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The impact of controller support tools in enroute air traffic control on cognitive error modes: A comparative analysis in two operational environments

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ABSTRACT

Air traffic is increasing worldwide. In order to accommodate the anticipated rapid growth in air traffic in the future, changes are required to increase the capacity of the airspace. Although major structural changes in air traffic management in Europe are still underway through the implementation of 4D trajectories, many changes happened and are happening now through the introduction of new automated features in the enroute air traffic control systems. Examples of such air traffic control features are electronic coordination and conflict detection tools designed for air traffic controllers. Although it is likely that these controller support tools may decrease the possibilities of cognitive error, the introduction of new tasks may also introduce new sources of cognitive error. This paper describes the results of a qualitative analysis conducted in two European Area Control Centers, and compares possible cognitive error modes using the TRACEr method. The results show that for an operational environment equipped with controller support tools, the cognitive errors that may occur, have changed. Errors related to detection, memory, decision-making and action execution may decrease. However, new tasks related to the controller support tools may also introduce new errors such as those related to timely detection of information. Furthermore, the results show that there is a shift in type of errors which may occur during the execution of tasks. System safety may be increased through eliminating or reducing possibilities for cognitive error, increasing error recovery opportunities and indirectly through reducing mental workload related to the execution of tasks.

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1. Introduction

In Europe, air traffic transportation demands have increased significantly and were exceeding capacity limits of the European airspace network (Eurocontrol, 2008; International Civil Aviation Organization, 2007). In order to deal with these expected traffic demands in the future, a structural redesign of the European airspace is planned to increase the capacity of airspace sectors. Programs such as the Single European Sky ATM Research Program (SESAR) and USA‘s Free Flight-based NextGen (Eurocontrol, 2008; Joint Planning and Development Office, 2007; SESAR Consortium, 2008) aim to increase the capacity of airspace sectors through the introduction of 4D trajectories. The implementation of 4D trajectories incorporates significant changes, including a different organization and management of the airspace, higher levels of automation and modified distribution of tasks between pilots and air traffic controllers (Langan-Fox et al., 2009; Guibert et al., 2010; Rognin et al., 2001; Straussberger et al., 2008). Although these new operational scenarios have not yet been implemented in today's operations, many technological tools are currently being implemented in enroute control sectors as first steps towards the implementation of the operational scenarios as outlined and envisioned in programs SESAR and NextGen. Examples of these tools are the introduction of electronic communication between pilots and air traffic controllers, referred to as Controller–Pilot Data Link Communications, which is part of the LINK 2000+ programme (EUROCONTROL, 2009), and the implementation of controller support tools such as electronic coordination between airspace sec-

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tors, (System Supported Coordination), conflict detection and traffic monitoring.

An example of such an initiative in Europe is Eurocontrol's First Air Traffic Control Support Tools Implementation (FASTI) Program (FASTI, 2006, 2008). The objective of this program was to increase the capacity of the airspace sectors by reducing the workload of controllers for routine tasks and to increase safety by supporting controllers with Medium Term Conflict Detection tools, Monitoring Aids and System Supported Coordination. Electronic coordination allows air traffic controllers to electronically request and propose changes to flight trajectories, instead of coordination by telephone, required for tactical air traffic management. Currently, a number of European Area Control Centers (ACC) are already equipped with these technologies (EUROCONTROL, 2011; Le Roux, 2007).

The main advantages of these automated support systems are twofold. First of all, the new technologies may reduce potential sources of cognitive error. Controller support tools reduce or even completely eliminate the possibilities for certain cognitive errors. For example, the replacement of verbal or voice coordination with electronic coordination may create various advantages by eliminating cognitive errors resulting from mishearing or misunderstanding information exchanged over the phone or forgetting to record information (e.g. flight instructions on paper flight strips) for example during situations of high workload (Shorrock, 2005, 2007). Additionally, controller support tools may also provide opportunities to detect, diagnose and correct potential errors and thus reducing the operational impact of cognitive error through improved means for error detection, diagnosis and correction, also referred to as recovery opportunities (Shorrock, 2003).

