Safety Science 57 (2013) 27–34

Contents lists available at SciVerse ScienceDirect

Safety Science

journal homepage: www.elsevier.com/locate/ssci

Strategies in coping with complexity: Development of a behavioural marker system for air traffic controllers

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ARTICLE INFO

Article history:
Received 21 July 2011
Received in revised form 4 December 2012
Accepted 20 January 2013
Available online 24 February 2013

Keywords:
Complexity
Cognitive strategies
Teamwork
Behavioural markers
Error management
Air traffic control

ABSTRACT

To meet the increasing air traffic volume, organizations seek better tools to assess the traffic handling capacity of air traffic control (ATC) systems. This effort requires a better understanding of how complex situations are related to controller strategies and how controllers intervene to maintain control. Recent empirical studies and reviews have shown that controllers cope with complexity by adapting priorities, managing their cognitive resources, and regulating their own performance. This study discusses the development of a behavioural marker system to evaluate and provide feedback on the strategies that controllers use to cope with complexity. An extensive literature review provided the basis for an initial classification of strategies for coping with complexity which was tested in an observational study for reliability. After three iterations of adaptation to the taxonomy, two independent raters were able to reach acceptable levels of reliability in classifying video segments of simulated traffic scenarios. A potential application of the study regards the design of refresher training enriched with the principles of error management and the assessment of new technologies and controller tools on the handling capacity of ATC systems.

1. Introduction

The continued growth of civil aviation and the introduction of new air traffic management systems (e.g., free flight) have being changing the demands on air traffic control (ATC) services. The continuing growth of traffic requires an increase in the capacity of the airspace which can be achieved through the adaptation of airspace design (e.g., sector boundaries), controller tools (e.g., conflict resolution), and operating procedures (e.g., reduced separation minima). To assess the appropriateness of design interventions, however, it is important to understand how a given air traffic situation is related to the cognitive difficulty in controlling this situation and the associated workload (Mogford et al., 1995; Pawlak et al., 1996). Studying how controllers adapt their behaviour to cope with complexity is very important if we are to understand how modern technology and new demands may affect system performance. A comprehensive review of complexity in several domains showed that many definitions of complexity rely on the size or number of parts of the system which is not sufficient to account for the richness of what is meant by complexity (Edmonds, 1999). Another characteristic of complexity regards the connections between components and their dependencies that make it difficult to project system behaviour into the future. Xing and Manning (2005) proposed that complexity should be understood as a multidimensional construct with attributes encompassing the number and variety of elements as well as their relationships. On the basis of an extensive literature survey, a Eurocontrol report (Hilburn, 2004) identified several metrics of complexity based on regression models that weight task demands according to their predictive power. A well-known set of metrics is the *dynamic density metrics* (Laudeman et al., 1998; Masalonis et al., 2003) that attempt to predict change of mental workload over time. However, a unified dynamic density metric (Kopardekar and Magyarits, 2003) was found to account for less than half of the variance in self-ratings of mental workload.

Empirically derived metrics, such as the dynamic density metrics, focus on task demands and fail to model the capacity of controllers to respond; this may explain why a significant portion of variance remains unexplained (Loft et al., 2007). Recent studies have shown that the relationship between complexity and performance is not linear but it is an emergent property of the complex interaction between controllers and traffic situations (Athenes et al., 2002; Histon and Hansman, 2002; Mogford et al., 1995; Loft et al., 2007). This approach reflects earlier views of Sperandio (1978) that the relationship between complexity and performance outcome can be better understood by considering how controllers adapt their strategies to manage their cognitive resources and regulate their workload.

Brooker (2003) has postulated an adaptable function of performance over complexity that has been supported by earlier re-

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http://dx.doi.org/10.1016/j.ssci.2013.01.014

search. As complexity increases, controllers may change their priorities and the quality of service may become less important in favour of maintaining control of the whole stream of aircraft (i.e., fewer variables are taken into account). It is only above an upper traffic density that operational errors would become more frequent and general performance would deteriorate. It seems that there is little evidence to suggest that any sudden and uncontrolled fall of performance occurs, except at very high traffic flows.

