Error Management Training

An investigation of expert pilots' error management strategies during normal operations and flight crew training

Study One: Interview Study to identify Error Management practices in experienced Training Captains.

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EXECUTIVE SUMMARY

Human error remains a significant causal factor in the majority of aviation incidents and accidents. In response to the ubiquity of human error, it has been suggested that a key to maintaining safety in high-risk industries lies in the development of specific error management training programs. However, we are still some way from defining best practice in error management training.

The study for which the results are presented in this report sought to investigate the wide range of individual expertise with respect to the management of errors during normal flight operations, and the development of error management skills in the training environment.

The study adopted an interview-based approach to the investigation of the core components of effective error management, and error management training within the commercial aviation environment. As an explicit objective of the study was to collect data with respect to the tacit knowledge of domain experts, the study was designed within an interpretive framework. Participants were volunteer pilots who each had significant instructional experience, and who were currently working, or had recently worked, in Training and Checking roles within the commercial airline environment. A total of 14 experienced aviators (instructors, check captains, and training captains) were recruited for the study.

The interview data provides a range of insights into the processes of error management employed by expert pilots. Error avoidance is the first stage in error management, and adopts the perspective that the minimisation of error is a critical first step in enhancing safety in normal operations. While it is accepted that the task of eliminating human error is an impossible goal, there are certainly a wide range of techniques that can be employed to avoid, and thus reduce the occurrence, of error. Fourteen components of error avoidance were identified from the analysis of interview data, which have been grouped under four broad categories:

Situation Awareness
- Attention, Vigilance and Comprehension
- Pre-action attention
- Self-Monitoring

Multi-Crew functions
- Monitoring other crewmember(s)
- Communication
- Teamwork and Support

Task Management
- Avoidance of Error Producing Conditions
- Active dependence on Standard Operating Procedures
- Planning and Preparation
- Gates
- Deliberate and Systematic Decision-Making
- Review and Evaluation

Attitudinal Factors
- Conservatism
- Diligence

Error detection mechanisms were found to share much in common with the strategies identified above for error avoidance, as effective error detection depends to a large degree on maintaining situation awareness. However, aside from a focus on situation awareness, the interview data suggests that effective error detection also includes a range of multi-crew coordination factors, as well as unique attitudinal factors. A total of nine components of error detection were identified, under three broad categories.

Situation Awareness

- Maintaining a Mental Model of the Flight
- Monitoring: Scan and Systematic Check
- Detecting Divergence
- Self-monitoring

Multi-Crew Functions

- Monitoring and Cross Checking of other crewmember(s)
- Familiarity with other crewmember(s)
- Communication

Attitudinal Factors

- Expectation of Error
- Comfort Levels and Intuition

Error response is the third phase of error management, and involves the rectification of the error, or the resolution of any problem-state caused by an error. Once the error has been detected, this process should present few problems for the crew who has regained situation awareness. The following discussion highlights areas in which error response can be managed in order to create efficiencies in the error management process and enhance the safety of normal flight operations. From the interview data, a total of nine components of error response were identified under four broad categories:

Situation Awareness

- Information Gathering and Problem Diagnosis
- Projection into the Future and Identification of Alternatives

Task Management

- The Maintenance of Safety
- Deliberate Decision-Making Process

Multi-Crew Functions

- Communication and Information Sharing
- Management of Error Response
- Workload Management

Attitudinal Factors

- Acceptance of Error
- Avoidance of Rumination

Error management training refers to the structured development of error management skills in the training environment. A critical premise for error management training is that it should not form a separate element of a training curriculum, but rather elements of error management training should be integrated into ground, simulator and line training, as well as inform aspects of ongoing development of expertise in already experienced pilots. Data from the interviews highlighted eight core components of error management training grouped under three broad categories.

Experiential Factors

- Exposure to Error Producing Conditions
- Exposure to Errors and Problem States
- Structured "Hands-On" Training in Error Management and Solutions

Attitudinal Factors

- Understanding Cause and Effect
- Development of Confidence
- Development of Self-Analysis Skills

Debriefing

- Choice of Error-Events to Debrief
- Focus of Error-Event Debrief

This study provides a detailed account of error management, through the analysis of experts' understanding of error avoidance, detection and resolution. From the results of this study, it is evident that elements of error management share much in common with our current understanding of Crew Resource Management (CRM). Aspects such as situation awareness, task management and communication are all common elements of CRM programs in modern airlines. However, this study provides specific new detail with respect to the actual cognitive processes of error management that we commonly group together under such categories as situation awareness. Moreover, the results of this study place significant emphasis on *metacognitive* processes that underlie the more evident cognitive, affective and interpersonal components of error management. The findings of this study reinforce a model of error management that emphasises the process of mismatch emergence as the driver of error detection, problem identification and error resolution.

This study also provides a wide range of perspectives that in turn can inform a comprehensive curriculum structure for error management training. The study highlights three important new developments for error management training: 1) the need to focus more on cognitive skill development and the affective domain; 2) the need to integrate technical and non-technical skill development; and 3) the need to increase the experiential components of error management training.

CONTENTS

1 INTRODUCTION

1.1 Research Context

Human Error remains a significant causal factor in the majority of aviation incidents and accidents. In response to the ubiquity of human error, it has been suggested that a key to maintaining safety in high risk industries lies in the development of specific error management training programs. However, we are still some way from defining best practice in error management training.

Due to the lack of a strong scientific foundation to the design and specification of Error management training programs, a major research project has been initiated in order to provide an empirical foundation for error management training programs in the commercial aviation setting. The primary objective of this research project is to provide the Australian aviation industry with a concrete training package for error management training for flight crew.

In order to achieve this objective, two studies at the University of South Australia were funded by the Commonwealth of Australia through the Department of Transport and Regional Services on behalf of the Australian Transport Safety Bureau. This report presents the findings from Study One: Interview Study to identify Error Management practices in experienced Training Captains.

The study for which the results are presented in this report sought to investigate the wide range of individual expertise with respect to the management of errors during normal flight operations, and the development of error management skills in the training environment. A fundamental premise of this study was that individual experts, in the form of experienced Training Captains, would have developed over the course of their careers considerable knowledge and skill with respect to error management. However, it was assumed that the majority of this knowledge and skill would be largely tacit in nature. Furthermore, as the focus on error management is relatively new, there have been few, if any, empirical studies that have sought to systematically investigate, unpack and document this tacit expertise with respect to error management. Accordingly, the investigation of this tacit knowledge was taken to be a critical first step in providing an empirical foundation for error management training programs in commercial aviation.

1.2 Background

The safe actions and satisfactory performance of personnel are essential aspects of maintaining safety across all sectors of the aviation industry. Accepted models of accident trajectory typically include both active failures of personnel and systems, as well as latent conditions which may lie dormant in an organisations' operational system for considerable time (Reason, 1990). Closely aligned to the concept of active failures and latent conditions and are the terms error and threat respectively, concepts which have recently been the focus of considerable research in the commercial aviation setting.

The diagram presented in Figure One outlines a model of accident trajectory. Human error, as described by the term “unsafe acts” is implicated as the final element in accident trajectory. While human error is seen as the most “immediate” contributing factor to accident occurrence, the model emphasises the role of error-producing conditions and the organisational processes which promote error occurrence as essential foci for investigation.

Operational personnel act as the last line of defence in complex operational environments (Reason, 1997). Safety is often maintained through the actions of individuals “at the coal-face” through their response to complex and sometimes ill-defined problems. Accordingly, the management of threat and error has been suggested to be a necessary focus of any organisation's attempts to effectively maintain safety in high-risk operations (Klinect, Wilhelm, & Helmreich, 1999). Furthermore, human error is now accepted as a natural part of everyday performance, and can occur both spontaneously or can be precipitated by a variety of environmental and personal factors such as individual proficiency, workload, fatigue, and team-dynamics.

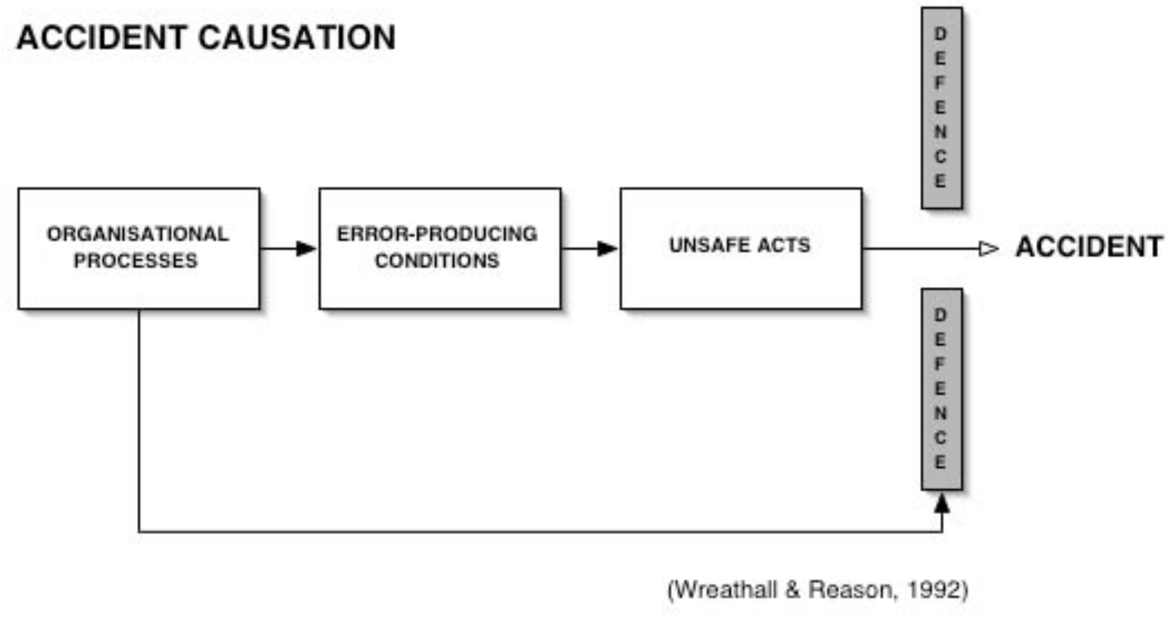

Figure One: A Model of Accident Causation

As Helmreich (2000) suggests, given the ubiquity of human error, and the wide range of factors which promote error, a key to safety lies in effective error management by operational personnel. In response to the increasing sophistication in our understanding of the role of error management in enhancing operational performance and safety, error management training programs are becoming innovative new elements of many airline's training systems (Phillips, 2000). However, recent research has highlighted a number of challenges facing effective error management training programs. Thomas (2003), in a study of Line Training in the commercial airline setting, highlights the difficulties associated with the effective detection of error events during training, and the lack of instructor debrief and analysis of errors as they occur. Current error management training practices lack large-scale empirical investigation, and existing evidence suggests that they may require considerable refinement and improvement.

Indeed, the continued findings of low levels of error detection during audits of normal operations suggest that error management training is an area requiring urgent investigation. This project seeks to investigate effective strategies for error management training.

1.3 Error Occurrence in Normal Flight Operations

Considerable research has demonstrated that there is a consistent and systematic underlying rate of error during normal flight operations. Error is both a natural element of human performance, and even the most highly trained, skilled and experienced operators naturally and frequently make errors. New observational audit methodologies, such as the Line Operations Safety Audit (LOSA) have demonstrated that crews make on average between one and five errors per flight sector (Klinect, 2002). The vast majority of errors are inconsequential within the environment of commercial airline operations, given the multi-layered systemic safety defences employed within this high-risk environment. However, it has also been demonstrated through the systematic observational analysis of normal operations that up to half of the errors committed by crews remain undetected (Thomas, 2004; Thomas, Petrilli, & Dawson, 2004)

Considerable existing research examining the general occurrence of human error across a wide range of everyday and work environments has informed systems for the classification of error. Through the classification of error, we risk creating an illusion of understanding the causal factors involved through a simplistic process of re-labelling and grouping similar types of error. However, it is possible to build effective mechanisms for safety-related change through analyses of error that de-emphasise the construction of cause and focus on the identification of patterns in error occurrence. These "genotypical mechanisms of failure" elucidate the means by which operators create safety in practice, and map universal patterns of safety breakdown (Dekker, 2003).

