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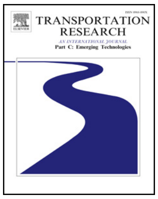

Surrounding traffic complexity analysis for efficient and stable conflict resolution

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ABSTRACT

The constant increase in air traffic demand increases a probability of the separation minima infringements in certain areas as a consequence of increased traffic density. The Annual Safety Report 2016 reports that in recent years the number of infringements, measured per million flight hours, had been increased at a lower rate (Eurocontrol, 2018). However, this level of infringements still generates a continuous pressure on the air traffic control (ATC) system and seeks for more control resources ready to tactically solve potential conflicts, while increasing at the same time the operational costs. Considering present air traffic management (ATM) trade-off criteria: increased airspace capacity and traffic efficiency but reducing the cost while preserving safety, new services must be designed to distribute the separation management ATC task loads among other actors. Based on the Single European Sky Air Traffic Management Research and Next Generation Air Transportation System initiatives, this paper proposes an innovative separation management service to shift the completely centralized tactical ATC interventions to more efficient decentralized tactical operations relying on an advanced surrounding traffic analysis tool, to preserve the safety indicators while considering the operational efficiency. A developed methodology for the proposed service is an application-oriented, trying to respond to characteristics and requirements of the current operational environment. The paper further analysis the traffic complexity taking into consideration the so-called domino effect, i.e. a number of the surrounding aircraft causally involved in the separation management service by the means of identification of the spatiotemporal interdependencies between them and the conflicting aircraft. This complexity is driven by the interdependencies structure and expressed as a time-criticality in quantifying the total number of the system solutions, that varies over time as the aircraft are approaching to each other. The results from two randomly selected ecosystem scenarios, extracted from a simulated traffic, illustrate different avoidance capacities for a given look-ahead time and the system solutions counts, that in discrete moments reach zero value.

1. Introduction

The main air traffic management (ATM) mission is to provide a set of services to preserve the required separation between aircraft to meet safety target levels, while competitiveness of the air transport is maintained by means of an efficient system, environmentally

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friendly and socially valuable (Di Gravio et al., 2015; Cook et al., 2017). Safety performance indicators are achieved through a set of mechanisms for the prevention of imminent hazardous situations that could evolve towards major incidents or even accidents (Gluchshenko & Foerster, 2013). These mechanisms are known as safety nets (Eurocontrol, 2013) and are structured in four main layers according to an operational time horizon:

- Strategic level: hours before flight departure, a ground regulation can be issued if a demand is greater than the available capacity and the system is in a maximum deployment state. By limiting the number of aircraft crossing an air traffic control (ATC) sector, the probability of a separation minima infringement can be reduced, but it cannot guarantee a conflict avoidance.
- Tactical level: medium term conflict detection (MTCD) function usually starts 20 to 15 min prior to a potential safety event occurrence, in which the air traffic controllers issue directives to one of the aircraft involved in a conflict to preserve safety distance.
- Pre-operational level: short term conflict alert (STCA) usually fires a warning to the ATC 120 to 90 s before a collision might occur.
- Operational level: Traffic alert and Collision Avoidance System (TCAS), is the last service to avoid a pairwise collision. The main difference with respect to previous safety net layers, is that TCAS is airborne system that functions independently of the ground-based safety nets, and provides collision avoidance protection for a broad spectrum of aircraft types.

Despite the excellent safety indicators achieved by the present safety net mechanisms, it is recognized that a lack of integration between the different safety layers introduces several penalties in key performance areas such as capacity (latent capacity) and operational efficiency (delays and maneuvers out of preferred trajectories). Furthermore, the pressure to accommodate more flights to satisfy the increment of air transport demand (Eurocontrol, 2018), will strain the loose ties between the safety nets with a negative impact on safety indicators. It is notable, for example, that present TCAS II v.7.1, has been designed for operations in the traffic densities of 0.3 aircraft per squared nautical mile [NM^2] (Tang et al., 2016). TCAS demonstrates excellent performances in cases of the pairwise encounters but, unfortunately, shows some operational drawbacks in its logic due to well reported induced collisions from specific surrounding traffic (ST) scenarios with higher density (Murugan, 2010). In (Jun et al., 2014), there are illustrated several ST scenarios in which TCAS resolution advisories (RAs) can induce a conflict.