Secondly, new technologies may also decrease task demands such as mental workload. For example, automated systems may support controllers directly at reducing the required mental workload related to required execution time for simple and routine tasks. Additionally, controller support tools may support controllers in reducing the required mental workload related to the detection and analysis of conflicts as well as the identification of conflict solutions (e.g. Kirwan and Flynn, 2002a). Mental workload is one of the most important factors driving human performance in air traffic control, also referred to as a *performance shaping factor* (Shorrock and Kirwan, 2002; Shorrock, 2003).

1.1. Challenges

Changing the operational work environment through the implementation of controller support tools in enroute control is a delicate process, since implementing new automation systems modifies the distribution of tasks between human and automated systems. For instance, conflict detection and analysis is now shared between automated systems and human agents which previously were solely allocated to the humans (air traffic controllers). This includes new tasks including monitoring conflict detection tools, interpreting the information and assessing the reliability of the conflict detection tools as well as identifying and analyzing possible discrepancies and making a final decision. Therefore, to what extent automation tools support controllers in making accurate and fast decisions, heavily depends on the reliability and the accuracy of the prediction tools, as well as the controller's ability to assess the accuracy of these predictions. The accuracy of the trajectory predictions may be impacted by winds, but also on the availability of airspace, phase of flight (e.g. holdings) as well as up-to-date information of aircraft performance. For example, in an experimental study conducted by Metzger and Parasuraman (2005), automation support tools increased controller's performance and reduced controller's mental workload, but only when the automation was reliable. Controller performance was better without support tools when the automation was inaccurate. Therefore, in order to make accurate statements about to what extent automation support tools may impact controller performance is highly dependent on the reliability and the accuracy of the support tools during all environmental conditions.

Various concerns have also been raised concerning the replacement of voice coordination with electronic coordination in air traffic control. As with datalink, electronic communication relies on the visual modality instead of auditory modality (Stedmon et al., 2007). Electronic communication messages may fail to be detected, and therefore may not be suitable for urgent situations which require immediate action (FASTI, 2009).

Cognitive error analysis is a useful approach to understand how these automated systems impact human performance at an individual level, and therefore safety and reliability of air traffic control (Kirwan, 2001). Although many studies have been conducted to evaluate the impact of new automated support tools using a cognitive error analysis (e.g. Kirwan, 2001; Shorrock, 2005, 2007), only few studies have conducted a complete systematic cognitive error analysis for an operational environment equipped with controller support tools. An example of such a systematic analysis was the human error analysis conducted in the FASTI project (Dehn et al., 2007).

1.2. Research aim

The aim of this paper is to compare the "classical" operational environment with paper flight strips with a 'stripless' work environment regarding the types of human error that may occur. The 'stripless' work environment includes dynamic and real-time integration of flight data onto the radar screen, electronic coordination, monitoring aids and provides controllers with Medium Term Conflict Detection tools.

The 'stripless' operational system may not only directly reduce the possibilities for cognitive errors by addressing the design of the operational system, but also through increasing the opportunity for detecting errors and reducing workload (an important *performance shaping factor*), required for the execution of tasks (Shorrock, 2003). Controller support tools, in particular monitoring tools, may especially support controllers under non-routine conditions or situations characterized by high levels of uncertainty such as weather conditions, when aircraft behavior is more difficult to predict.

This paper therefore tries to identify:

1. What potential human errors are likely to be reduced and what new errors are introduced in the new operational system? To what extent does the new operational system support controllers in routine and non-routine conditions?
2. Which tasks in 'stripless' operations support controllers, by reducing the mental workload required for the execution of these tasks?

This paper builds on previous research conducted within the human factors study of the FASTI project (Dehn et al., 2007). The FASTI project developed a Cognitive Task Analysis and conducted a human error analysis for all changed tasks as well as new tasks. Building on the results from the FASTI project, the aim of this paper is not only to identify new sources of potential cognitive error, but also to identify which errors are potentially reduced in 'stripless' operations.

1.3. Background

The main task of air traffic controllers in enroute air traffic control sectors is to ensure efficient and safe air transportation of aircraft within their area of responsibility, maintaining the separation

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