1.3.1 Errors in Planning and Errors in Execution

The most common system for the classification for errors involves the differentiation between errors committed in the planning of actions, and errors committed in the execution of actions.

The term *mistake* is used to describe the errors that occur in the planning of actions and involve errors where the plan for specific action is deficient or fundamentally flawed. In this instance, an operator might execute a plan of action flawlessly, but not achieve the desired outcome due to an inherent problem with the plan of action itself. As Reason (1990) suggests, mistakes frequently occur through the failures of higher-order cognitive processes involved in judging the available information, setting objectives, and deciding on the means to achieve a desired outcome. This type of error relates directly to Rasmussen's (1986) knowledge-based behaviours, which involve conscious reasoning during problem-solving activities. Accordingly, these errors are frequently referred to as *knowledge-based mistakes*.

However, mistakes are frequently also observed with respect to less conscious or deliberate planning processes. Termed *rule-based mistakes*, these forms of error involve the incorrect initiation of actions in response to existing behavioural routines. Frequently, rule-based mistakes involve an automatic response to misdiagnosed problem, or the automatic misdiagnosis of a situation. Rule-based mistakes occur through the interference of biases or quasi-automatic intervention of more familiar rules, and can occur in relation to both the identification of a situation and the selection of action (Rizzo, Ferrante, & Bagnara, 1995).

Similarly, two broad types of error can be categorised at the execution stage. Firstly, *slips* involve unintentional actions or active failures in the execution of a plan. In these situations, the intended action is appropriate, but due to low level attentional failures in highly practiced and automatic behaviours, incorrect action is executed (Norman, 1981). For instance, simple errors in psychomotor performance such as moving a lever forward instead of backward typify slips.

Secondly, *lapses* are defined as errors that occur as a result of memory failures, and most frequently involve forgetting a procedural step or planned action. For instance, a task, or individual task step, is omitted through a failure in memory processes. Again, it has been suggested that attentional failures, or diversion of attention through distraction, are important mechanisms in the production of lapses.

1.3.2 Unintentional Errors, Violations and Unsafe Acts

A fundamental problem facing the construction of a robust classification system for error involves the distinction between unintentional errors and the wilful deviation from rules, procedures or regulations. The most strict use of the term error does not include the notions of violations, intentional non-compliance or wilful deviations. By definition, error is unintentional and does not include actions in which the operator has consciously and deliberately chosen to deviate from required practise.

However, frequently the outcome of both an unintentional error and a violation are the same, and at both can have the same negative impact on safety. For instance, either a lapse in concentration or the intentional disregard for a speed restriction can lead a car travelling more than 10kms above the sign-posted limit. In the majority of cases, the law does not differentiate between unintentional error and the violation, with both actions leading to a speeding fine.

In order to adequately capture both the intentional and the unintentional types of human error, Reason (1997) uses the term *unsafe acts* to describe both errors and violations. Unsafe acts describe a wide variety of human behaviours and include both unintentional errors and intentional acts of non-compliance with policies, procedures or regulations. The figure below provides a detailed diagrammatic representation of the classification of errors in relation to unintended and intended actions.

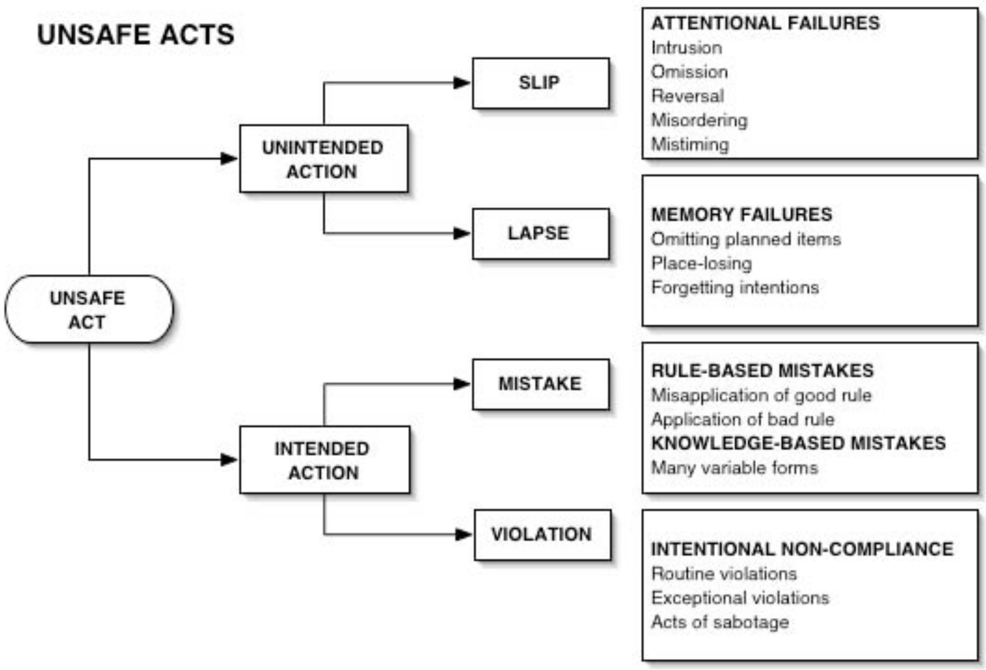

Figure Two: Classification of Unsafe Acts (Reason 1990).

1.4 Error Management – Fundamentals and Current Knowledge

As Wreathall and Reason (1992) have put so elegantly, "the history of accidents and their analysis is also the history of human contribution to accidents". Illustrated in Figure One above, it is the unsafe acts of human operators that are often primary factors in accident causation. However, rather than treating the variety of error events, captured by the term "unsafe acts", as aberrant mental processes which need to be eradicated, it has become accepted that systems-based approaches to human error management offer the greatest potential from the perspective of safety management in high risk industries. The systems-based approaches to error management employ countermeasures that are based on the assumption that though we cannot change the human condition, we can change the conditions under which humans work. Expanding this perspective, error management has two components: 1) limiting the incidence of dangerous errors; and 2) creating systems that are better able to tolerate the occurrence of errors and contain their damaging effects (Reason, 2000).

While systemic defences are essential in the containment of inevitable error occurrences during normal flight operations, the systems-based approach must also be complemented by components of error management which focus explicitly on the management of error at the level of the individual operator and the specific team environment in which they operate. With respect to the normal flight operations in the commercial airline environment, this relates to the management of error by the operating crew within the flight deck environment.

Researchers at the University of Texas have developed a model of Threat and Error Management that provides a broad functional structure for error management processes during normal flight operations (Helmreich, Klinect, & Wilhelm, 1999). This model provides a basic descriptive framework for the occurrence, management and outcome of errors during normal flight operations. As described in Figure Two, errors can occur spontaneously, or as a result of poor threat management. Within the model, "threat" can be defined as a situation or event that has the potential to impact negatively on the safety of a flight. In relation to the existing literature on error occurrence, these "threats" are typical error producing conditions.

In turn, errors are defined as crew action, or inaction, that leads to a deviation from crew, organisational or regulatory intentions or regulations. The full Threat and Error Management Model is described in Figure Three.

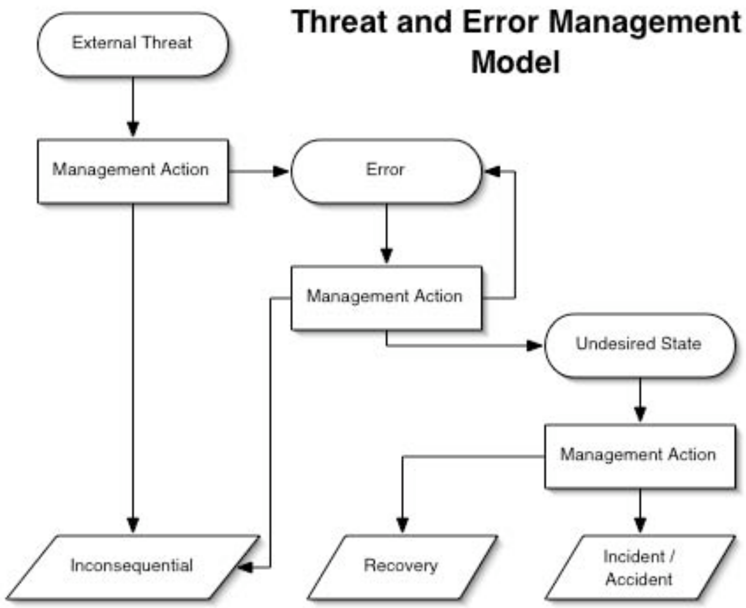

Figure Three: The University of Texas' Threat and Error Management Model.

According to the Threat and Error Management model, error management has two critical components: 1) error detection; and 2) error response. Error detection simply involves being aware that an error has occurred. Error response involves the actions crew-members take in order to rectify or mitigate the error once it has been detected. This model provides an intuitive framework for the analysis of unsafe events during normal system operation, and has been seen to possess high levels of explanatory value, utility and ecological validity through numerous real-world applications. However, while this model provides an effective descriptive framework for the observation of error in real-world environments, more detail is required in relation to the individual processes that give rise to effective error management.

Strategies for error management 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, significantly more detail is required if we are to adequately understand the processes for error management during normal flight operations. This task is imperative if we are to produce error management training programs that are based upon a foundation of empirical research and as such are scientifically defensible.

2 METHOD

2.1 Participants

Participants were volunteer pilots who each had significant instructional experience, and who were currently working, or had recently worked, in Training and Checking roles within the commercial airline environment. Volunteers were recruited using an information sheet for the study, which was distributed through both formal and informal networks of airline Check and Training pilots.

A total of 14 experienced aviators (instructors, check captains, and training captains) were recruited for the study. Demographic details of participants were collected using a short questionnaire, a copy of which is provided as Appendix One. All participants were male and were aged between 35 and 64 years. In total, participants had between 6000-17000 flight hours experience in both civilian and military aircraft (M= 10918.27; SD= 3855.85), with 1-15 years in long haul aircraft (M= 5.96; SD= 4.71), and 2-31 years in short haul aircraft (M= 13.73; SD= 10.04). In a training role, participants had 1.5-35 years of experience (M= 11.17; SD= 8.98).

2.2 Design and Procedure

The study adopted an interview-based approach to the investigation of the core components of effective error management, and error management training within the commercial aviation environment. As an explicit objective of the study was to collect data with respect to the tacit knowledge of domain experts, the study was designed within an interpretive framework.

Interview-based studies have historically been shown to provide an excellent approach to the initial exploration of ill-defined knowledge domains, and provide an opportunity for exploration of new areas for investigation in substantial depth.

The study utilised an adapted form of the Critical Decision Method, which is a well established cognitive interview technique (Klein, Calderwood, & MacGregor, 1989). The Critical Decision Method involves a semi-structured interview of experienced personnel and is designed to efficiently gather data on the bases of the proficient performance of complex tasks. Specifically, the Critical Decision Method is utilised to identify aspects of expert performance from a cognitive perspective, and serves to highlight the frequently hidden components of expertise that underlie and drive the overt observable behaviours. Furthermore, this technique has been utilised in the process of training system specification, as a method for identifying and defining training requirements.

The Critical Decision Method, as adapted for this study, involves an interview of approximately one-hour duration for each participant. The interview protocol first involved a short questionnaire, which served three major purposes: 1) to gather data on the demographic details of participants involved in the study; 2) to introduce the participants to the major definitions of error types; and 3) stimulate participants' thinking about error occurrence and management. This short questionnaire took approximately 10 minutes to complete.

The interview proper was broken into three major sections, with the Critical Decision method being used three times to explore different aspects of the management of error in normal operations as well as training. The three sections of the interview were broadly: 1) the management of slips and lapses; 2) the management of mistakes: and 3) error management from an instructional perspective.

The Critical Decision Method, as mentioned above, is a semi-structured interview process designed to explore the cognitive foundations of expert performance. From the perspective of error management, the Critical Decision Method was adapted to probe the error management strategies utilised by expert pilots, and explore the cognitive processes involved in effective error detection and error response. Accordingly, the basic structure of the Critical Decision Method, as adapted for this study, was as follows:

1) ***Select Error Event:*** Pilots were required to select and retrieve from memory an error they had made themselves, or had witnessed, during a normal flight or in the training environment.

2) ***Elicit an Unstructured Account of the Error Event:*** Pilots were required to give an unstructured account of the error event and describe the circumstances leading up to the event.

