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Dynamic airspace configuration by genetic algorithm

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HIGHLIGHTS

- An algorithm to solve a dynamic airspace configuration problem is proposed.
- The considered problem is formulated as a graph partitioning problem and is solved using genetic algorithms.
- Airspace configurations obtained using the developed algorithm, outperform the existing airspace configurations.

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ABSTRACT

With the continuous air traffic growth and limits of resources, there is a need for reducing the congestion of the airspace systems. Nowadays, several projects are launched, aimed at modernizing the global air transportation system and air traffic management. In recent years, special interest has been paid to the solution of the dynamic airspace configuration problem. Airspace sector configurations need to be dynamically adjusted to provide maximum efficiency and flexibility in response to changing weather and traffic conditions. The main objective of this work is to automatically adapt the airspace configurations according to the evolution of traffic. In order to reach this objective, the airspace is considered to be divided into predefined 3D airspace blocks which have to be grouped or ungrouped depending on the traffic situation. The airspace structure is represented as a graph and each airspace configuration is created using a graph partitioning technique. We optimize airspace configurations using a genetic algorithm. The developed algorithm generates a sequence of sector configurations for one day of operation with the minimized controller workload. The overall methodology is implemented and successfully tested with air traffic data taken for one day and for several different airspace control areas of Europe.

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1. Introduction

With the continuous air traffic growth and limited resources such as air traffic controllers, there is a need for decreasing airspace congestion by adapting current airspace design to new traffic demands. In order to manage air traffic safely and efficiently, the airspace is currently divided into 3D airspace volumes called *sectors*. An elementary sector is defined as a volume of the airspace within which the air traffic controller can perform his controlling function. Each sector assigned to a team of controllers is called a controlled sector. A set of controlled sectors composes an airspace configuration. An air traffic control (ATC) workload is a way of evaluating an air traffic situation inside the controlled sectors in terms of several factors. The first factor is related to the number of potential conflicts in the sector. The second one is linked to the monitoring workload in the sector. The last factor is a coordination workload, which takes into account all aircraft that cross sector frontiers (in this case pilots and controllers have to exchange information in order to ensure a safe transfer of aircraft between two sectors).

During the course of a day, the ATC workload fluctuates based on traffic demands between various origin-destination pairings. As the traffic in the airspace is changing with time, it is necessary to consider dynamic reconfiguration of the airspace for which the number of controlled sectors and their shape will be adapted to the current traffic situation. Initial sectors can be temporarily combined with others into a new controlled sector in order to improve efficiency of the airspace configuration. This process is called dynamic airspace configuration (DAC).

In DAC, airspace configurations are generated so as to reduce the coordination workload between adjacent controlled sectors and to achieve workload balancing between them for each time period of the day. The DAC process also has to ensure that configurations are stable over time periods. Other important aspects of DAC concern the reduction of multiple entries of an aircraft in the same sector and the maximization of the average flight time through the sector. The DAC problem is even more critical in the SESAR or NextGen framework. In comparison with a currently used fixed route network, the SESAR program introduces the user preferred routing (UPR) or free routing concept to enable the airspace users to plan freely 4D trajectories that suit them best. Contrarily to a fixed-route network, a free-route environment will produce a much larger number of different trajectories, for which the dynamic nature and flexibility of the DAC process will work most efficiently.

Our contribution aims at improving today's airspace management in Europe in a pre-tactical phase. Our research is part of SESAR Programme (Project SJU P07.05.04) co-financed by the EU and Eurocontrol. The aim of this project is to develop research prototype (decision-support tool) to support new sectorization methodologies based on 4D trajectories to deal with the implementation of the free routing concept in the short-term future.

In this paper, we present a genetic algorithm (GA) to solve the DAC problem. Our goal is to produce a solution (airspace configurations for several time periods) that satisfies most constraints and minimizes all costs. Our approach is based on a graph partitioning algorithm. The method is able to find a solution even for large problems such as, for example, configuration of the French Airspace for 24 h.

This paper is organized as follows: Section 2 presents an overview of related works. In Section 3, a mathematical model of the DAC problem is proposed. Here, the DAC problem is described as a multi periods graph partitioning problem. A pre-processing step is presented in this section as well. In Section 4, GA is introduced. Section 5 describes a GA approach for the DAC problem. Results are presented in Section 6. Finally, conclusions are presented in Section 7.

2. Previous related works

Till now, only several works concerning DAC have been produced. In fact, DAC is a quite new paradigm for airspace systems. The DAC concept consists in allocation of airspace as a resource to meet new demands of the airspace users. Further introduction to the DAC concept can be found in Kopardekar et al. (2007) and in Zelinski and Lai (2011). The DAC concept should not be confused with dynamic sectorization. The main aim of dynamic sectorization is to adapt the airspace to changing needs and demands of the airspace users, by creating an absolutely new sectorization for each time period of the day (Chen et al., 2013; Delahaye et al., 1998; Martinez et al., 2007). This means that at each time period controllers can be obliged to work with new sectors that have different design, as they are not composed of static airspace blocks, but built from “scratch”. From an operational point of view, this is not desirable, since controllers become more efficient as they become more familiar with airspace, i.e. controlled sectors.

Existing approaches on DAC are based on a model in which the airspace is initially divided into 2D or 3D functional airspace blocks (Delahaye et al., 1995; Klein et al., 2008; Zelinski and Lai, 2011) so that the DAC problem becomes a combinatorial problem. Configurations are constructed from controlled sectors, built from pre-defined airspace blocks. Nevertheless, several works are using already existing and operationally valid ATC sectors (Gianazza, 2010) to construct configurations, or even full configurations (Vehlac, 2005) to build an opening scheme.

Numerous works on airspace configuration have been produced in USA. A comparative description of 7 works can be found in Zelinski and Lai (2011). In Zelinski and Lai (2011) first three described works proposed methods for the DAC problem. These works were focused mainly on reducing delays and reconfiguration complexity in airspace configurations. Among these works, the most promising one is presented in Bloem and Gupta (2010). This work used as an input a set of given functional blocks (elementary sectors) and the number of open positions at each period. An output was a set of controlled sectors grouped into configurations. The workload of the sector was computed as the maximum number of aircraft in the sector during a given period of time divided by a monitor alert parameter (MAP). The method minimized a workload cost and a transition cost. It also satisfied several constraints (taking into account as soft