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Dynamic airspace sectorisation for flight-centric operations

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ABSTRACT

Today's air traffic operations follow the paradigm of 'flow follows structure', which already limits the operational efficiency and punctuality of current air traffic movements. Therefore, we introduce the dynamic airspace sectorisation and consequently change this paradigm to the more appropriate approach of 'structure follows flow'. The dynamic airspace sectorisation allows an efficient allocation of scarce resources considering operational, economic and ecological constraints in both nominal and variable air traffic conditions. Our approach clusters traffic patterns and uses evolutionary algorithms for optimisation of the airspace, focusing on high capacity utilisation through flexible use of airspace, appropriate distribution of task load for air traffic controllers and fast adaptation to changed operational constraints. We thereby offer a solution for handling non-convex airspace boundaries and provide a proof of concept using current operational airspace structures and enabling a flight-centric air traffic management. We are confident that our developed dynamic airspace sectorisation significantly contributes to the challenges of future airspace by providing appropriate structures for future 4D aircraft trajectories taking into account various operational aspects of air traffic such as temporally restricted areas, limited capacities, zones of convective weather or urban air mobility. Dynamic sectorisation is a key enabling technology in the achievement of the ambitious goals of Single European Sky and Flightpath 2050 through a reduction in coordination efforts, efficient resource allocation, reduced aircraft emissions, fewer detours, and minimisation of air traffic delays.

1. Introduction

The sectorisation of airspace considers requirements of air traffic management (safety, capacity and efficiency), users (unhindered access) and environment (restricted areas over cities, residential areas, etc.). Particularly, air traffic control requires the airspace to be structured in order to accommodate an appropriate operational infrastructure for airspace users and operators. The airspace sectorisation is primarily triggered by operational demands (such as handling of mixed traffic, balanced controller work load, procedure design or capacity management), territorial aspects (air sovereignty) and operational performance (Eurocontrol and FAA, 2016). In order to respond to the needs and future challenges of the air traffic (seamless European airspace), the European Commission (2004) initiated the Functional Airspace Block (FAB) design to implement multinational management and increase the airspace efficiency.

The dynamic airspace sectorisation presented in this paper deals with highly variable traffic patterns, which demand mid/short-term airspace adaptations. Our target is to create an appropriate, continuous airspace sectorisation in a fast and efficient way, which is able to react on current air traffic flows and efficiently support the airspace controller, even in uncommon traffic situations. Key drivers for dynamic traffic situations are characteristic air traffic flow patterns in Europe and the intercontinental connections (eastbound, westbound), as well as military actions (Islami et al., 2017), disruptive events such as volcanic ash eruptions (Luchkova

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et al., 2015), zones of convective weather (Kreuz et al. (2016)), prevention of contrails (Rosenow et al., 2017), consideration of commercial space operations (Kaltenhäuser et al., 2017) and integration of new entrants (Sunil et al., 2015; Temme and Helm, 2016), which demand an efficient operational solution.

Furthermore, our approach bridges the gap between structured and unstructured airspace designs and will also be a fundamental key element for an efficient management of the future urban airspaces. If, in the future, the urban area consists of a significant amount of movements of personal air vehicles, the frequency of traffic will follow the daily time-dependent demand for transportation. Similar to today, there is a clear indication of a highly used infrastructure, which changes over the day (e.g. morning and evening peaks in and out of the city). However, the urban airspace will also be limited and fragmented due to immanent safety aspects (e.g. minimum distance requirements) or restricted areas (e.g. critical infrastructure). The dynamic sectorisation provides a scalable approach to balancing the air traffic demands and operational requirements by clustering traffic patterns, identifying areas of high-density traffic and providing an efficient planning and control structure to support airspace operators and users. Air traffic management in urban areas is expected to be one of the most challenging tasks in the coming years. Instead of deriving future flow control methods from today's operations, we propose a fundamental change and provide an appropriate solution for handling dynamic traffic demands efficiently.

