Transportation Research Part C 18 (2010) 930–936

Contents lists available at ScienceDirect

Transportation Research Part C

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

Air traffic control complexity as workload driver

Jelena Djokic [a,*], Bernd Lorenz [a], Hartmut Fricke [b]

[a] EUROCONTROL CEATS Research, Development and Simulation Centre, Ferihegy 1, "A" Porta, H-1185 Budapest, Hungary
[b] Institute of Logistics and Aviation, Technische Universität Dresden, Dresden, Germany

ARTICLE INFO

Article history:
Received 15 August 2008
Received in revised form 5 March 2010
Accepted 10 March 2010

Keywords:
ATC complexity
Task demand
Controller's activity
Workload

ABSTRACT

This paper describes an investigation into ATC complexity as a contributory factor in changes of controllers' workload. ATC complexity, together with equipment interface and procedural demands comprise the task demands on the controller; subsequent controller activities are mediated by performance shaping factors to create workload. In order to establish a link between ATC complexity and a controller's subjective workload, complexity factors are identified and subsequently related to workload indicators. The studied data comes from a real-time simulation using Controller-Pilot Data-Link Communication (CPDLC) technology, recently completed at EUROCONTROL CRDS in Budapest.

1. Introduction

Over the past decade Air Navigation Service Providers (ANSPs) have coped with significant traffic growth (SESAR Consortium, 2006a). The most pressing problem facing the European Air Traffic Management (ATM), therefore, will be to provide sufficient capacity to meet this increased air traffic demand, while at the same time the safety level of air travel has to be maintained or even improved. Airspace capacity that lags behind air traffic demand inevitably leads to flight delays, which in turn means an economic loss to airlines (SESAR Consortium, 2006b).

In the current air traffic control (ATC) environment the key limiting factor to increasing sector capacity is the workload of the air traffic controller. Therefore proposed solutions for increasing airspace capacity aim at reducing controller workload - which includes: the delegation of separation tasks from ground to the aircraft (e.g. Airborne Separation Assurance System (ASAS-TN2 Consortium, 2008)), a re-sectorisation of the airspace, and the introduction of new controller support tools in order to reduce the amount of work, or at least the difficulty of the controller tasks. As the work of air traffic controllers is predominantly cognitive in nature a considerable amount of research has been undertaken to understand the complex task demands that drive the workload of a controller (see Hilburn (2004) for a recent review). The term "workload" denotes a subjective quality reflecting the individual controller's perception of the task demand imposed on him/her by the current air traffic situation. Thus, many studies implicitly assume that controller workload varies as a function of both directly measurable air traffic factors (number of aircraft in the sector, speed variability, proximity of aircraft, etc.) and controller's activity mediated by factors such as the controller's abilities, age, fatigue, and level of experience (Loft et al., 2007).

The present paper examines the relationship between task demands as defined by a set of ATC complexity factors, controller's actions and subjective workload in the frame of ATC real-time simulations. Thus, the present study attempts to predict subjective workload as criteria on a moment-to-moment basis using a linear combination of ATC complexity

* Corresponding author. Tel.: +36 1 297 2241; fax: +36 1 297 2228.
E-mail addresses: jelena.djokic@eurocontrol.int (J. Djokic), bernd.lorenz@eurocontrol.int (B. Lorenz), fricke@ifl.tu-dresden.de (H. Fricke).

0968-090X/$ - see front matter
doi:10.1016/j.trc.2010.03.005

factors and controller's activity measures as predictors. Apart from enriching the research base on ATC complexity as an underlying driver of controller workload the knowledge of this relationship can be of quite a practical use for the planning and the conduct of ATC real-time simulations. In real-time simulations quite often the number of aircraft to be handled by the controller is systematically increased to either investigate capacity margins or to demonstrate that a proposed new operational concept has the potential to increase capacity, i.e. to improve the accommodation of increased traffic by the new concept. However, increasing the number of traffic may simultaneously induce changes in other traffic factors that likewise have an impact on the controllers' workload and performance. Therefore, it is necessary to identify all potential complexity variables and determine their interrelationships in order to better predict how a chosen traffic sample would increase the workload. This appears to be even more important when the simulation team wants to employ a series of traffic samples with identical 'difficulty', i.e. identical complexity, when e.g. familiarisation effects of using the same traffic samples across repeated exercises are to be minimized. Accordingly, it was one of the more practical aims of the present study to derive a set of suitable complexity factors with which a pre-analysis of traffic samples in the context of real-time simulations can be performed.