3) ***Describe the Error Event Using a Timeline of Events:*** To assist in the elicitation of the error event, pilots were required to explain the sequence of events during error detection and error response using a timeline.

4) ***Identification of Error Causation and Specific Probing***: Pilots were asked a range of questions in regards to cause of the event. Pilots were also presented with a list of factors that may have promoted the error event:

(a) Lack of attention/distraction;
(b) Duty-time or Time on Task;
(c) High workload;
(d) Lack of training;
(e) Poor communication;
(f) Inadequate Sleep;
(g) Stress;
(h) Body-clock/Circadian;
(i) Poor procedures (SOPs);
(j) Time limitation;
(k) System design; or
(l) Unfamiliar/novel event.

5) ***Identification of Error Detection and Specific Probing:*** Pilots were asked a range of questions in regards to the error detection mechanisms used to alert them to the event. Pilots were also presented with a list of detection mechanisms that they might have used:

(a) Self-monitoring (detected own error through scan);
(b) Monitoring the other crewmember;
(c) A/C System Warning;
(d) A/C Status or Performance;
(e) Checklist; or
(f) Other.

6) ***Identification of Error Response and Specific Probing:*** Pilots were asked to explain the error response mechanisms used to manage the error event and were also asked to describe the strategies they used to consider alternative courses of action and the consequences of the error.

7) ***Identification of Critical Components of the Training Environment:*** Pilots were asked to verbalise in as much detail as possible, the error management strategies they believe are pertinent to effective operational performance and should be developed during training and normal flights. This discussion also included techniques for error management training.

A copy of the interview protocol is provided in Appendix Two. The recordings of the interviews were then subjected to detailed analysis and coding according to the strategies outlined below.

2.3 Analysis

As the objective of the study was to explore and document the error management strategies utilised by expert pilots, in order to inform the syllabus and curriculum structure of an error management training package, the analysis of interview data was undertaken with explicit reference to the interpretive research design.

Accordingly, the study did not seek to test pre-defined hypotheses or adopt any detailed quantitative analysis of data. Rather, analysis of the interview data was undertaken around three major objectives:

1) Documentation of key error management strategies;
2) Coding and analysis of emergent themes in error management; and
3) Identification of key cognitive skills underpinning effective error management.

3 RESULTS

3.1 Critical Components of Error Avoidance

Error avoidance is the first stage in error management, and adopts the perspective that the minimisation of error is a critical first step in enhancing safety in normal operations. While it is accepted that the task of eliminating human error is an impossible goal, there are certainly a wide range of techniques that can be employed to avoid, and thus reduce the occurrence, of error. Fourteen components of error avoidance were identified from the analysis of interview data, which have been grouped under four broad categories:

3.1.1 Situation Awareness

The ability of crews to notice and comprehend events during operations, and project the current situation into the future was found to be an essential component of error management. In relation to error avoidance, a number of sub-elements of situation awareness were identified as critical.

1) Attention, Vigilance and Comprehension

Definition: Crewmembers' ability to notice and comprehend events on the entire flight deck and ability to project the events into the future.

The first, and most basic, element of situation awareness involves the primary functions of maintaining attention throughout the operation, and understanding the ramifications of the current situation and all planned actions.

Simply paying attention at all times, and remaining vigilant throughout the operation, are both critical to error avoidance. The data highlighted that errors frequently occurred through lack of attention and not thinking sufficiently about actions during the flight.

Another critical component of situation awareness is remaining vigilant to situations in which errors frequently occur, and where situational demands increase the likelihood of error occurrence. Already highlighted in the literature as important in error management, this aspect of situation awareness involves being aware of "areas of vulnerability" (Sumwalt, Thomas, & Dismukes, 2002). For the participants in this study, experience played an important role in the identification of areas of vulnerability, and providing cues to situations in which situation awareness was critical. As one participant stated in relation to areas of vulnerability:

> *You have to be doubly aware of what could occur…we've got to be doubly careful…*

Experience and expertise play a significant role in the ability of a crewmember to comprehend the current situation and project that situation into the future. Being able to relate current events to past experiences, and the understanding of the consequences of events were both highlighted in the data as important aspects of situation awareness.

2) Pre-Action Attention

Definition: Directing attention to actions prior to, and during, the performance of the action.

A number of participants indicated that a critical component of error avoidance was performing a "pre-action check", or ensuring that actions have been completed exactly as intended. The literature on error occurrence highlights the propensity for errors to occur during highly automated tasks, typically employed by experts operating in familiar and repetitive environments (Reason, 1990). Accordingly, pre-action attention plays a critical role in error avoidance.

> *I think that I try to develop good habits based on little mental joggers I suppose… one that I do, as an example, is part of the after start drills is normally to turn the APU off but I have trained myself that whenever I reach for the APU switch I think about, do we need it off or on. I don't just do it as part of the drill and go.*

The conscious and deliberate check on planned actions is already embedded procedurally into various aspects of airline operation, typified through the cross-check of FMC inputs prior to execution. Similarly, an informal version of this process is embedded in the mnemonic of "Identify-Confirm-Select", which has been designed to force a pre-action check, and increase the conscious attention being applied to automatised tasks.

From a cognitive perspective, pre-action attention involves bringing automatised tasks momentarily into the conscious workspace for a mental cross-check against the "map" or "model" of the particular task, to ensure that actions are being executed as planned. Accordingly, this technique serves as an important part of error avoidance.

3) Self-Monitoring

Definition: Crewmembers' ability to monitor their own performance and determine when they themselves are not entirely comfortable or cognisant with the situation or sequence of events.

The process of self-monitoring involves awareness of one's own performance, and the ability to detect when there is a degradation in performance, or a degradation in mental state though such factors as task overload or distraction.

Self-monitoring is a metacognitive activity. That is to say, it involves conscious awareness of one's own mental state. To this end, metacognition is an essential element of being able to detect adverse mental states such as distraction, lack of attention, or rushing, which are frequently highlighted as error producing conditions.

The notion of awareness of one's own limits and abilities emerged as an important aspect of self-monitoring. A number of participants referred to personal "gates" or a "comfort-zone" of safe performance.

> *It gets back to that feeling of being out of your comfort zone, I think if you start to feel out of your comfort zone, something is causing it and you need to just assess what it is and I suppose that's the same with distraction, you know, you suddenly feel that your being rushed or that you're forgetting something and when you feel that you need to sit back, and just take stock…*

Another critical process involved in self-monitoring is the detection of self disengagement from the task or situation. Often referred to using terms such as "getting behind the aircraft" or "zoning out", self-disengagement can have a wide variety of genotypes, including a lack of experience or external factors such as personal stress. However, self disengagement from the task or situation is an important trigger for loss of situation awareness, and thus subsequent error. The ability to detect the onset of self disengagement, or loss of situation awareness, is therefore a crucial aspect of error avoidance.

Discussions with the expert Training Captains during the study suggested that effective self monitoring was dependant on sufficient cognitive resources remaining available for this metacognitive task. Periods of high-workload or distraction not only increase the likelihood of loss of situation awareness, but also decrease the cognitive resources available for self-monitoring. This "double-edged sword" presents a complex problem for error management training. However, it is likely that the identification of key cues to self disengagement is a metacognitive technique which could enable advances in error avoidance during normal line operations.

3.1.2 Multi-Crew Functions

When operating in a multi-crew environment, the maintenance of shared situation awareness, and the development of a cohesive operational plan is critical in maintaining safety and avoiding errors. A number of multi-crew functions support this objective.

4) Monitoring the Other Crewmember(s)

Definition: Crewmembers' ability to monitor the performance of the other crewmember(s) and determine when they are not entirely comfortable or cognisant with the situation or sequence of events.

Monitoring the other crewmember(s) on the flight-deck was highlighted in the interviews as another essential element of error avoidance. The simple monitoring of the other crewmember serves a dual function of both an error avoidance and error detection strategy:

> *I do it discretely I think, and I would hope they do the same to me, that's what team work is about but yeah, just be careful in areas where you know the pitfalls are when you ask them to do something…when you're asking for critical systems to be switched or changed, have a quick glance to make sure they are reaching for the right one… monitor their actions.*

The detection of circumstances when the other crewmember is on the verge of disengagement from the current task is an important cue for loss of situation awareness. Several participants indicated the role of communication and direct questioning in establishing potential loss of situation awareness in the other crewmember:

> *I'll ask them, I'll say you know "penny for your thoughts", "what are you doing?", "what's your plan of attack?"…you know "how you going?". You generally get a bit of a look, like if they look like a rabbit in the headlights…like you know, they're just sitting there hanging onto the thing, going "OK, now its taken me for a ride…"*

As errors are frequently caused through loss of situation awareness, or through the negative impacts of task overload and distraction, the recognition of these cognitive precursors to error in the other crewmember(s) provides an important facet to error avoidance.

5) Communication

Definition: The effective flow of information between all crewmembers to ensure that situation awareness is shared, plans clearly articulated, and any concerns voiced in a timely manner.

An open flow of information within the multi-crew environment is critical to maintaining shared situation awareness. Communication plays a vital role in a range of safety critical error avoidance processes such as planning, decision-making, and workload sharing.

Furthermore, as a mechanism to detect the potentially unsafe progression of a flight, and avoid the occurrence of error, the timely voicing of any concerns is essential. The interviews highlighted that one of the difficulties in this task is being able to elicit information as to another crewmember(s) actions or intentions without conveying a sense of criticism, questioning their abilities, nor second-guessing their judgement. Diplomacy and interpersonal skills were reinforced as important aspects in maintaining the open flow of communication within the multi-crew environment.

6) Teamwork and Support

Definition: The support of the other crewmember through delegation and sharing of workload, as well as specific support duties such as flightpath monitoring and proceduralised callouts.

Participants highlighted the role of workload delegation in error avoidance, especially during times when the pilot flying might be working close to cognitive capacity due to demanding flying conditions. The ability for one crew-member to reserve some cognitive capacity for maintaining both the monitoring of the other crew-member(s) actions, as well as retaining a "big picture" perspective of the safety of the whole flight operation appears to be another essential component of effective error avoidance.

Support calls such as those made prior to reaching an assigned altitude form important aspects of error avoidance. For example, one participant described the development of support and monitoring functions put in place to avoid altitude deviations:

> *So what we did, we had an altitude alert, a manual one, which you put in yourself, and the emphasis was on crew training in that type of aircraft to be painfully aware that you are not going to be alerted to the fact that you had 1000 feet to go, and that the non-flying pilot had to be very careful that you had "1000 foot to go" callouts. And we also added "500 feet to level" as well. It was a change in training and in procedures.*

These multi-crew processes provide the opportunity to utilise the frequently lower workload of the pilot not flying in essential backup monitoring functions.

3.1.3 Task Management

Elements of task management form important aspects of error avoidance. While Standard Operating Procedures provide a generic framework for task management, other less proceduralised elements were found to contribute to the goal of error avoidance.

7) Avoidance of Error Producing Conditions

Definition: Crewmembers should remain vigilant for error producing conditions such as overload and distraction, and be adaptable to changing conditions through the effective management of workload and prioritisation of tasks.

A wide range of error producing conditions are known to increase the likelihood that error will occur during normal line operations. Awareness of adverse conditions, either personal such as stress or fatigue, or environmental or operational conditions, and their consequences, forms an essential element of error avoidance. Adaptability and responsiveness of crewmembers to these error producing conditions is critical. A number of strategies were highlighted in the interviews as important aspects of error avoidance, including workload management, prioritisation of tasks, anticipation of high workload and distraction, and effective planning. As one participant explained:

> *Preplanning as much as possible, having set…points of which different things will happen, to the best of your ability try and have greater awareness of environmental conditions such as wind… anticipate a high workload due to the decreased time available.*

Building in "buffers" to increase the safety margin when error producing conditions are anticipated also forms an important element of adaptability and responsiveness:

> *Because I know speaking for myself and a lot of other guys, …guys tend to tinplate their backside a bit when they're operating back of the clock, like carry more fuel so that if they've got to make a decision, they don't have to make it straight away.*

Similarly, sticking with previously established plans, offers considerable opportunities for error avoidance when crews are aware of error producing conditions.

