Cognitive Strategies in Emergency and Abnormal Situations Training: Implications for Resilience in Air Traffic Control

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Abstract. The management of emergencies and abnormal situations in the Air Traffic Control (ATC) system entails substantial challenges for the air traffic controllers. The inherent complexity and dynamics of the ATC system can give rise to numerous cases of failure and controllers have to develop failure-sensitive strategies to counteract and forestall any paths to failure. Failure-sensitive strategies in the form of individual and joint cognitive strategies may be considered as an important resource of resilience in the ATC system. By hypothesizing that these failure sensitive strategies are observable during the training in handling abnormal situations, a field study was performed to elicit and document in a reliable manner the controllers' individual and joint cognitive strategies. This paper summarizes initial findings with the potential of providing insights in cultivating sources of resilience in the ATC system.

1 INTRODUCTION

Resilience represents the ability of a system to adapt or absorb disturbances, disruptions and changes and especially those that fall outside the textbook operation envelope (Woods et al, 2007). Emergencies and abnormal occurrences represent critical situations close to the margins of safe operation that challenges the controller operational practices and supervisory systems.The joint human and technical system is stretched to accommodate new demands and this offers opportunities for studying aspects of system resilience. In this sense, emergencies and abnormal situations are fertile grounds for stories of resilience, which can stipulate human factors research.

The ATC system is a highly complex safety critical system with countless anticipated and unanticipated paths to failure. As the controllers at the sharp end of system become sensitive to the potential paths to failure, they develop failure-sensitive strategies to counteract failure paths. An emergency presents controllers with many challenging issues. Is the situation unusual and how far to pursue monitoring of the situation? As soon as a disturbance is detected, a problem-to-be-solved is formulated and the need to re-plan for the situation becomes prominent. To respond to an emergency, controllers should demonstrate problem-detection skills and re-planning strategies. As an occurrence evolves over time, new threats may appear whilst current threats may change their demands.The need for gathering new information to fill in the gaps, correct explanations, clarify assumptions and evaluate candidate hypotheses is amplified. This calls for strategies in recognizing the situation, anticipating how the situation will evolve in future, and how to manage uncertainty.

On the other hand, the joint performance of controllers and supervisory systems is also challenged in an emergency. ATC requires synchronization of many inter-dependent activities within a short time window and this calls for demonstration of joint cognitive strategies. Coordination is the main prerequisite for synchronization but it comes at the cost of information exchange. New tasks are added and ordinary prioritization is altered. Therefore, increased workload must be balanced by intra-team reallocation of tasks. In addition, safety critical situations are not tolerant to errors, which implies that controllers should create their own opportunities for error detection and correction. These individual and joint cognitive strategies can be seen as important sources of resilience in the ATC system that would merit from a systematic classification.

Traditionally, the focus of controllers' training has been on fulfilling regulatory requirements. Effective handling of emergency and abnormal situations was considered as a by-product of technical skills training. However, a growing number of recent incidents and accidents in ATC and aviation have indicated that effective handling of emergencies requires more than technical skills (Kirwan et al, 2005). A critical need arises, therefore, to identify and document controllers' failure-sensitive strategies as sources of resilience (remaining sensitive to the possibility of failure). To this end, a field study was undertaken to probe into the cognitive strategies of controllers in emergency training.

2 METHOD

The research method was based on observations and ratings of human performance in simulator-training scenarios for Ab-Initio students and operational controllers. This method of identifying cognitive strategies and rating their quality was preferred to the analysis of incident and accident reports that focus on technical aspects and operational errors. Observational data were combined with qualitative data from briefing and debriefing simulator sessions, focused interviews with controllers and instructors, and finally a documentation analysis involving key operational documents and training curricula. These research techniques belong to the *"experiments in the field"* family of methods and are based on scaled world simulations that capture critical aspects of the targeted situations (Woods & Hollnagel, 2006). Four Ab-Initio student and 22 operational area controllers, participated in the study. Student controllers were receiving their unusual occurrences training and operational controllers were attending their annual refresher training as part of their competency scheme.

In the first stage of the study, an inventory of cognitive strategies was compiled on the basis of a literature review from the Naturalistic Decision Making (NDM) and Cognitive Systems Engineering (CSE) paradigms. Four prominent sources of references were used for the individual cognitive strategies.The Recognition Primed Decision (RPD) decision-making model (Klein, 1998), the Recognition/Meta-Recognition (R/M) decision-making model (Cohen et al, 1996) and the Contingent Operator Stress Model (COSMO) decision-making model (Kontogiannis, 1999). The fourth was a model of anomaly response as a multi-threaded process (Woods & Hollnagel, 2006). These models were selected based on the plethora, the importance of the cognitive strategies they integrate and the consistency of the research paradigm with the field study requirements.

