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A method to estimate air traffic controller mental workload based on traffic clearances

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ABSTRACT

Workload estimation is a complex domain which has been investigated extensively over the years. Past estimation techniques have focused on measuring workload directly from the air traffic controllers (ATCOs) or inferring it from traffic factors. The limitations of these techniques are interfering into the ATCO job and not being able to capture the differences amongst individual ATCOs respectively. This paper presents a novel technique overcoming these limitations, able to accurately estimate the workload experienced by the ATCO based exclusively on the clearances provided to air traffic. The technique, which was calibrated for the EUROCONTROL Maastricht Upper Area Control (MUAC) Centre, thereby has the potential to more accurately estimate actual airspace capacity. It is independent of the level of system automation and therefore applicable not only with the current ATM system, but also in the anticipated future highly automated environments as well as during the transition period. The paper discusses potential applications such as real time monitoring of operational workload and post-operations identification of sector workload imbalances. Both can contribute towards enhancing the performance of the ATM system.

1. Introduction

The Air Traffic Management system is undergoing a series of transformations to improve safety and efficiency. In Europe, this evolution is driven by the Single European Sky (SES) ATM Research (SESAR) programme. The shift is from an airspace-based concept to the concept of Trajectory Based Operations (TBO), where instantaneous and predicted aircraft positions are shared between all relevant stakeholders. In order to support this concept, several pillars, including collaborative planning, net-centric information sharing, integrated airport operations, strategic de-confliction new separation modes and advanced automation are required. The latter will have a direct impact on ATCO workload, as it will modify ATCOs' functions.

Research has shown that automation does not necessarily reduce ATCO workload (Endsley, 1996; Kauppinen et al., 2002; Lisanne, 1983; Sollenberger et al., 2004). In order to support the implementation of the SESAR operational concept and demonstrate the benefits released by the introduction of operational improvements there is a need to develop techniques and methods to quantify their impacts on the performance of various ATM system elements, including ATCO workload. Various studies have tried to quantify the impact of decision support tools and automated air traffic control (ATC) systems on ATCO workload (Jha et al., 2011). However, these studies have various limitations, including interference with ATCO functions, inability to capture ATCOs' individual differences, and large post-operations analysis. The methodology described in this paper aims to address these limitations in order to provide a more accurate ATCO workload estimation both for real time use and post processing.

Section 2 introduces the ATCO role in today's ATC system, and discusses the complexity that generates ATCO workload. Section 3 reviews the different existing methods for workload estimation and sets the basis for proposing a new method developed in Section 4.

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Section 5 explains the configuration of the data set used to carry out the workload estimation and the pre-processing method. Section 6 details the calibration tasks of the workload estimation model. Section 7 develops the method to compute the perceived complexity and shows the results of the calibration process for the workload model. In Section 8 the quantitative perceived complexity is translated into a qualitative mental workload scale. Section 9 introduces the tool developed for the workload calculation. Section 10 discusses the proposed model performance in comparison to the occupancy metric, identifying the benefits of the new technique. Section 11 lists potential applications of the model fore real-time operations and after-operations. Section 12 identifies the limitations of the proposed model and Section 13 discusses the requirements for an improved model performance.

2. Air traffic controller workload

2.1. ATCO role

The role of ATCOs is to control air traffic in a safe, ordered and expeditious manner (Seamster et al., 1993). In order to achieve this goal, en-route ATCOs work in pairs: the radar or Executive Controller (EC) and the coordinator or Planner Controller (PC). The EC is responsible for maintaining traffic separation, by issuing clearances to the traffic through Voice Communication Systems (VCS) or, increasingly data-link messages. The PC supports the EC in their tasks, by strategically planning traffic and coordinating entries and exits with neighbouring sectors.

In order to accomplish their targets, ATCOs carry out physical and cognitive tasks. Some of these tasks are service-oriented (e.g. communication) and others are cognitive (e.g. monitoring). Resources, such as other controllers, automation or pilots, are used to support task accomplishment. Every process is commanded by the internal ATCO core: the mental model and mental picture that build the situational awareness (Kallus et al., 1997).

Airspace capacity has traditionally been defined as the maximum traffic that can be controlled under acceptable workload levels (Majumdar et al., 2002). Although the ATCO can comprise the safety of the ATC operation with different operational errors due to a degraded cognitive performance (Reason, 1990; Hollnagel, 1998). Rodgers et al. (1998) show that increased complexity and subsequently workload leads to more frequent operational errors. Due to this fact, ATCO workload is closely linked to the maximum capacity of the airspace above which, separation losses can occur.