> *A lot guys would be reticent, for example, to do a high speed approach…they won't accept track shortening or an increase in workload, if they've already planned something out, you know, air traffic control might say, oh you know "direct to left base is available, advise"…and we go, "no we'll stick with the instrument approach, we'll stick with what we've got planned". Because, you know, we know we're possibly fatigued or we're tired so why don't we stick with Plan A. Rather than go with an un-briefed situation, try and brief along the way and pick it to pieces…*

Accordingly, the effective avoidance of error producing conditions requires *recognition* of the increased likelihood of error and *adaptation* to the changing demands of a complex operation.

8) Active Dependence on Standard Operating Procedures

Definition: Crewmembers should ensure that performance is always in line with Standard Operating Procedures and shortcuts are avoided.

The development and adherence to routines in normal operations was highlighted as playing an important role in error avoidance. While Standard Operating Procedures provide a formal framework for the completion of tasks and operation of the aircraft, they also provide protection against error occurrence through the establishment of routines within the operation.

> *Its important to do things the same way every time…these things become a routine and …if you take a short cut you generally trip yourself up.*

Standard Operating Procedures, and the routines embedded within them, provide a mechanism to defend against error though well rehearsed sequences of tasks and through well rehearsed triggers for actions.

9) Planning and Preparation

Definition: Crewmembers should ensure that plans are well thought-out and all actions are undertaken with purpose and with a clear understanding of potential consequence.

Effective planning is essential in the avoidance of error. Systematic planning and briefing allows for the evaluation of plans according to adequacy, and allows for risk management behaviours through the mental analysis of anticipated potential consequences of elements of the plan. In the multi crew environment, systematic planning and briefing also allows for the development of a coherent shared mental model of the operation:

> *It's a matter of getting people to do their briefings and their preparations in a disciplined manner so that they don't miss anything.*

The construction of clear mental models of the planned operation is an essential element of error detection and avoidance. The process of planning assists in the construction of this comprehensive mental model:

> *You need to build yourself a mental plan and give yourself acceptable buffers on each…gate or transition point, and say "well hey - my descent point that I had imagined is going to be here and I will give myself plus or minus on that one the environmental conditions and requirements, so basically it should be here". Cross checking what the computer is coming up with, so as you said yes planning out…*

10) Gates

Definition: Crewmembers should develop regular points of reference which stipulate expectations for aircraft configuration and performance against which the current, and projected, situation can be systematically checked.

The development of specific rules of thumb, that provide set parameters for aircraft configuration and performance, enable pilots to undertake systematic checks of the current situation, and project that situation into the future. These rules of thumb are frequently referred to as "gates" which define the parameters of safety through which the aircraft is expected to pass. These "gates" enable the timely detection of deviations from plans and therefore play an important role in both the avoidance and detection of error.

> *Most of us have our own little gates where you want the aircraft to be, and I use "gates"…for example if he's not slowing down and taking the first stage of Flap about 15 miles I start thinking to myself "now does this guy know what he's doing?" and then the prompting will start or the questioning: "how do you think the profile is looking?". He says "Oh yeah - Flap 1" and straight away you can stop it…*

These "gates" can be used to monitor one's own performance, as well as the performance of the other crewmember(s).

11) Deliberate and Systematic Decision-Making

Definition: Crewmembers should ensure that decisions are made in a timely yet methodical manner such that each stage of the decision-making process is reviewed and evaluated.

A deliberate and methodical process to decision making defends against the occurrence of error when circumstances demand that operational decisions are made to guide the actions of the flight crew. A deliberate decision-making mnemonic such as

GRADE (gather, review, analyse, decide, evaluate) builds defences against rushed and ill-considered decision-making.

> *For some people…(who make) errors of their own propensity to rush a little bit, something like GRADE can be very good for them, because when they sort of start feeling that urge to do something they have this alarm bell that goes off... slows them down…and gives them a mechanism or a formula for, not just slowing down, but then something that they can work with to solve the problem.*

However, in some circumstances, a decision must be made in a timely manner, and the "luxury" of interactive analysis of various decision options must be undertaken under considerable time pressure. Interviewees indicated that decision making was best without the constraints of time pressure, and that decisions made quickly were frequently sub-optimal.

> *A slower decision making process…more consideration of the pro's and con's of going each way, more thought…I may have been able to change my mind. I could have perhaps communicated better with the co-pilot…you know if the time pressures aren't there you might have been able to have a committee meeting to decide, make a decision…*

In these circumstances, when decisions are made under considerable time pressure, the ongoing monitoring of the outcomes or consequences of the decision must be undertaken, to ensure that the actual decision made was optimal and not flawed.

12) Review and Evaluation

Definition: Prior to, during, and after implementation, decisions should be reviewed and evaluated such that potentially erroneous decisions can be modified or discarded.

Another critical component of error avoidance involves the monitoring and review of decisions prior to, during, and after implementation of actions. The ability to play out the consequences of actions in the mind, consideration of a range of options and double-checking elements of the decision were highlighted as important defences against error.

> *I guess make sure that people continually review the consequences of their decision. Training them to continually evaluate…(being able to) change your mind, don't lock yourself into a decision…*

Especially when decisions are made under time pressure, the ongoing monitoring of the consequences of the decision, and the flexibility to review and possibly modify the decision are critical in error avoidance.

3.1.4 Attitudinal Factors

Attitudinal factors are elements of the affective domain, which, in contrast to the cognitive (thinking) and psychomotor (action) domains, present a less well-understood element of everyday operational performance and expertise. It is however, well accepted that affective components are primary drivers of performance. This is to say, our attitudes and values are important mediators of performance. It was evident from the interviews that this is certainly the case with respect to error management.

13) Conservatism

Definition: Crewmembers should assume the worst and be conservative in their decision-making.

Another critical element in error avoidance involves a conservative approach to operations. While the commercial imperatives of airline operations demand on time performance and efficiency in aircraft operation, a conservative approach to the management of normal operations can be achieved in sympathy to commercial imperatives, and was highlighted as an important factor in error avoidance.

> *Probably anticipate the worst I guess and that's the thing…if you've configured and sort it out early is important and that's what you try and teach guys, you know you're better off being conservative rather than the other way, where you're going to get yourself into those sorts of situations.*

One important factor in this conservative approach is to assume and accept that errors will occur during everyday operations, and to ensure that safeguards are established to circumvent errors, or the consequences of these errors.

> *We all make mistakes…I really believe the secret of error management is to recognise that errors will happen. And once you've recognised that then it's much easier to say, "Hell I've stuffed up". If you believe you're not going to make mistakes then you're going to say "Hang on - There's something wrong with the aeroplane, there's something wrong". Whereas (a better approach to error management would be) "Hell that doesn't look right, maybe I've put something wrong in there"…*

14) Diligence

Definition: Crewmembers should be aware of the potential for error through rushing actions, and at all times remain patient, diligent, disciplined and pay attention to detail

A fundamental aspect of airmanship is paying attention to detail and remaining diligent through a professional approach to flight operations. This aspect of airmanship also plays a significant role in the avoidance of error.

> *I do say…don't rush your checklist - you know, that's your safety net… we've had 2 or 3 instances where the aircraft has got airborne unpressurised because the guys have missed setting the pressurisation panel before start. Missed it in the checklist, not set it correctly after start, missed it in that checklist, checked the wrong thing after take off…and its got airborne unpressurised…And they checked the wrong indicator and all other things are a lack of vigilance and discipline…Yeah, take your time…*

3.2 Critical Components of Error Detection

Error detection mechanisms share much in common with the strategies identified above for error avoidance, as effective error detection depends to a large degree on maintaining situation awareness. However, aside from a focus on situation awareness, the interview data suggests that effective error detection also includes a range of multi-crew coordination factors, as well as unique attitudinal factors. A total of nine components of error detection were identified, under three broad categories.

3.2.1 Situation Awareness

Situation awareness plays a crucial role in error management, not the least with respect to error detection. The underlying processes involved in establishing a clear mental model of the desired progress of the flight, and the maintenance of a constant vigilance in comparing the ideal state with the actual state of the flight form the fundamental components of effective error detection.

1) Maintaining a Mental Model of the Flight

Definition: Crewmembers should maintain a clear mental model of the current situation, and the desired situation in the future through careful planning.

The maintenance of a comprehensive mental model of the current status of the operation, and the future operational requirements is an essential premise upon which effective error detection is built. This mental model provides the “frame of reference” against which any deviations from plans, intentions or Standard Operating Procedures can be easily detected.

A comprehensive mental model must be dynamic in nature, constantly being updated throughout the operation in response to changing environmental and operational conditions. This dynamic mental model is built from three major factors: 1) experience and expertise; 2) planning and briefing; and 3) ongoing situation awareness and evaluation of plans. In short, an adequate mental model is critical to the effective detection of error.

2) Monitoring: Scan and Systematic Check

Definition: Crewmembers should maintain a constant scan, monitoring all aspects of the operation and systematically checking for errors.

The processes of vigilance and monitoring form a foundation to error detection. Vigilance and monitoring can be seen to occur on a number of levels. Firstly, error detection can occur through the constant maintenance of vigilance, or an ongoing scan of the workspace:

> *I do a sort of a constant scan, or I try to, just to keep a general awareness of where everything should be. If you are not doing anything, just sit back and have a look around and see if there's anything that's unusual.*

Secondly, the monitoring process can take the form of a systematic check. This process involves a conscious analysis of the work-environment, searching for the presence of an error:

> *What I do every time now is that I back up the FMC calculations with a mental descent profile calculation just to make sure that they agree.*

While both forms of monitoring are important contributors to effective error detection, the systematic check forms an important defence against potentially consequential error, and is specifically relevant for gross error detection.

3) Detecting Divergence

Definition: Crewmembers’ ability to detect a divergence from plans, or a mismatch against the mental model of the situation.

Possibly the most critical component of error detection is the ability to identify divergence from plans, or a mismatch against one’s mental model of the situation. This process brings together the mental model of the situation that has been built through a combination of expertise, planning and the establishment of “gates”, along with the process of monitoring and systematic check, such that the actual "reality" of the operation is evaluated against the ideal mental model:

> *Having a plan to start with… having an idea of what you want to do so that you can see divergence at the earliest case…*

The literature on error detection has identified a process of "mismatch emergence" whereby conflict arises between the expected state of the work system and the actual observed state of the system as the critical point in the error detection process (Rizzo et al., 1995). This process was highlighted in the interviews as critical in an operational sense:

> *You had a pretty good idea in your own mind where you would start the descent, within plus or minus 10 or 15 miles roughly at the same point in time, and we had passed that point by about that and I thought we should be coming down now or something should be happening and it wasn't. So that prompted me to look at what the aeroplane was being told to do…*

And in another situation,

> *Basically our proximity to the airport and our altitude and the fact that it was three times the profile (alerted us to the error)…it just wasn't working, we were not going down and slowing down enough… You could just see visually and also mathematically it indicated that we were getting high again.*

Through an accurate understanding of the desired conditions, status and performance of the aircraft, deviations are able to be quickly detected, errors identified and then corrected in a timely manner. The process *of mismatch emergence* need not only occur when a situational deviation is already present, but can also occur proactively through the projection of the current situation into the future, and the evaluation of the likely status, conditions and performance against the mental model for future phases of flight. For instance, through what is essentially a process of mental simulation, errors in plans can be detected prior to any actual consequence on the flight:

> *Well, I suppose that you have two people in the cockpit, and maybe one was going through the stresses that the Captain was going through, and (as the F/O) you had the chance to watch everything that was going on, and you were thinking about the consequences and the possibilities, and he had this tunnel vision about keeping the aeroplane under control, and you have the ability to be monitoring the aircraft and the fuel and everything else that goes with it…I was looking at everything and I just said "look, were going to have a fuel problem here, were not going to have enough fuel to divert", and after a quick discussion he said "yes", and he didn't hesitate and he requested direct tracking back to Sydney.*

4) Self-Monitoring

Definition: Crewmembers' ability to monitor their own performance and remain vigilant for errors in their actions or decisions throughout the flight.

In a similar way to the role of self-monitoring in error avoidance, the function of self-monitoring also plays an important role in the detection of errors. The self-monitoring process actively seeks to identify instances where adverse mental states such as distraction, overload, tunnel vision, fatigue, or loss of situation awareness might have resulted in an error. Self-monitoring provides prompts for the systematic search for error:

> *You need to make a conscious effort to go back and realize when you were taken out of the loop.*

The use of these "metacognitive prompts" to alert operators to the possibility that an error has occurred appears to be an important new form of error detection strategy that has the potential to be further developed through training intervention.