To ensure a more efficient allocation and a harmonised task load distribution, we consequently changed the current paradigm of traffic flow, which is determined by airspace structure ('flow follows structure'), to a dynamic approach of a structure that is adjusted to the traffic flow sequentially ('structure follows flow'). We contribute to the future flight-centric air traffic management with our specific approach of dynamically optimising the airspace focusing on the sector structure and resource allocation, considering both operational and economic efficiency targets (e.g. task load, fragmentation of flights by sectors). The approach of a dynamic reorganisation of airspace during the day of operation has several advantages, such as improved capacity utilisation through flexible use of airspace or appropriate distribution of task load for air traffic controllers and fast adaptation to changed operational boundaries. Dynamic Airspace Sectorisation (DAS) is a flexible method encompassing the idea of unstructured and (rigid) structured airspace, but differs from Dynamic Airspace Configuration (DAC), where predefined airspace blocks are combined to form new structures (merging and splitting). We are assuming a continuous airspace that will be separated without a specific demand for underlying structures but which considers both the current/future air traffic flows and the controller's ability to manage all assigned aircraft. DAS enables a continuous restructuring of airspace sectors that depends on current requirements, and will be an important element for efficient air traffic operations, taking into account both regular and disruptive events. In particular, DAS covers today's regular airspace structure and regional, trajectory-based, flight-/flow-centric operations challenged by SESAR Joint Undertaking (2015). As emphasized, we also see the DAS approach as a sustainable solution for future air traffic management in the context of urban flight operations. Our DAS solution can be adapted to different airspace management concepts and already covers all operational aspects needed for balanced handling of dynamic air traffic flow. It is scalable and therefore able to cope with a city's lower airspace (Cho and Yoon, 2018) as well as a huge part of the upper airspace (Schultz et al., 2017).

1.1. Status quo

Over the years, several authors have developed ideas for an automatic creation of airspace sectorisation or the adaptation of airspace sectors. Durand et al. (2015) provide a brief overview on metaheuristics used in airspace management. One of the first approaches using evolutionary algorithms was developed by Delahaye et al. (1998). Other approaches applied the principles of graph theory, Voronoi diagrams, linear integer programming or clustering of flight tracks. A detailed overview of recent work is given by Li et al. (2010) and Sherali and Hill (2011). A comparison of eight different methods is provided by Zelinski and Lai (2011). Furthermore, a survey on the work carried out in the area of dynamic airspace sectorisation is given by Flener and Pearson (2013), listing relevant approaches of recent years in a systematic manner. Many of these ideas are of a more theoretical nature and not all are directly applicable to an authentic non-convex airspace problem.

1.2. Objectives and document structure

The objective of our research is to automatically provide an appropriate airspace sectorisation, comparable to today's sector structure, without incorporating explicit expertise of air traffic controllers. This is necessary for a more flight-centred approach to sectorisation where the structure of the sectorisation depends highly on the predicted traffic. Especially for new approaches, such as the idea of ecologically sensitive flight operations, where airspace shall be closed due to contrail management, it will be necessary to adapt the airspace to the changed requirements of the environment. Therefore, it is not possible to rely on controller knowledge due to variable and dynamically changing constraints. In our case, the controller behaviour is implicitly covered by a task load model. Furthermore, the aim of our approach is to efficiently consider varying air traffic flows in different time intervals and react on specific events which influence the air traffic system, such as zones of convective weather.

When developing the idea of automatic sectorisation (AutoSec), we had in mind both flight-centric operations and multi-criteria optimisation. AutoSec allows the creation of an appropriate airspace structure in a three-step approach: (1) fuzzy clustering of traffic flows on the day of operations, (2) generation of new sector structure based on Voronoi diagrams and (3) application of evolutionary algorithm in order to adjust and optimise the new sector structure depending on dynamic demands over the day of operations. Within this paper, we compare the actual sectorisation of a specific airspace with evolutionary optimised solutions, which are based in a first step on real airspace and in a second step on newly created airspace structure. The optimisation in both cases is carried out with the same evolutionary algorithm and evaluation function (Gerdes et al., 2016).