The paper is organized as follows: In the following section we will give a brief overview of research on ATC complexity and the derivation of task demand metrics from which a selection for the purpose of the present study was made. A more detailed description of controller's activity and workload measures used in the study follows. Next is described the real-time simulation experiment which provided the data base for the calculation/collection of the predictor and criterion metrics. What follows is a description of the approach for statistical analysis and the presentation of the results. Finally, these results will be discussed and conclusions drawn.

2. ATC complexity

A straightforward determinant of controller workload is simply the number of aircraft for which the controller is responsible in a specified time and sector. This measure is referred to as the sector load. Predicting sector load and avoiding sector overload is the basic tool upon which current traffic flow management is built. However, the level of difficulty experienced by the controllers depends on additional factors beyond the number of aircraft present in a sector (Sridhar et al., 1998). To be able to capture more accurately ATC complexity, it is necessary to take into consideration also flight characteristics of each individual aircraft as well as interactions between pairs of aircraft. Important flight characteristics of aircraft relate to instantaneous changes of the state of the aircraft, e.g. changes in altitude, heading or speed. Interactions between aircraft are considered not only in terms of potential conflicts but also include the pattern of how aircraft converge and the degree of what in (Delahaye and Puechmorel, 2000) has been referred to as the disorder among aircraft, i.e. the variability in headings and speeds of aircraft. Despite the fact that ATC complexity has been the subject of a significant number of studies (see Hilburn (2004) for a recent review), and many complexity factors have been proposed, up to now a comprehensive and generally accepted set of measures has not been defined.

For the purpose of the present study, a list of complexity factors was selected that has been consistently found to be important and for which detailed calculation formula have been reported. The factors were partially elicited from work described by Delahaye and Puechmorel (2000), Chatterji and Sridhar (2001), Kopardekar and Magyarits (2003), Gianazza and Guittet (2006), Laudeman et al. (1998) and Chatton (2001).

The selected overall set of 24 complexity factors is presented in Table 1. It is out of the scope of this paper to describe all 24 factors in detail. For a more thorough review of the listed factors readers are referred to the indicated source literature.

3. Controller activity – link between task demands and controller's workload

Even though task demand factors can capture one aspect of the ATC situation, it should be kept in mind that ATC is a dynamic environment and that controllers actively interact with the traffic, and therefore have an important influence on ATC complexity and hence the level of safety.

Several researchers agree that workload is a result of such a complex interaction between the task demand and the way the controller actively manages the situation (e.g. Hilburn, 2004; Loft et al., 2007; Majumdar et al., 2004; Pawlak et al., 1996). Moreover controllers, by performing certain activities, regulate the evolution of the task demands with the aim of keeping workload at an acceptable level. Nevertheless, not all controller tasks are observable. As defined by (Histon and Hansman, 2002), there are four controller tasks while managing the ATC situation: monitoring, evaluating, planning and implementing the formulated plan. Furthermore, out of these four tasks only one is observable, and that is the implementation process. It means that by taking only objectively measurable (sub)tasks into consideration, it is possible to capture only one aspect of comprehensive controller activity involved. However, as this aspect of the controller's activity is directly connected with changes made by the controller on the ATC situation, we considered it sufficient for our study.

Thus, in the current study, controller's input (data entries) and radio communication were used as the representatives of performed controller's activities (the study is based only on the executive controller data entries, and not planning controller, and therefore no phone communication is not considered here).