3.2.2 Multi-Crew Functions

The multi-crew environment provides enhanced opportunities for error detection. However, these opportunities are only maximised if effective multi-crew coordination is present. Previous research has identified the important role another crewmember plays in the process of error detection (Thomas et al., 2004). The interviews highlighted a range of multi-crew functions underpins enhanced error detection.

5) Monitoring and Crosschecking of Other Crewmember(s)

Definition: Crewmembers' ability to monitor the performance of the other crewmember(s) and remain vigilant for errors in their actions or decisions throughout the flight.

Monitoring, cross-check and back-up of the other crewmember(s) forms a critical component of error detection in the multi-crew environment. Two, or more, crewmembers provide important layers of defence and redundancy such that errors are more likely to be detected:

> *I would expect that as part of the course – as I always say there are two of us flying the aeroplane, I may miss a requirement going into Sydney, it is a requirement that the person who is sitting next to me tells me that I have missed it.*

The extension of an individual's scan to include the other crewmember(s) and their actions might have implications for individual workload, but is indicated as a crucial component in error detection:

> *Because I routinely look over there - it was only the fact that I was looking at what was going on his side and I thought, "****!"*

Breakdowns in these monitoring, cross-check and back-up functions are frequently implicated in instances where errors remain undetected:

> *Greater diligence in my monitoring and over seeing the FMC inputs at the time in which they were being put in (meant that the error was not detected)… I was distracted by weather and the ATC requirements at the time… but it was my role and job to cross check it and I didn't do that in the time that was required…*

A number of critical cues exist for pilots in detecting instances where errors are likely to have been committed by other crewmember(s).

> *You can usually tell by the body language…that that person is not, if you like "in the loop" or aware that something's coming up… You can get a lot from body language from people when your that close to them, its like we're just sitting here and you can tell by looking at them if they're with you or they're not.*

6) Familiarity with Other Crewmember(s)

Definition: Being familiar with the operating style of the other crewmember(s) and being able to anticipate the actions of the other crewmember(s).

The role of crew familiarity has been anecdotally, and empirically, validated as an important contributor to effective crew coordination and specifically error management. An understanding of the other crewmember(s) during a flight provides clear indication of the propensity for errors to occur during normal operations:

> *If they make that mistake and they make another one, you know that there's something not (right), they've not had enough sleep, they're worried about something, they're unusually distracted and you think you can get that from very good conscientious vigilant pilots just on a day to day basis…*

Familiarity implies an understanding of a range characteristics of the other crewmember(s) including: 1) experience and expertise; 2) operating style; 3) areas of operational strength and weakness; 4) existing stressors; 5) level of alertness or fatigue; and 6) ongoing level of task engagement, situation awareness and workload. An understanding of these factors appears to play an important role in error detection.

7) Communication

Definition: The effective flow of information between all crewmembers to ensure that any concerns are voiced in a timely manner, and any errors are identified and corrected.

The ability to voice any concerns is critical in both error avoidance and error detection. Once mismatch has emerged between the mental model of one crewmember, and the current situation of a flight, participants indicated the need to speak up, particularly if the pilot flying appears not to be concerned that a divergence from a personal "gate" or normal operational envelope has occurred. This process must be managed from the perspective of the multi-crew operation, and the need to maintain shared situation awareness. Frequently, participants indicated the use of gentle questioning to prompt for further information:

> *For example, they might be going very fast and you sort of say to them, "what's your (plan), where are you going to decelerate?"…And you can see the penny drop and they'll go "decelerate - oh ****! I hadn't thought about that"…*

Similarly, the role of information exchange is essential in error detection, as the timely sharing of information is critical in the maintenance of shared situation awareness:

> *There are two of you there, and don't be afraid of speaking up if you see something that could be potentially threatening, or help your partner with the flying. Give him as much information that you can…*

While effective communication plays a role in error detection, it is also important to note that poor communication, or indeed any form of conflict, has the opposite effect, and can in fact hinder the detection and management of error on the flight deck.

3.2.3 Attitudinal Factors

Attitudinal factors, or elements of the affective domain, again play a critical role in establishing an environment in which errors can be easily detected. The results of this study highlight two broad attitudinal bases for sound error detection.

8) Expectation of Error

Definition: Always remaining vigilant for error, and expecting that during every flight errors will occur.

The expectation that error will occur as a natural part of everyday flight operations informs a critical mindset that is prepared for, and ever watchful for, the occurrence of error. Participants highlighted that accepting that errors do, and will, occur, is a necessary precursor to error detection and then management:

> *I think, as I said before, error acceptance is one of your (critical components of error detection), in other words understand that errors will be made, don't be*

complacent… I think complacency is probably your biggest cause of errors. Just expecting that the other guy will do the right thing…or expecting that the other guy has done the right thing without checking.

It is evident from this study that the expectation of errors provides an important attitudinal foundation for error management.

9) Comfort Levels and Intuition

Definition: Being attuned to personal levels of comfort with the progress of the operation, and not dismissing intuitive indications that things might not be exactly as desired.

Little scientific credence has been given to the intuitive "feelings" of discomfort or unease that can indicate the presence of an error. However, the results of this study indicate that these intuitive indications do provide valid indicators of error:

> *Quite often one of the primary things that happens is that it doesn't feel right and the old saying "if it doesn't look right and it doesn't feel right, it's probably not right" and I say to people, you know, if you think there's something wrong there probably is something wrong so use that as a warning. If you are feeling uncomfortable, don't just think well its me, ask a question or have a look.*

From the perspective of error detection and management, these intuitive feelings provide a strong metacognitive prompt for the process of systematic check, in order to identify possible errors or potentially unsafe consequences of decisions and actions.

3.3 Critical Components of Error Response

Error response is the third phase of error management, and involves the rectification of the error, or the resolution of any problem-state caused by an error. Once the error has been detected, this process should present few problems for the crew who has regained situation awareness. The following discussion highlights areas in which error response can be managed in order to create efficiencies in the error management process and enhance the safety of normal flight operations. From the interview data, a total of nine components of error response were identified under four broad categories.

3.3.1 Situation Awareness

The overall function of situation awareness is a critical element of all aspects of error management. In relation to error response, situation awareness in the form of an accurate and comprehensive understanding of the problem-state is essential in the correct diagnosis and solution of error events.

1) Information Gathering and Problem Diagnosis

Definition: Crewmembers should systematically search for information that will assist in the correct diagnosis of the problem state.

The first essential step in error response involves the correct identification of an error, or the correct diagnosis of problem-state that may have arisen as a result of an error. In certain situations, the error or problem-state is obvious, and easily confirmed and identified. However, in other circumstances, the exact nature of the error or the resultant problem-state requires significant analysis. In these situations, information gathering and problem diagnosis activities must take place.

I looked for the cause…sometimes there are valid reasons such as the wind may be different and that means that you are going down later and that is normal, but first I went to look through what I thought was the cause of the problem which was some misprogramming of the FMC, this was my first thought particularly as the aeroplane's flight path is governed by automation at this stage, so I thought "well, what is controlling the auto flight at the moment?" which was the FMC, so I looked through there and worked out that it was misguiding the aeroplane and discovered that little issue.

In many situations, time constraints place limitations on the lengths and depth of any systematic information search in the problem identification process. In this regard, elements of prioritisation and workload management provide boundaries for the problem identification process.

Firstly I considered that it was timely and had to be rectified in a very timely fashion, in that given the time and distance to run did we have sufficient room and time and manoeuvring space to satisfy that requirement, so could I get the required delta in performance to achieve what I wanted, and I determined that we had.

It is important to note that this aspect of error management does not actually necessitate the identification of the error. Rather, this aspect of error management requires the correct identification of the problem-state and the rectification of that state in order to maintain safety. In certain situations, the exact nature, cause, or origin of the error is not needed in order to ensure that safety is maintained.

I suppose we looked at each other and went "ah!", and we looked straight up and knew exactly what had happened…and just reinstated the hydraulic pumps back on which then clears the warning we had and then actually physically looked at what I was supposed to be doing and turned off the correct switches.

However, identification of the error itself does assist in learning from the event and ensuring that the problem has been correctly diagnosed. Furthermore, as one participant highlighted, one systematic information gathering process involves working backwards from the current situation and trying to establish the cause of the problem-state, as this will assist in the resolution of the error-related situation.

2) Projection into the Future and Identification of Alternatives

Definition: Effective response to error involves identification of the potential consequences of the error or problem-state and the identification and analysis of possible solutions.

The final stage of situation awareness involves the mental projection of the current state into the future. This aspect of situation awareness forms an important element of error resolution, during which the potential consequences of the error or problem-state are investigated, and possible solutions are identified and analysed. In some instances, the solution is obvious, and requires fast and decisive action to be taken by the crew. For instance, when faced with an altitude deviation, once the crew are alerted to the error, error response is obvious:

We immediately stopped the climb, and went back down 500 feet to our level.

For the most part, the process of problem solving involves a quick analysis of viable alternatives that are readily apparent to the crew:

I figured there would be lots of paperwork if I didn't make the altitude restriction and didn't talk to somebody about it… There were two (possible) actions, one was make the aircraft perform and the other was to consult with air traffic control on an option to fix the problem…

However, in some instances, the correct diagnosis of the problem-state resulting from the error requires significant investigation. In these instances, the interview data suggests that a balance must be achieved between the maintenance of safety, and the deliberate decision-making processes involved in the resolution of the problem-state.

3.3.2 Task Management

The process of striking balance between the maintenance of safety, and the deliberate decision-making processes involved in the resolution of the error or resultant problem-state involves a number of task and workload management processes. It was evident from the interviews that effective error management depends on the appropriate prioritisation, sharing and management of operational tasks and overall workload.

3) The Maintenance of Safety

Definition: Safety remains the primary concern of error response and crewmembers should ensure that any actions taken in response to error do not impact negatively on safety.

In certain situations, the realisation of error occurs simultaneously with the realisation that safety has been significantly compromised. In these situations, the response to error must be decisive and safety-minded.

> *Well I didn't have to think hard about it because actions were automatic because we were in a very unsafe situation and it was resolved by me taking over and climbing the aircraft and we were both very comfortable with the resolution of the matter because if I hadn't done it we'd be a statistic.*

However, the majority of errors that occur during normal flight operations do not have an immediate impact on safety. It was highlighted in the interviews that errors should be managed within the parameters of Standard Operating Procedures and shortcuts should not be taken to save time in the resolution of errors. Furthermore, the primary envelope of safety must be retained in the resolution of error. For instance, the following describes how the fundamental envelope of safety is retained throughout the error resolution process.

> *Yeah, I basically tried to fix the problem as best as my experience could do, which was basically getting the aircraft configured and stabilised by the required height. Then I figured well if that doesn't work, go round and keep it safe. However we managed to salvage it.*

4) Deliberate Decision-Making Processes

Definition: Pilots should mentally walk through the problem and make decisions as necessary.

Whilst still operating within the time constraints placed on crews through operational requirements, it is ideal to adopt a deliberate and considered approach to the resolution of errors, or error-related problem-states. Rushed or hasty attempts in the rectification of error have the potential to further exacerbate any negative consequences of errors:

> *I think that the first strategy of error management is think about it, sit back, don't rush… I haven't come across anything in an aeroplane yet that will kill you in a split second except doing something drastically wrong in a split second. So take the time to think about the solution once you've detected the error.*

The study highlighted that whilst the decision-making process involved in resolving an error might not take a significant amount of time, it is imperative to explore a range of options, selecting the most appropriate option as well as recognising possible contingency plans in options which might be less desirable, yet still maintain acceptable buffers to the safety margins:

> *I've been in like foul weather and around thunderstorms and stuff before and I know to treat them with a healthy respect, you just know what your in for. I considered going into it or going around it. You know…with our TCAS - I knew there were no aircraft around there in our immediate vicinity. So I was confident that I could go there and…I might have broken a regulation but, you know, to keep the wings on the aircraft is the main game. There's always a range of options had the diversion not been available for whatever reason. We can still go through the weather but we would have had to adjust the aircraft configuration, slowed it down or put it at an appropriate speed. You know we could have if we hadn't already done it, put the seatbelt on and made a PA. Yes, I remember seeing the wind direction, where it was coming from…the wind will actually blow the turbulence down…so you can be in clear air and cop extreme turbulence off them, so that sort of thing I did have the presence of mind…So we could have gone left or right, so I said "we're out of here - lets go left".*

It was noted on a number of occasions during the interviews that decisions were made in a compressed timeframe, yet still involved an assessment of the possible solutions and what could be described as a methodical approach to error resolution:

> *Not slow down your thought process but very deliberately force yourself to consider all the options.*

Again, the requirement to constantly monitor and evaluate the outcomes to the error resolution process was also highlighted. From these results it is evident that significant parallels exits between the cognitive processes involved in error resolution and traditional problem solving.