To address these drawbacks in present and future air traffic, further research in the ATM sector is required towards development of a collaborative, proactive and decentralized separation management system considering a socio-technological approach in which both human behaviour and automation will play an important role (Prandini et al., 2011; Brázdilová et al., 2011). That envisages an operational seamless integration of the safety net mechanisms and procedures in such a way that any pair of aircraft involved in a conflict, together with the ST aircraft, behave as a stable and efficient conflict free air traffic system.

This article introduces an ATM framework relying on the concept of aerial ecosystems to transform opposite targets between a separation management function at the tactical level, and a collision avoidance function at the operational level, into a seamless cooperative efficient conflict-free framework. The framework is based on the so-called explicit coordination in conflict resolution. In many cases, the explicit coordination is an approach which is generally avoided for the main reason: the time it might take to solve a cluster of conflicts (Kuchar & Yang, 2000; Zeghal, 1998). Waiting for a new resolution means it could become more extreme than might have been necessary. Nevertheless, the available solutions space is being compressed in time.

A vector-based approach with an implicit coordination has also been shown to be able to solve the multi-aircraft conflicts in an effective and efficient way without the risks of deadlocks and waiting times. For instance, the modified voltage potential (MVP) is one of the approaches that was implemented for the conflict resolution in the multi-aircraft environment (Sunil et al., 2015). Within this approach, the conflict detection is performed by a state-based extrapolation of traffic positions, within a prescribed look-ahead time (LAT), using traffic transmitted state information (position, speed and heading). MVP is subsequently used to resolve conflicts in a pairwise manner. This method results in the implicit cooperative resolution strategies, where the distance between the conflicting aircraft at the CPA is increased to, at least, the minimum separation requirements. However, the concept extends the TCAS logic since LAT in this case is set to 60 s before the CPA, which practically means the method does not consider the SM-CA integration. Furthermore, less available space for the cooperative resolution exists, and consequently, the business preferences of the airspace users cannot be considered.

Another factor delimiting this approach in the effect of swarming (Maas et al., 2016). To cooperatively resolve the conflicts before collision avoidance, the aircraft are required to align their velocities and adjust their inter-distances for computation of the moment for triggering the cooperative resolutions. On the contrary, the ecosystem concept elaborated in this paper extends the time horizon providing more decision capacity at the SM level. The aircraft are aware of a potential deadlock moment while flying to the CPA, and given a possibility to interactively negotiate the solution, not requiring a priori any adjustment in velocity or heading and following the trajectories as approved. Moreover, identification of a higher number of the causally involved aircraft into enlarged ecosystem volume provides an opportunity for an efficient modeling of the optimal resolution trajectories, usually with the minimal deviations.

In recent years, more research efforts have been done in the field of the cooperative flights for unmanned aerial systems (UAS), focusing on development of the efficient trajectory planning and collision avoidance algorithms. Most of algorithms apply optimization techniques to generate the smother (or, less deviated) and safer trajectories. Sun et al. (2017) developed a collision avoidance algorithm for cooperative UASs based on an optimized artificial potential field (APF). The algorithm identifies both the static and dynamic (another UAS companions) obstacles from the single UAS perspective, as an ownship, and preservers from collisions. As such, it updates the trajectories in a planning phase by modifying the UAS state variables and smoothing the trajectory or mission profiles. However, the closure rates or relative speeds among UAS companions are not fully considered taking into consideration a speed change or acceleration of an UAS, after collision avoidance with a static obstacle. Moreover, the algorithm proposes a basic