cognitive control and also refers to an individual's knowledge about their own cognition (Cohen, Freeman, & Wolf, 1996; Croskerry, 2003; Fernandez-Duque, Baird, & Posner, 2000). Accordingly, metacognitive strategies play an important role in attentional processes such as error detection (Croskerry, 2003; Fernandez-Duque et al., 2000). Consequently, it appears reasonable to assume that error detection may be improved by enhancing pilots' metacognitive skills. Specifically, training programs may first aim to strengthen pilots' metacognitive abilities that underlie the classifying, checking, evaluating, and anticipation of errors made by themselves and other crew-members. Second, training programs may aim to enhance the metacognitive skills that classify, check, evaluate, and anticipate pilots' own cognitive strategies that underpin error detection processes.

Notably, an error management course incorporating metacognitive strategies has recently been developed for emergency medicine personnel (see Croskerry, 2003), but has not yet been trialled in the medical workplace. Evidently, this course appears to focus on the metacognitive skills that are related to diagnostic processes and decision-making, yet does not focus on skills relating to the detection of the more frequent forms of error such as slips and lapses. In response to these developments, our laboratory is developing a "gold-standard" error management training course for the aviation industry that includes the training of metacognitive strategies. Our aim is to validate this training package in several aviation organisations in the near future.

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