3.3.3 Multi-Crew Functions

Effective communication and crew interaction forms a foundation for effective error management. As nobody likes to make significant errors, error events are typically associated with negative affective components. Accordingly, it is important that the management of the response to error from the perspective of multi-crew flight operations is undertaken in a sensitive yet assertive manner.

5) Communication and Information Sharing

Definition: Crewmembers should share information and communicate openly in the response to error.

As the response to error frequently requires significant trouble-shooting, problem-solving and decision-making processes, it is critical that all relevant information is gathered, reviewed and alternative options are evaluated. This process demands the sharing of information and open communication and between crewmembers.

> *Well if you've got any doubts, ask somebody. Tell ATC if you've got a problem was always my strategy and then see if you can sort it out between you.*

The sharing of information and open channels for communication extend beyond the confines of the flight-deck when managing error. For instance, with errors relating to Air Traffic Control or airspace requirements, open communication is also essential in error resolution.

6) Management of the Error Response Process

Definition: Errors committed by another crewmember should be communicated using a process that provides adequate opportunity for error detection and management by the crewmember that committed the error.

Error comes with significant negative implications, due to a natural human reluctance to admit fallibility and the high levels of professionalism demanded by the industry. Accordingly, the establishment of an appropriate communication environment in the resolution of error requires a delicate balance between assertiveness and tact. This balance presents some, not insignificant, difficulties during normal operations:

> *You have got to sit back sometimes and say well all right should I take it or should I challenge this fellow, do I offer suggestions, do I take over?*

Consideration and diplomacy are required in the effective management of error, to the degree that the safety of the operation can be assured. In some instances, a simple prompt is all that is required in order to trigger an action that has been omitted:

> *Yeah you just tell them "look 20,000". That's all you have to say, you don't even have to give him the action, you just have to clue him up, "there's 20,000" and he'll go "oh mate, sorry mate". So the idea is that with the action you let him know, give him an opportunity to correct his own mistake because that way your not…confrontational, you know your not sort of saying "you're an idiot". So…he's then got the opportunity (a) to fix it himself, which is important for guys and (b) brings him back up to where he should have been with you in the progress of the flight.*

However, in some circumstances a more deliberate process is required in order to alert the other crewmember to the occurrence of error, and to ensure that safety is maintained. For instance:

> *The First Officer could be either very inexperienced or very experienced. On the very inexperienced side, the operation may get out of the Captain's comfort zone because of inexperience and because of the First Officer getting too high and too fast and not noticing it, so we tell the Captains the first time they recognise that to speak up and say "you're too high and you're too fast" and then if there is no reaction, tell them what to do, "you're too high, you're too fast you need to take the speed back". If no reaction "I have control", put it back to where you're comfortable with it and if you want then give it back to the First Officer to do the rest.*

This systematic process of error management involves three major steps: 1) highlight the problem-state; 2) re-state the problem and offer guidance for resolution; and 3) take control of the aircraft. These stages respond to the need to provide the person who committed the error the opportunity to detect then resolve the error himself or herself, which from the interview data was found to be an important personal aspect of error management.

7) Workload Management

Definition: The basic principles of workload management should be employed in the response to error.

The effective prioritisation, distribution and scheduling of tasks was found to be a critical factor in effective error management.

> *Having made the error I would stress that they need to not box themselves in and not be both looking at charts at the same time to make sure that it is clear that one person is controlling the aeroplane and one person is listening to the radio at least… and this is what I did in the case that happened to me, realised that I*

> *hadn't done these things, I said "ok look you have control, you have the radio" and then I got my charts out and decided what needed to be done.*

If error is viewed as a normal part of everyday flight operations, the extension of good practice in workload management to the process of error resolution is a natural progression.

3.3.4 Attitudinal Factors

Again, with all aspects of error management, attitudinal factors play an important role in the effective response and resolution of error events. While not always easily defined, and less easily trained, these attitudinal factors nevertheless form an important aspect of error management.

8) Acceptance of Error

Definition: Any instances of error should be accepted as such, in order to effectively resolve the situation, and learn from the occurrence of error.

A major barrier to effective response to error, is a failure - or denial - to accept the occurrence of error. Highlighted previously in relation to error detection, if a problem-state is not identified as possibly a result of an error, the process of problem identification and resolution becomes stifled. It was highlighted in a number of circumstances that a constant awareness of the possibility of error is an essential component of error management.

> *So there's an exchange of gratitude there and I'll generally say something, like you know to allay their concern, like particularly if you've flown with them first time and that's their first mistake they've made with you. "Oh look sorry mate, that's fine, there's no problem, we're all human".*

Once a problem-state is identified as resulting from an error, and the crew are operating within an environment that accepts error as a natural element of human performance, a number of barriers to effective error resolution are removed.

9) Avoidance of Rumination

Definition: Crewmembers who have made an error should not dwell on the error, but rather focus on error management processes and learning from the occurrence of error.

A similar attitudinal factor to the acceptance of error involves avoidance of rumination. The negative thought processes involved in severe self-criticism and dwelling on the occurrence of error provide little benefit to the goal of effective error management. Rather, acceptance of error should be coupled with a focus on the development of solutions:

> *One general strategy I have is that I have come over the years to accept that errors are inevitable so not to dwell on the error but to concentrate on the solution, if you like and I think that's a general strategy.*

The interview data highlighted that severe self-criticism and rumination can have clear detrimental effects on the overall quality of flight operations:

> *I actually trained pilot once, a long time ago and I remember sitting under the control tower at Essendon Airport with him there one day. I said…"I noticed you made a few errors on that last one". He said, "Oh yeah, I've got them written down here". He said "Every time I make a mistake, I write it on my flight plan so that I can go back over it". And I said "There's the problem, you know, you're thinking about the last mistake you made and that's causing you to make the*

next one, so you write two down now, and then you're thinking about those two while you're making the third one."

3.4 Critical Components of Error Management Training

Error management training refers to the structured development of error management skills in the training environment. A critical premise for error management training is that it should not form a separate element of a training curriculum, but rather elements of error management training should be integrated into ground, simulator and line training, as well as inform aspects of ongoing development of expertise in already experienced pilots. Data from the interviews highlighted eight core components of error management training grouped under three broad categories.

3.4.1 Experiential Factors

The exposure to a wide range of conditions, and error-related events, during training is an essential element of developing effective skills in the management of error. Accordingly, error management training must have a significant experiential focus. In order to achieve this goal, it is apparent that both simulation and line training should include a specific structured focus on the generic non-technical skills that form the foundation of error management.

1) Exposure to Error Producing Conditions

Definition: Error Management Training should expose pilots to a wide range of error producing conditions, such that they are better able to detect and adapt to these conditions.

The first aspect of effective error management training involves an emphasis on the awareness and exposure to conditions that increase the likelihood of error. The expectation of error, and the ability to detect error producing conditions were found to be essential elements of effective error management. Accordingly, guided exposure to aspects of normal operations where errors frequently occur is a primary element of error management training:

> *The best way to do it is to put a little higher workload on pilots in the simulator, so that any problems that have arisen during the simulator session can be discussed, and you can say well this is what happened today, so you can be made aware of these problems by the simulator… I think its just making people aware of what's going on and the times that these things can happen.*

Awareness of "areas of vulnerability" is best demonstrated through exposure to these elements of the operation, and first-hand experience of the increased error-rate during these times. Aspects such as distraction, multiple and conflicting tasks and other areas of high workload should therefore be experienced and analysed from the perspective of error occurrence and management.

2) Exposure to Errors and Problem-States

Definition: Error Management Training should expose pilots to a wide range of errors that occur, and the problem-states that arise from these errors.

Leading directly on from exposure to error producing conditions, the second important aspect of error management training appears to be exposure to errors, and the problem-states that arise from these errors. During normal and training operations, in both the simulator and on the line, error will naturally occur, and trainees will no doubt be exposed to a wide variety of errors and problem-states. Error management training must harness these error events in a manner which not only analyses the technical aspects of the errors, but also the non-technical and generic error avoidance, detection and response strategies as explored in previous sections of this report.

> *I always say to people when I'm training pilots, and I have been doing this for 17 years, that I won't make, that I don't deliberately make mistakes to catch people out but I make enough mistakes in the normal operation so that they need to watch me…*

Another effective technique for exposing trainees to errors and problem-states involves the instructor purposefully making common errors.

> *I'll say, "OK on this flight I'm going to do a couple of things that may be a little unusual just to check that you're watching me"…*

This approach reinforces the situation awareness and multi-crew functions at the core of error detection and response, and provides another "hands-on" mechanism to develop error management skills. Furthermore, it can be done in a planned manner such that the generic non-technical strategies for error avoidance, detection and response can be explored in specific detail.

3) Structured "Hands-On" Training in Error Management and Solutions

Definition: Error Management Training should expose pilots directly to the non-technical aspects of error management in order to develop the generic strategies and skills in error avoidance, detection and response.

The final aspect of experiential modes of error management training involves structured and guided training to specifically develop the non-technical skills used in error avoidance, error detection and error response. Just as technical procedures are frequently learnt through drill and rehearsal, so too can the generic non-technical skills that form the basis of error management.

> *As a result of this experience, I train in thorough cross-checking and cross-checking what is in the charts and the pilots themselves…*

Processes described in this report such as the "systematic check", "building gates", "detecting divergence", "pre-action attention" and "using metacognitive prompts" can all be specifically trained and rehearsed during simulator and line training. Even through these skills are frequently described as generic non-technical skills as they are specifically cognitive in nature, they are nonetheless *competencies* that can be defined, specified and drilled during training.

3.4.2 Attitudinal Factors

As highlighted previously, a range of attitudinal factors underpin effective error management in the environment of normal flight operations. These affective elements of expertise are contentious from the perspective of training. There is frequent debate over whether attitudes can be specifically trained. However, it remains likely that attitudes can be nurtured and developed through the role of experience and example in the training environment.

4) Understanding Cause and Effect

Definition: Error Management Training should assist trainees in experiencing and understanding the negative consequences of mismanaged errors and problem-states, as well as the success of effective error avoidance, detection and response strategies.

The need to develop a clear understanding of "cause and effect" with respect to the (mis)management of error was highlighted during the interviews as a critical component of error management training. The exposure to the real consequences of poorly managed error, as well as the effectiveness of error management strategies, facilitates the development of healthy error management attitudes.

An understanding of "cause and effect" with respect to error management forms an important part of experience, and is captured in the informal process of "learning from mistakes":

> *I scared myself very early in the piece when I was learning to fly in a thunderstorm with mucking around with a weather radar poorly trained…and it was very good experience. Yeah we got spat out the bottom of a thunderstorm in Mt Isa, it was bloody mind-blowing…*

This process of learning from experience can be formally embedded into an error management training program. Such an approach can complement, as well as "short-cut", the informal aspects of learning from experience, and can be achieved within a more controlled environment.

> *We try and let the trainees learn from their mistakes… we really try to push and let them push themselves into such a hole… and then we help them get out of it, and you do see that on the line as well so it is a learning thing…*

This process of controlled transgression through the safety envelope is a powerful learning mechanism, and has been formally adopted in military training environments (Naikar & Saunders, 2003).

5) Development of Confidence

Definition: Error Management Training should develop pilots' confidence in the management of error and related problem states, whilst discouraging over-confidence and invulnerability.