Increases in ATCO workload are managed by the ATCO by means of using different strategies to ensure that the primary goal, traffic separation, is achieved (Sperandio, 1978). This is accomplished through degraded the performance of other ATCO secondary objectives (e.g. efficiency) and by a more extensive use of cognitive resources (Robert and Hockey, 1997). However, when this regulatory process cannot meet the desired outcome, decrements in the accomplishment of the primary goal may occur.

Therefore, due to the relation between workload and the accomplishment of traffic separation, workload has been used as the main indicator for airspace capacity (Majumdar and Polak, 2001; Welch et al., 2007). In order to quantify ATCO workload, it is necessary to understand scenario complexity which is its main driver. This is discussed in the next section.

2.2. Complexity

Complexity is a magnitude that captures the level of difficulty of the ATCO job. There are two types of complexities for the ATCO: physical and mental. Therefore, complexity is usually divided into objective and perceived complexity (Li and Wieringa, 2000).

Objective complexity represents the complexity of the scenario based on quantifiable factors (e.g. traffic levels or mix of aircraft), regardless of the actual ATCO task execution. Various studies (Chatterji et al., 2008; Christien and Benkouar, 2003; Flynn et al., 2006; Gianazza et al., 2009; Kopardekar et al., 2008; Manning and Pfleiderer, 2006; Mogford et al., 1994; Terzioski et al., 2012) Djokic et al. (2010) have tried to capture the most important complexity factors affecting ATCOs. Mogford et al. (1995) make a clear division between the traffic pattern (dynamic traffic complexity) and the airspace procedures and characteristics (static sector complexity). However, these do not capture the variations of the cognitive processes between ATCOs, which modify the objective complexity of the scenario, resulting in a so-called perceived complexity.

Therefore, the concept of perceived complexity is more relevant, as it better accounts for individual differences between ATCOs for a scenario with a given ‘objective complexity’. The concept of perceived complexity was first introduced in Pawlak et al. (1996). In this study, perceived complexity is analysed with emphasis on ATCO mental rather than physical workload. (Histon and Hansman, 2002) use the perceived complexity concept in their differentiation between three complexity sub-groups: the ATCO-independent complexity, referred to as system complexity; the cognitive complexity associated with the mental picture of the ATCO; and the perceived complexity, the ATCO’s perception of the complexity of their mental representation. The complexity perceived by the ATCO will directly influence the strategy chosen to control the traffic, and therefore the workload experienced.

2.3. Workload

Based on the perceived complexity, which is generated by objective and subjectively perceived factors, the ATCO elaborates a strategy to control the air traffic (Fig. 1). In the strategy, The ATCO chooses from different control modes depending on the specific demand of the air traffic situation (Hollnagel, 2002). In this control mode a prioritization of the ATCO objectives is accomplished which reflects the workload experienced by the ATCO (Kallus et al., 1999). In fact, the formulated plan requires of a certain level of effort or workload to be accomplished. After formulating an initial plan to control the scenario, it is assessed in workload terms. If the workload resulting from the strategy planned does not match the desired workload, an iteration process is evoked until the plan produces an acceptable workload (Sperandio, 1978). This regulation process is typical especially during busy periods, when ATCOs have to prioritise their tasks. In order to accurately estimate mental workload, there is a need to build models able to capture this iterative cognition process.

Workload is a construct (Pawlak et al., 1996; Majumdar et al., 2002) i.e. a non-directly observable magnitude, which in turn leads to other observable phenomena. It indicates the human cost employed to accomplish a set of tasks (task load) to deliver a certain performance (Hart and Staveland, 1988; Low, 2004; Majumdar et al., 2005). By its own nature, workload is subjective and individually associated to each ATCO perception. In line with complexity, workload can be subdivided into physical and mental workload. In this paper the focus is on the latter, to account for the fact that, with the introduction of higher levels of automation, there is a shift towards increasing ATCO cognitive activity (Low, 2004). This paper infers the workload construct by means of identifying the strategy chosen and measuring the associated perceived complexity, an approach already used by Pawlak et al. (1996).

Traditionally workload has been quantified as a function of task demand, which is driven by scenario complexity. This approach assumes that every traffic scenario has a unique associated