A critical review of the literature (Loft et al., 2007) adopted a systems control model to examine the relationship between complexity and performance (Fig. 1). On the one hand, performance can be adjusted by explicit control of the airspace (shown in the outer feedback loop) to reduce complexity. In this sense, controllers can take action to change future task demands fed back through the system (e.g., by accepting aircraft early or by putting aircraft in a holding pattern). On the other hand, complexity can be managed by reorganizing priorities and choosing a different strategy (see dashed lines for feedforward and inner feedback loops). Looking at feedforward (at left), controllers may become aware that a large number of aircraft are about to enter the sector and thus adjust their strategy so that the communication load with aircraft on frequency becomes less. Looking at feedback (at right), controllers may become aware of potential conflicts and thus adjust their priorities toward achieving safety at the expense of quality of service. In these ways, the model in Fig. 1 shows that controllers monitor both the goal-state discrepancies and their own capacity to respond in order to develop their self-regulation strategies. The present study aims to classify strategies used by controllers to regulate their performance and maintain resilience despite high levels of complexity. The focus of this study has been on the inner feed-forward and feedback loops used by controllers to anticipate the 'work to be done' and assess the 'work in progress'. Attention should be paid, not only to individual strategies, but also to coordination and communication patterns that reduce workload and mitigate complexity.

2. Aims and structure of the study

The current study aims to examine how controllers adapt their performance to complex traffic scenarios. A critical review of the literature was undertaken to develop a classification of strategies that controllers use to mitigate complexity such as, adapting cycles of recognition and anticipation (Histon and Hansman, 2002), replanning (Brooker, 2003; Amaldi and Leroux, 1995), handling uncertainty, team coordination and restructuring (Stein et al., 2006; Koros et al., 2006). The classification of complexity mitigation strategies should be enriched with several behavioural markers that use domain specific language to exemplify performance concepts and facilitate the evaluation of strategies. Behavioural markers are 'observable, non-technical behaviours that contribute to superior or substantial performance within a work environment' (Klampfer et al., 2001, p. 10). It is important that behavioural markers describe observable behaviours and have a causal relationship with the performance outcome. Markers should exemplify concepts in a clear manner and relate to each other in a meaningful way (e.g., they may relate to a theoretical model of performance). Although behavioural markers cannot capture every possible aspect of performance (Flin et al., 2008), an effort was made in this study to identify those that have a direct influence on performance outcome. To test the reliability of the taxonomy, an observation study of experienced approach controllers used four simulated scenarios that were specifically designed to create complex traffic situations. Two independent raters have been presented with a large number of video segments of the simulated scenarios and applied the taxonomy. The evaluation process was iterative so that improvements could be made until a satisfactory level of agreement could be reached between the raters. A behavioural marker system of complexity mitigation strategies can be used to assess new technologies and foresee weaknesses that may lead to delays and errors in conflict resolution. It can also provide designers with useful knowledge to design flexible tools and emerging technologies that match the strategies of controllers.

The article presents several sources of complexity in air traffic control, models of the relationship between complexity and performance, and intervening factors (e.g., self-regulating strategies) in the introductory section. Section 2 presents the aim and structure of the study in order to develop an initial taxonomy of complexity mitigation strategies and make it more consistent and reliable in a following observational study. A literature review is undertaken in Section 3 to develop an initial taxonomy which is tested in an observational study of expert approach controllers (Section 4) in coping with abnormal situations and emergencies as part of an informal refresher training program. The results show how refinements in the categories have improved inter-rater reliability in a set of four ATC simulated scenarios (Section 5). Finally, we discuss the results in the context of adaptation of controller strategies and conclude with implications for error management training and design of ATC systems (Sections 6 and 7).

3. Complexity mitigation strategies in the ATC literature

The typical method for the initial development of behavioural marker systems is to carry out a literature review of domain specific research, followed by interviews and critical incident methods

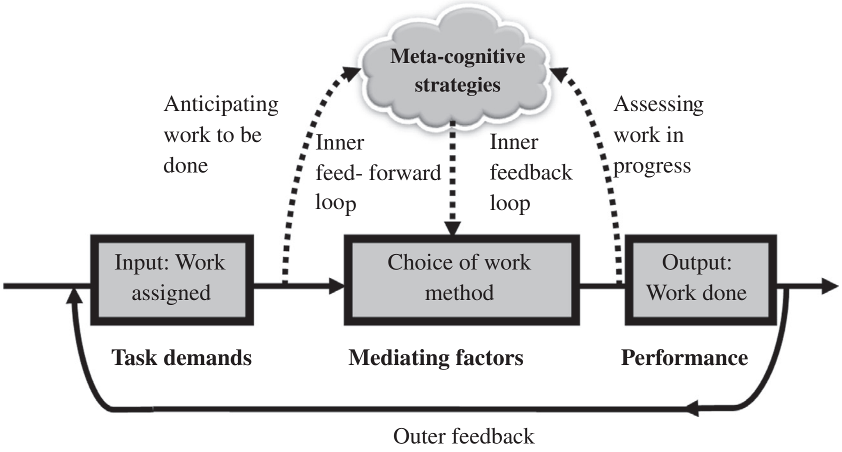

Fig. 1. A cognitive model of controller activities (adapted from Loft et al., 2007).