The development of confidence was found to be an important element of error management training. Confidence appears to be an important attitudinal foundation in the error management strategies of situation awareness and mismatch emergence, as confidence in one's understanding of the situation, the required "gates" and "acceptable buffers" of safe performance, as well as the ability to resolve problem-states are all critical to safe operational performance:

> *Well firstly I always like to let them tell what happened first, so, "that didn't work out too well, what do you reckon happened there?" So see how much they recognise or how much they learnt or what they recognise about what happened…Don't do it with put downs, that's a stupid thing to do. It's not what you need to say at that stage of the game. Do it by suggesting better ways to do it rather than telling them about the wrong way that they did it. So yeah, I think it's very easy with a trainee to destroy their confidence, it's also very easy to build it up and you can build it up just by telling them better ways to do things rather than telling them the wrong things they've done.*

However, it was also highlighted that overconfidence and aspects of invulnerability need to be dealt with through error management training. These "hazardous attitudes" have frequently been highlighted as detrimental to safety, and accordingly must be the focus of intervention within the training environment:

> *To put it in the vernacular, sometimes you've got to give them a kick in the ass. So sometimes you have to admonish them, I suppose, sometimes you have to tell them how you stuffed up and you did it because you were smart. It doesn't happen very often…but it can.*

6) Development of Self Analysis Skills

Definition: Error Management Training should assist pilots in developing skills in self-analysis and reflection on performance, whilst developing strategies to avoid excessive self-criticism.

It was frequently highlighted in the interviews that self-analysis skills formed an important component of error management training. The ability to analyse one's own performance, and learn from error is essential to the ongoing development of expertise. This process involves:

> *Self-reflection in working out how the error arose…where did this error occur and why did it…*

However, it was also acknowledged that self-criticism and rumination work against effective error management. Acceptance that errors will occur, frank analysis of the causes of the error and the identification of strategies to better avoid, detect and respond to such errors are all part of the ongoing development of expertise.

3.4.3 Debriefing

The final components of error management training relate to the role of debriefing and analysis in the ongoing management of error. Debriefing provides the opportunity for the consolidation of learning, through the deeper analysis of the causes and consequences of error once the event has been resolved.

7) Choice of Error-Events to Debrief

Definition: Error Management Training should identify appropriate error events for further analysis through debrief, and debrief should be completed in a timely manner.

One of the most critical components of debriefing error events relates to the choice of events to form the focus of subsequent analysis and discussion. Data from the interviews highlighted the need to limit the number and types of errors that form the focus of debrief in error management training. In general, it was suggested that:

a) Minor errors and everyday "finger-trouble" need not be debriefed;

b) Any error that indicates a lack of understanding or knowledge should be debriefed;

c) Any errors that were not detected by the trainee should be debriefed; and

d) Any errors that were consequential, or posed a threat to safety should be debriefed.

There was general consensus that the debrief of error-events should occur as soon as possible after the event has occurred. In some instances, an error might be able to be discussed in-flight, or during the simulator session if time and workload permits. Alternatively, the discussion of errors might occur directly after the training session or training flight. It is widely accepted that the length of time between error occurrence and debrief has an effect on the impact and quality of learning that can be achieved.

8) Focus of Error-Event Debrief

Definition: Error Management Training should adopt a focus on both the technical and non-technical aspects of error generation and management.

The focus and emphasis of the debrief of error events plays a critical role in error management training. It is interesting to note that the experienced instructors suggested that minor errors or "finger trouble" should not be debriefed. This suggests that the typical focus of error debriefing is on the technical aspects of error occurence, rather than the non-technical or generic skills which enable effective error management to take place.

This study suggests that the non-technical skills which form the foundation of effective error management are essential components of error management training, and therefore must form an important focus in any debrief. This is not to say that error management training is solely non-technical in focus. Rather, it is evident that both the technical (systems knowledge, procedures and techniques) and non-technical (generic cognitive and interpersonal) aspects of error management must form the dual focus of error management training.

A generic structure for the debrief of error events in error management training could mirror the process of error management, and include the following sequence:

a) The causes of the error and the error producing conditions that were present;

b) The strategies that were used to avoid the error and what could be done better;

c) The strategies that were used to detect the error and what could be done better;

d) The consequences of the error and technical options available to resolve the error; and

e) The strategies that were used to resolve the error and what could be done better.

This sequence logically follows the process of error management, and provides the opportunity to systematically work through the error event from occurrence to resolution, within the real-world context in which the error was encountered.

4 DISCUSSION AND CONCLUSIONS

4.1 An Integrated Perspective on Error Management

This study has provided a detailed account of error management, through the analysis of experts' understanding of error avoidance, detection and resolution. From the results of this study, it is evident that elements of error management share much in common with our current understanding of Crew Resource Management (CRM). Aspects such as situation awareness, task management and communication are all common elements of CRM programs in modern airlines.

However, this study has provided specific new detail with respect to the actual cognitive processes of error management that we commonly group together under such categories as situation awareness. Moreover, the results of this study place significant emphasis on *metacognitive* processes that underlie the more evident cognitive, affective and interpersonal components of error management.

The findings of this study reinforce a model of error management that emphasises the process of mismatch emergence as the driver of error detection, problem identification and error resolution.

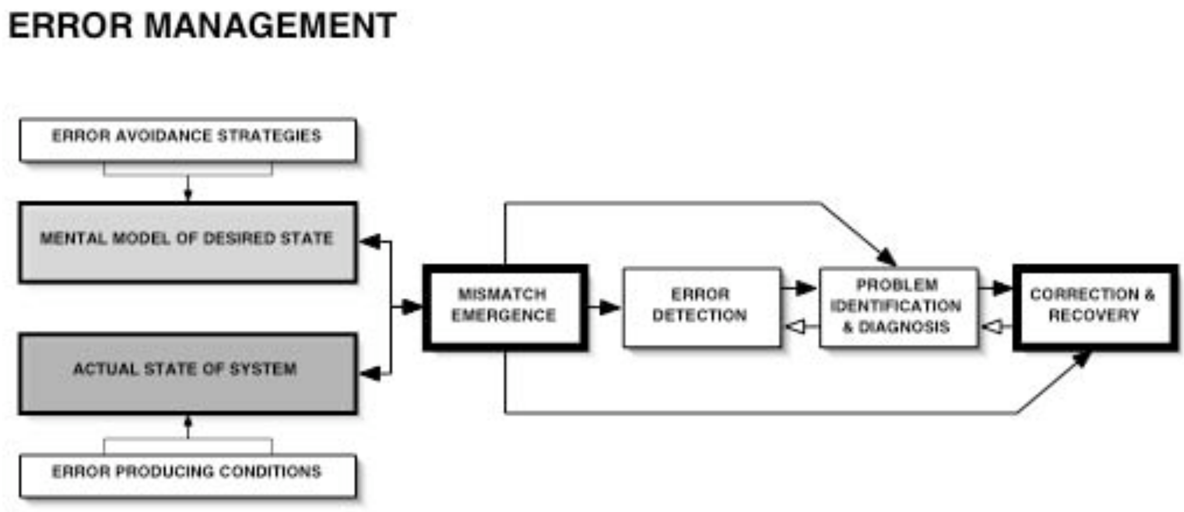

Figure Four: A Model of Error Management

This model of error management, as first proposed by Rizzo et al., (1995) and subsequently expended in this study, has several unique features that suggest it offers considerable explanatory power in relation to the detection of safety breaches in dynamic real-world contexts.

Firstly, the model makes explicit that the crucial mechanism involved in error detection is that of mismatch emergence, whereby conflict arises between the expected state of the work system and the actual observed state of the system. The results of this study emphasise the role of situation awareness, and in particular the construction of a dynamic mental model of the desired and expected state of the "system": the aircraft status and configuration in space and time. This study has identified a range of cognitive and metacognitive processes that provide an adequately comprehensive framework for mismatch emergence to reliably occur.

Secondly, the model is consistent with naturalistic explanations of expert behaviour whereby action schema are frequently activated in response to environmental stimuli with little or no conscious processing on behalf of the operator. Indeed, the model allows for situations whereby safety breaches are contained through immediate response to the emergence of a mismatch in system state. Accordingly, error management can itself be seen as dynamic expert behaviour rather than a serial and rational process.

In everyday environments, corrective action is frequently applied prior to a clear understanding of the exact nature of the problem, or even recognition that a specific error has been committed. This error management pathway is illustrated through the bottom arrow in the figure above. Using an example of expert pilot performance, a significant glide-slope deviation is likely to be corrected through automatised actions of changes in attitude and thrust long before the problem state is clearly defined and the originating error, such as the speed-brake remaining extended, is actually detected. In this example, mismatch emergence leads directly to correction, then through a backwards flow of information through the model, the problem-state is diagnosed and the original error can then be detected. Utilising the language of Rasmussen's (1987) levels of performance, this form of error management could be termed *skill-based error management* with respect to the high levels of automatic cognitive processing at play.

In situations where the mismatch emergence does not immediately activate any specific corrective schema, a process of problem identification might in turn activate a variety of possible corrective schema through the application of stored rules. For instance, the detection of adverse weather in close proximity to the aircraft might activate a variety of stored rules relating to the impact of wind strength and direction on the movement of weather cells, the requirements for aircraft configuration in weather, and the impact of the direction of deviations from track on total track miles and time to destination. Accordingly, this form of error management could be termed *rule-based error management*, as it involves the identification and activation of stored rules from the long-term memory.

In certain situations, where the mismatch emergence presents ill-defined or ambiguous system states, more conscious processing might be required to actively search for an error in order to accurately identify and diagnose the problem-state. Only once this conscious search for errors has been undertaken, and the error detected, can appropriate recovery action be taken. For instance, the detection of problems with the descent profile as governed by the automatic flight system might lead to a conscious search for an error in the programming of the flight management computer. It therefore follows that this form of error management can be termed *knowledge-based error management*, with respect to the high levels of conscious processing involved.

4.2 Implications for Error Management Training

This study has provided a wide range of perspectives that in turn can inform a comprehensive curriculum structure for error management training. Much of what has been identified in this study is in line with existing human factors knowledge, and many parallels are to be found with existing Crew Resource Management training programs. However, this study has also provided a range of new perspectives on error management, and the types of processes that might contribute to effective error management training programs. Furthermore, the study highlights three important new developments for error management training: 1) the need to focus more on cognitive skill development and the affective domain; 2) the need to integrate technical and non-technical skill development; and 3) the need to increase the experiential components of error management training.

4.2.1 Cognitive Skill Development and the Affective Domain

The results of this study highlight the important role of non-technical skills in error management. Such skills as situation awareness, construction of accurate mental models and mental simulation, anticipation and contingency planning, self-monitoring, and deviation detection are all generic cognitive processes that have been identified as critical components of error management.

Accordingly, any successful error management training program should develop an explicit focus on the development of these skills in pilots. This task is somewhat more difficult than the training of technical skills relating to areas such as systems knowledge, procedures, and aircraft handling. This difficulty is primarily because these types of cognitive skills are not directly observable, and in many respects difficult to define as they generally involve complex and multi-faceted thought processes. However, the task is by no means impossible, and the Human Factors research agenda for the near future can contribute considerably by providing new insights into areas such as:

1) The development of competency specifications for cognitive skills; and
2) The types of training interventions that enable the development of cognitive skills.

Similarly, the role of the affective domain in error management has been emphasised by the participants in this study, particularly with reference to the attitudes that form an essential foundation for effective error management. The avoidance of such "hazardous attitudes" such as invulnerability, over-confidence, and the denial of error were identified as affective components that needed to be avoided or even "trained-out" in pilots. Moreover, the study identified attitudes such as conservatism, diligence, patience, discipline and confidence as essential components of error management. It is therefore necessary to further examine how these affective aspects of error management can be developed in the training environment.

4.2.2 Integration of Technical and Non-Technical Skill Development

This study has highlighted the complementary role of technical knowledge and skill alongside a wide range of non-technical skills in effective error management. Therefore, the integrated development of technical and non-technical skills through carefully designed training programs appears to be fundamental in the error management training process.

Similarly, it is unlikely that any error management training program will achieve the greatest possible benefit unless it is integrated within existing forms of simulator-based training and aircraft-based training. Error management training must be experiential and practical in nature, such that the wide range of error management skills can be practiced and rehearsed within real-world contexts.

4.2.3 Ensuring error management training is experiential in focus

The results of this study have highlighted that error management training cannot be seen just as a “classroom” activity. Rather, in order to explore and develop the wide range of competencies that underpin effective error management, specific experiential forms of training must be used.

The error management competencies highlighted by the experienced pilots interviewed in this study are all context-driven, and likely to be affected themselves by a range of error producing conditions such as high-workload, stress and distraction. Accordingly, the task management elements of effective error management dictate a need to embed an error management training focus within existing experiential forms of training in commercial aviation.