For the identification of patterns of joint cognitive performance, a compilation was made of four well-established frameworks from the same research paradigms. The first one was the Anaesthetists' Non-Technical Skills, (ANTS) which is a validated and widely accepted framework (Fletcher et al, 2004). The second framework is more generic and can be applied in any type of team and organization. The Big Five, (Salas et al, 2005) is a teamwork model that has been developed by critical review of empirical studies and theoretical models of teamwork, team effectiveness and team performance over the last decades. The third framework is the NOTECHS (Non Technical Skills) from the aviation domain. This framework was the outcome of a research project that investigated possible ways to evaluate non-technical skills of multi pilot aircrew (Flin et al, 2003).The fourth model is a taxonomy of classifying shared cognition breakdowns (Wilson et al, 2007).

To provide a basis for rating human performance, several metrics of performance were examined that looked deeper into elements of performance that should be demonstrated as indicators of failure-sensitive cognitive strategies. For instance, planning strategies could be rated by looking into the following metrics: standard planning (i.e., application of standard operational action-scripts) and contingency planning (i.e., application of non-formally prescribed precautionary action-scripts). The elements of each strategy were balanced (i.e. two elements for each individual strategy and two or three elements for each joint cognitive strategy) in order to avoid uneven coverage of the collected data.

3 RESULTS

For the ratings of controllers' performance, we used a 7-point behaviourally-anchored scale as it was thought to give a good rating sensitivity to subject matter expert observers. The collected data were submitted to a Principal Component Analysis (PCA) to establish the construct validity by revealing factor solutions that corresponded to the hypothesized models of individual and cognitive performance. PCA was used in a confirmatory factor analysis role and specific hypothesis were tested about the structure and relationships between the factors that underlie the collected data. With regard to the individual and cognitive strategies, a five-factor solution and a four-factor solution respectively emerged that confirmed the hypothesized models of individual and joint human performance. The five individual cognitive strategies and four joint cognitive strategies that were identified in the PCA analysis of the 20 metrics of performance are summarized in Table 1. The 20 metrics of cognitive strategies were illustrated with good and poor exemplars (i.e., behavioural markers). This refinement of cognitive strategies was based on interviews with controllers and instructors so that they were able to apply this method on their own and achieve greater consensus in their judgement. An inter-rater validity study is currently in progress to test the screening cognitive strategy tool and promote greater use within the ATC environment.

Table 1. Cognitive and Joint Cognitive Strategies & Metrics of Performance

Individual Cognitive Strategies	***Metrics of Performance***
Recognition	Noticing Distinguishing Cues
	State Projection
Managing Uncertainty	Critiquing Situational Models
	Critiquing Goals
Planning	Standard Planning
	Contingency Planning
Anticipation	Threat Acknowledgement
	Exploiting less Busy Periods to Perform Planning
Managing Workload	Prioritizing Tasks
	Interruption Management
Joint Cognitive Strategies	***Metrics of performance***
Coordination	Team Coordination
	Shared Situation Understanding
	Intent Communication
Information Exchange	Unsolicited Dissemination of Proactive information
	Provision of Updates on Situation Status & Management
	Ensuring an Undisrupted & Ungarbled Information Flow
Error Management	Detection of Errors by Other Team Members
	Provision of Feedback to Enable Error Correction
Workload Distribution Management	Detection of Workload Distribution Problems
	Situation Driven Reallocation of Tasks

The five individual and four joint cognitive strategies that corresponded to the hypothesized models as emerged using PCA are analyzed below.

Anticipation: A cognitive strategy that enables a controller to timely and accurately detect and respond to a threat. Anticipation engages with response planning during low tempo periods. It is the process of recognizing and preparing for difficult challenges and brings forward the notion of threats. Threats can be defined as events or errors that occur beyond the control of the controller and must be managed in order to maintain the margins of safety.

Recognition : A cognitive strategy that enables a controller to timely and accurately detect early signs of an impending emergency and play out mentally the progression of events. Emergencies and abnormal situations can occur suddenly when the flight crew formally declares an emergency or may evolve slowly over time. In the first case, recognition is effectively reduced to the level of an accurate classification of the emergency type (i.e. a symptom-fault matching). In the latter case when the emergency is evolving over time, a pattern of cues is available.

