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Generation and recovery of airborne delays in air transport

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ABSTRACT

The analysis of the causes behind the appearance and propagation of delays is one of the major topics inside Air Transport Management research. Existing research focuses by and large on Air Traffic Flow Management regulations and reactionary delays; less attention has been devoted to the study of the mechanisms governing the generation and absorption of delays while airborne, in spite of their important economical and environmental consequences. Here we present a methodology to detect delay-generating events, based on the comparison of planned and real trajectories; these events are then used to characterise several aspects of the dynamics of the system, *e.g.* its resilience. We apply this methodology to a historical data set of flights crossing the European airspace during 2011, and observe an overall resilient system, able to absorb as much delays as it generates; yet resilience is not constant, but strongly depends on the phase of the flight, and shows high spatial and temporal heterogeneities. We anticipate the proposed methodology to open new doors for the development of a better systemic performance, by enabling the characterisation and understanding of this fundamental type of delay.

1. Introduction

The analysis and characterisation of delays is one of the most important research topics in air transport management. Delays have profound implications in the cost-efficiency and safety of the system, and contribute to the negative impact of air transport on the environment. In monetary terms, delays have cost over 1.3 billion euro to European airlines in 2007 (Eurocontrol Performance Review Commission, 2007), at a rate of several hundred euro per minute (Cook et al., 2004). The economical impact of delays are not just felt by airlines, but encompasses passengers and the whole society (Cook et al., 2009; Cook and Tanner, 2011). It is further recognised that delays can significantly repercute on safety, especially when delays are not handled through ground programs (Duytschaever, 1993). Finally, both ground and airborne delays imply a use of fuel that has a direct environmental impact through CO and NO_x emissions; to illustrate, 1 min of ground delay implies between 1 kg and 4 kg of fuel consumption, one order of magnitude higher in the case of airborne delay (Carlier et al., 2007).

It is thus not surprising that a special attention has been devoted by the scientific community to the study of delay-related phenomena. Contributions encompass both the quantification of delay impact (Cook et al., 2004, 2009; Cook and Tanner, 2011; Ferguson et al., 2013), the assessment of delay causes (Santos and Robin, 2010; Pejovic et al.,

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2009), delay forecasting (Zografos and Madas, 2006; Rebollo and Balakrishnan, 2014), and the design of strategies for their mitigation (Wu and Caves, 2002; Delgado and Prats, 2012; Nosedal et al., 2014). Of special relevance are the studies about *reactionary delays* (AhmadBeygi et al., 2008; Jetzki, 2009; Fleurquin et al., 2013; Pyrgiotis et al., 2013; Fleurquin et al., 2014), *i.e.* the propagation process according to which one aircraft's late arrival is the cause of the delay of the following flight; and the analysis of the appearance of delays due to Air Traffic Management (ATM) regulations, *i.e.* Air Traffic Flow Management (ATFM) delays, caused by the limited capacities of both airports (Hansen, 2002) and airspaces (Glockner, 1996).

Little attention has hitherto been devoted to the assessment and study of non-AFTM delays, and specifically of the causes behind the generation and absorption of delays while the flight is airborne. Such delays may appear for different reasons, *e.g.* congestions not foreseen in the pre-tactical planning phase or adverse weather conditions. At the same time, *negative* delays may also appear, for instance when an air traffic controller reduces the trip time by opening direct routes. The importance of the study of such events was already recognised back in 2000 by EUROCONTROL, which stated that:

> " . . .*there is insufficient reliable data to enable the causes, locations and origins of all air transport delays to be clearly identified and analysed.*" (Performance Review Commission, 2000)

The same organisation, one year later, explicitly included "*en-route delay statistics and causal information*" in the list of topics that would need further development in the future (Performance Review Commission, 2001). Nevertheless, 15 years later, airborne delays are only mentioned in 2014 CODA delay report as a difference between departure and arrival punctuality, a simple positive or negative indicator also known as the *Delay Difference Indicator* (CODA, 2014).

The importance of non-ATFM delays is expected to grow in the near future, due to their important environmental impact. To illustrate, as calculated in (Carlier et al., 2007), airborne delay fuel consumptions are estimated to be about 6 times higher than ground ones, with emissions of NO_x, HC and CO about 3 times higher. In the frame of the increasing environmental sensitivity and of more strict air transport emission regulation (Scheelhaase et al., 2012), it will be more and more important to understand non-ATFM delay causes, in order to design better mechanisms to transform them in ground delays.

The quantification and analysis of non-ATFM airborne delays is far from being a trivial task. A simple comparison of delays at take-off and landing does not provide information about how the overall delay was generated; it is consequently necessary to follow the flight through its course, and compare planned and executed trajectories. This involves several challenges: (i) of data availability, as aircraft trajectories are seldom public; (ii) theoretical, for the need of algorithms able to compare the two trajectories, and of metrics able to quantify delay-related deviations; and (iii) computational, in order to achieve acceptable computational costs in the aforementioned metric evaluation, for the thousands of flights daily operating worldwide.

In this contribution, we propose a first step toward the understanding of airborne delays, by presenting a methodology to assess the appearance of non-AFTM delays from historical data. We discuss a computational framework that compares planned and executed radar trajectories, to detect events in which the aircraft deviates from the original plan - spatial deviations that are, under an hypothesis of constant velocity, interpreted as a gain or loss of time, and thus as a delay. The analysis of such events allows a full characterisation of the system, in terms of: the spatial location of these events, which is related to the efficiency of different regions of the airspace; the relationship between the appearance of ground and airborne delays; and the system capacity of recovering from delays, *i.e.* its resilience. In order to illustrate the advantages of the proposed methodology, we further analyse a historical data set including all flights crossing the European airspace during 2011; and create graphical representations of the most efficient and resilient regions of Europe.

Beyond this introduction, this contribution is organised as follows. Section 2 presents the algorithms behind the identification of delay-generating events from planned and real aircraft trajectories. Afterwards, Section 3 reports on the application of this framework to a historical data set representing European flights in 2011, with results organised according to the dimension considered: temporal (Section 3.2), spatial (Section 3.3), and flight phase (Section 3.4). Finally, Section 4 draws some final conclusions and proposes future lines of research.

2. Assessing airborne delays

2.1. Identification of delay-generating events

As a first step towards the characterisation of airborne delay, we are here going to describe an algorithm to detect delay-generating events. We define such events as occurrences that affect the delay of a flight both positively or negatively; they are due to changes in the trajectory of an aircraft with respect to the initial plan, resulting in positive delays, *i.e.* when they introduce an unexpected delay, or in negative ones, *e.g.* if the travel time is reduced by ATC. Note that here *positive* and *negative* delays thus refer to their contribution to the total flight time, and not to the benefits/problems generated. Additionally, we here consider that aircraft fly at a constant velocity - see the end of this Section for a thorough discussion of this hypothesis. Hence a change in the distance to the destination is equivalent to a change in the flight time, and in the delay. This allows us to understand the proposed distance-based metric as a time-based one.