Over the last few decades, simulator-based training has come to form the bulk of experiential training in commercial aviation. The high fidelity full flight simulator provides the perfect environment for the exploration and development of error management competencies alongside the operational conditions in which error naturally occurs.

It is possible to conceive that error management training can be embedded within existing forms of cyclic simulator training without the need for additional time and resources. In other-words, it would be possible to design an Instrument Rating renewal simulator session that adopted an error management training focus. Using an approach to training that sought to train and assess the non-technical competencies of error management alongside the technical aspects of a raw data NDB approach, effective error management training can be achieved.

Curriculum design and instructor development therefore form important new foci for the continued development of error management training programs within commercial aviation.

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6 APPENDIX ONE: DEMOGRAPHIC AND BACKGROUND QUESTIONNAIRE

QUESTIONNAIRE – ERROR MANAGEMENT AND TRAINING

This questionnaire is designed to gather some background information. You are not required to complete any questions you do not wish to answer. All information collected in this questionnaire will remain strictly anonymous.

DEMOGRAPHIC DATA

Age:	<25	25-34	35-44	45-54	55-64	>64
Gender:	Male	Female				
Total flying hours (estimated):						
Background:	Military	Civilian	Both			
Years of airline flying:		Short-haul:		Long-haul:		
Years of military flying:						
Years flying automated (FMC) A/C:						
Years flying glass cockpit A/C:						
Years in a training role:						

DEFINTIONS

For the purposes of this study, we will be referring to "errors" as per the following definition:

*An **error** is any action or inaction that leads to a deviation from your intention, or a company SOP or regulation.*

According to this definition, an error might be a simple slip or lapse such as dialling in the wrong ATC frequency or forgetting to call for the after take-off checklist, or a more consequential mistake such as flying into weather which you thought was not as bad as it turned out to be. We will use three basic types of error for this study:

*A **slip** or **lapse** is an error in execution. Slips are unintended actions, such as making an incorrect automation setting or typing in an incorrect weight in the FMC. We often refer to these as "finger trouble". Lapses are simple failures of attention or memory, such as forgetting to arm the speedbrake on approach.*

*A **perceptual error** involves an instance of a visual illusion, spatial disorientation or misrecognition of an item.*

*A **mistake** is executing a flawed plan, such as accepting an impossible amount of track shortening from ATC, or flying into a dense radar return. We often refer to these as errors in judgement.*

ERROR OCCURENCE

The following questions relate to *your experience* of the occurrence of error during your flying career. On an average flight:

How many errors would be made?	
What percentage would be slips or lapses?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would be perceptual?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would be mistakes?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would be made by the CPT?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would be made by the F/O?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage could impact on safety:	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100

For each of the following factors, rate the likelihood that an *error would occur* as a result of the influence of that factor on everyday performance. Place an X on the line at the point that represents the level of likelihood of an error on a continuum from "highly unlikely" to "highly likely".

Lack of Attention or Distraction:	
highly unlikely	highly likely
Duty Time/Time on Task:	
highly unlikely	highly likely
High Workload:	
highly unlikely	highly likely
Lack of Training:	
highly unlikely	highly likely
Poor Communication:	
highly unlikely	highly likely
Inadequate Sleep:	
highly unlikely	highly likely
Stress:	
highly unlikely	highly likely
Body-Clock/Circadian Rhythm:	
highly unlikely	highly likely
Poor Procedure (SOPs):	
highly unlikely	highly likely
Time Limitation:	
highly unlikely	highly likely
System Design:	
highly unlikely	highly likely
Unfamiliar/Novel Event:	
highly unlikely	highly likely

ERROR DETECTION

The following questions relate to *your experience* of the detection of errors during your flying career. On an average flight:

What percentage of errors would be detected?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would the CPT detect?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would the F/O detect?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would A/C systems detect?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would ATC detect?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would someone else detect?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100
What percentage would remain undetected?	5 - 10 - 15 - 20 - 25 - 30 - 35 - 40 - 45 - 50 - 55 - 60 - 65 - 70 - 75 - 80 - 85 - 90 - 95 - 100

For each of the following factors, rate the likelihood that the specified mechanism is the *first mechanism by which an error is detected*. Place an X on the line at the point that represents the level of likelihood of an error being first detected by that mechanism on a continuum from "highly unlikely" to "highly likely".

Self-Monitoring (scan):

highly unlikely ______________________________ highly likely

Monitoring the other Crew Member (cross-check):

highly unlikely ______________________________ highly likely

Warning System:

highly unlikely ______________________________ highly likely

A/C Status or Performance:

highly unlikely ______________________________ highly likely

Checklist:

highly unlikely ______________________________ highly likely

7 APPENDIX TWO: INTERVIEW PROTOCOL

INTERVIEW PROTOCOL – ERROR MANAGEMENT TRAINING

This interview protocol is to be used by the interviewer as a standard structure for conducting the interview. As the interview is a semi-structured protocol, some flexibility is permitted, especially in relation to exploring areas of error management in more detail.

PRE-START CHECKLIST

Information Sheet	Provided	☐
Consent Form	Signed	☐
Demographic Questionnaire	Completed	☐
Audio Recorder	Recording	☐

PREAMBLE

The purpose of short interview is to gather information from experts about the strategies and techniques they use for error management during normal flight operations. We will be using the definition of an error described in the short questionnaire you have just completed. For the purposes of this study, we will be referring to “errors” as per the following definition:

> *An* ***error*** *is any action or inaction that leads to a deviation from your intention, or a company SOP or regulation.*

According to this definition, an error might be a simple slip or lapse such as dialling in the wrong ATC frequency or forgetting to call for the after take-off checklist, or a more consequential mistake such as flying into weather which you thought was not as bad as it turned out to be. We will use three basic types of error for this study:

> *A* ***slip*** *or* ***lapse*** *is an error in execution. Slips are unintended actions, such as making an incorrect automation setting or typing in an incorrect weight in the FMC. We often refer tho these as “finger trouble”. Lapses are simple failures of attention or memory, such as forgetting to arm the speedbrake on approach.*

> *A* ***perceptual error*** *involves an instance of a visual illusion, spatial disorientation or misrecognition of an item.*

> *A* ***mistake*** *is executing a flawed plan, such as accepting an impossible amount of track shortening from ATC, or flying into a dense radar return. We often refer to these as errors in judgement.*

INDICATIVE TIMINGS

1. Introduction	5 minutes
2. Demographic Questionnaire	10 minutes
3. Slips and Lapses (timeline and discussion)	15 minutes
4. Mistakes (timeline and discussion)	15 minutes
6. Training Strategies	15 minutes
TOTAL	**60 minutes**

ERROR EVENT: SLIPS & LAPSES – DESCRIPTION/TIMELINE

I would like you to think about a particular situation in which one or more errors were made during an everyday sector. At this stage lets only look at examples of slips or lapses.

Elicit an example and triage for correct identification as slip or lapse.

Using a timeline, please describe in as much detail as possible the errors and how they were managed.

Allow the participant to draw his or her own timeline on the "timeline sheet".

ERROR EVENT: SLIPS & LAPSES – FURTHER DETAILS

The following questions are to be used as probes to gather more detailed information:

Error Detection

- At what point on the timeline did you realise something was not going as intended?
- What was the first thing that alerted you to the error?
- Was the error surprising, or did you anticipate that it could occur?
- What information was available to you at the time of the error?
- Was this error similar to something you had experienced before?
- From the following list, which best describes the error detection mechanism:
  1) Self-monitoring (detected own error through scan);
  2) Monitoring the other crewmember;
  3) A/C System Warning;
  4) A/C Status or Performance;
  5) Checklist; or
  6) Other.

Error Causation

- What do you think caused the error?
- Were any of the following factors present, and if so, how did they contribute to the event?
  1) Lack of attention/distraction;
  2) Duty-time or Time on Task;
  3) High workload;
  4) Lack of training;
  5) Poor communication;
  6) Inadequate Sleep; or
  7) Stress;
  8) Body-clock/Circadian;
  9) Poor procedures (SOPs);
  10) Time limitation;
  11) System design;
  12) Unfamiliar/novel event.

Error Management

- Once you were aware that something was not going as intended, what did you do?
- How did you consider the consequences of the error? For example, did you imagine them or play them out in your mind?
- Did you consider a range of actions?
- Did you have to think hard about resolving the error, or were the actions automatic?
- Did you use any set "strategies" or "rules of thumb" to guide your actions?
- How was the situation resolved, were you comfortable with this resolution?

Error Management Strategies

- Do you think this error could have been avoided?
- Do you think you could have detected the error earlier, and if so, would this have been a benefit?
- What strategies would you use, or suggest as a technique, to avoid this situation in the future?
- With the benefit of hindsight, is there anything you would do differently, or anything you forgot to do?
- Do you think you could "train" someone to *avoid* this type of error?
- Do you think you could "train" someone to *quickly detect* this type of error?
- Do you think you could "train" someone to *better manage* this type of error?

ERROR EVENT: MISTAKES – DESCRIPTION/TIMELINE

I would like you to think about another specific situation in which one or more errors were made during an everyday sector. I would now like us to only look at examples of mistakes, which are errors in planning or judgement.

Elicit an example and triage for correct identification as mistake.

Using a timeline, please describe in as much detail as possible the error(s) and how they were managed.

Allow the participant to draw his or her own timeline on the "timeline sheet".

ERROR EVENT: MISTAKES – FURTHER DETAILS

The following questions are to be used as probes to gather more detailed information:

Error Detection

- At what point on the timeline did you realise something was not going as intended?
- What was the first thing that alerted you to the error?
- Was the error surprising, or did you anticipate that it could occur?
- What information was available to you at the time of the error?
- Was this error similar to something you had experienced before?
- From the following list, which best describes the error detection mechanism:

  7) Self-monitoring (detected own error through scan);
  8) Monitoring the other crewmember;
  9) A/C System Warning;
  10) A/C Status or Performance;
  11) Checklist; or
  12) Other.

Error Causation

- What do you think caused the error?
- Were any of the following factors present, and if so, how did they contribute to the event?

  1) Lack of attention/distraction;
  2) Duty-time or Time on Task;
  3) High workload;
  4) Lack of training;
  5) Poor communication;
  6) Inadequate Sleep; or
  7) Stress;
  8) Body-clock/Circadian;
  9) Poor procedures (SOPs);
  10) Time limitation;
  11) System design;
  12) Unfamiliar/novel event.

Error Management

- Once you were aware that something was not going as intended, what did you do?
- How did you consider the consequences of the error? For example, did you imagine them or play them out in your mind?
- Did you consider a range of actions?
- Did you have to think hard about resolving the error, or were the actions automatic?
- Did you use any set "strategies" or "rules of thumb" to guide your actions?
- How was the situation resolved, were you comfortable with this resolution?

Error Management Strategies

- Do you think this error could have been avoided?
- Do you think you could have detected the error earlier, and if so, would this have been a benefit?
- What strategies would you use, or suggest as a technique, to avoid this situation in the future?
- With the benefit of hindsight, is there anything you would do differently, or anything you forgot to do?
- Do you think you could "train" someone to *avoid* this type of error?
- Do you think you could "train" someone to *quickly detect* this type of error?
- Do you think you could "train" someone to *better manage* this type of error?

ERROR MANAGEMENT: TRAINING STRATEGIES

Error Awareness and Areas of Vulnerability

- Do you think there are certain situations in everyday flying that present “traps” or “pitfalls” where errors easily or frequently occur?
- Are there times when errors are made more frequently?
- Do you use general strategies to avoid errors on the line?
    - Do you monitor your own actions?
    - Do you keep a tab on your understanding of a situation?
- Do you use general strategies to quickly detect errors on the line?
- Do you use general strategies to better manage errors on the line?

Inter-Individual Metacognition

- How do you monitor a trainee in the simulator and on the line?
- Are you able to see when they don’t understand a situation or are about to make an error?
- What clues do you use in this process?
- What do you think are the critical components of error detection and management?

Training Strategies

- In your training role, do you use any specific strategies to assist trainees in error awareness, detection or error management?
- Do you discuss particular “pitfalls” where errors can easily occur?
- Do you debrief each error, or just some?
- When do you debrief the errors?

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