Managing Uncertainty: A cognitive strategy that enables a controller to timely and accurately assemble and assess a model of the situation and establish safety related goals. Emergencies and abnormal situations are closely associated with information-based uncertainty due to their dynamics. The controller has to assemble a model of situation, formulate goals and correct any tentative explanations or assumptions seeking information that may not be available or accessible. Flight crews are in general reluctant to provide conclusive information during emergencies and communication with the ATC is not their first priority. Even if they are willing to communicate their status, this may not be technically feasible.

Planning : A cognitive strategy that enables a controller to employ standard and/or contingency planning for the unfolding situation. Controllers have to make a plan and in certain cases to re-plan their actions in order to cope with the demands of the unfolding situation. Planning may have the form of standard and/or contingency planning. Depending on the situation, a minimal set of prescribed action-scripts in documented forms (e.g. checklists) are normally available in all ATC units. Controllers are trained in certain types of emergencies and this annual process is a major part of their competency scheme. Nevertheless, in many cases the need for contingency planning arises. It may be a textbook case of an abnormal situation but certain characteristics may warrant an additional form of precautionary planning (contingency planning) in order to counteract a possible escalation of the situation.

Managing Workload: A cognitive strategy that enables a controller to timely and accurately sequence the required tasks and respond to interruptions and distractions. From the onset of an emergency, the workload increases significantly due to a notable increase in the number of tasks, the available time and the importance of the tasks to be completed. Workload management functions as a mental task *regulator* enabling controllers to cope with the complexity of the situation. Issues related to switching attention between normal and situation related tasks as well as judging interruptibility are regulated by workload management.

Coordination : It refers to the extent to which controllers direct and coordinate other team members, establish situation assessment congruence and clarify intent. The structure of a team (as defined by the nature of the team's tasks and their allocation) can generate lateral (intra-team) and vertical (inter-team) dependencies, which require coordination to achieve orchestrated action. The importance of coordination requirements increases with the severity of the unfolding situation. The building blocks of coordination are the shared mental models and the concept of intent. The more congruent the shared mental models of a team, the more congruent the situation assessment and performance of a team. 'Communication of intent' serves to fill-in any gaps and/or tentative assumptions of the shared mental models.

Information Exchange : It refers to the extent that proactive information is disseminated between controllers and regular updates are made on the situation status without disruptions and garbling. Coordination requirements generate a pressing need for communication. Communication is depended mainly on information exchange and requires both sufficient time and cognitive resources to be accomplished. The team members exchange information to articulate their planning, their actions and their responsibilities. Therefore, the role of information exchange is crucial to the ability of team to achieve coordinated action and perform effectively in critical situations.

Error Management: It is the extent to which controllers can develop task monitoring and/or augmented monitoring strategies that enable them to detect errors and provide feedback for error correction. In handling critical situations, errors can be committed that vary from minor ones to major ones that complicate the situation and reduce the safety margins. Errors can be detected and corrected not only at the individual level but also more effectively through the team structure. The error detection process is based on monitoring strategies, which ran parallel to the normal tasks at the cost of cognitive resources (mainly attention and memory). In mature teams, the members employ efficient monitoring strategies that have been crafted during years of operational day-to-day experience and accumulated expertise in handling the available systems. These monitoring strategies enable them not only to *"catch"* promptly an error but also to correct it and/or provide feedback for error correction without hindering their individual and the other team-members' flow of tasks.

Workload Distribution Management: It is the extent to which controllers have developed workload balancing strategies that enable them to detect and counteract workload problems of team members. Workload is not a constant parameter and it naturally follows the changing requirements of the escalation pattern of a critical situation. The steeper the escalation pattern, the steeper the increase of the workload for both the controllers. The task sequence may be altered while new tasks (those induced by the critical situation requirements) are added in the task backlog. The controllers have to manage, not only the normal traffic in their sector, but also the critical situation and the interactions between them. The criticality of the situation increases and diversifies the normal distribution of the workload and generates imbalances between the tasks of the controllers. Therefore, a critical need arises for the implementation of strategies that balance and keep the workload below saturation point for all members of the operating team.

4 CONCLUSION

Hollnagel and Woods (2006) argued that we can measure the potential for resilience but not resilience itself. In line with this reasoning, we conclude that these failure-sensitive cognitive strategies provide important practical examples of the potential for resilience in two levels. Firstly, by providing insights on how adaptations by local actors in the form of cognitive strategies are employed to support resilience in cases of safety critical events. Secondly by using these cognitive strategies as the foundation blocks in the development of an advanced safety training program with the aim of cultivating sources of resilience in the ATC system.

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