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## Airline-driven ground delay programs: A benefits assessment

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### ABSTRACT

Three decades of research studies in ground delay program (GDP) decision-making, and air traffic flow management in general, have produced several analytical models and decision support tools to design GDPs with minimum delay costs. Most of these models are centralized, i.e., the central authority almost completely decides the GDP design by optimizing certain centralized objectives. In this paper, we assess the benefits of an airline-driven decentralized approach for designing GDPs. The motivation for an airline-driven approach is the ability to incorporate the inherent differences between airlines when prioritizing, and responding to, different GDP designs. Such differences arise from the airlines' diverse business objectives and operational characteristics. We develop an integrated platform for simulating flight operations during GDPs, an airline recovery module for mimicking the recovery actions of each individual airline under a GDP, and an algorithm for fast solution of the recovery problems to optimality. While some of the individual analytical components of our framework, model and algorithm share certain similarities with those used by previous researchers, to the best of our knowledge, this paper presents the first comprehensive platform for simulating and optimizing airline operations under a GDP and is the most important technological contribution of this paper. Using this framework, we conduct detailed computational experiments based on actual schedule data at three of the busiest airports in the United States. We choose the recently developed Majority Judgment voting and grading method as our airline-driven decentralized approach for GDP design because of the superior theoretical and practical benefits afforded by this approach as shown by multiple recent studies. The results of our evaluation suggest that adopting this airline-driven approach in designing the GDPs consistently and significantly reduces airport-wide delay costs compared to the state-of-the-research centralized approaches. Moreover, the cost reduction benefits of the resultant airline-driven GDP designs are equitably distributed across different airlines.

### 1. Introduction

The ground delay programs (GDPs), first formally described by [Odoni \(1987\)](#), have been a topic of air traffic flow management research for almost three decades. GDPs are used when the demand for flight operations at an airport exceeds capacity for a certain period of time, with the most common cause being a reduction in airport capacity due to bad weather. In a GDP, flights bound for congested airports are delayed on the ground (prior to their departure), so as to match the arrivals at the destination airport with the capacity at that airport. The underlying motivation is that, as long as a delay is unavoidable, it is both safer and less costly for the

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flight to absorb this delay on the ground rather than in the air. Numerous previous research studies have focused on many different aspects of GDPs, including optimal assignment of ground delays using optimization models, better understanding of the underlying system dynamics using data analytics and machine learning (Cook and Wood, 2010; Kulkarni, 2011; Kulkarni et al., 2013, 2014; Bloem and Bambos, 2015; Kuhn, 2016; Estes et al., 2017; Ren, 2017; Gorripaty et al., 2017), actual field experiments (Shisler et al., 2013), as well as some recent studies that attempt to integrate ground delay strategies with some other traffic flow management ideas including cruising speed adjustments, cruising altitude changes, and aircraft reroutings (Delgado and Prats, 2013; Jones et al., 2015, 2017). Note that rather than attempting to cite all major GDP-related studies, we have simply cited some of the most important recent studies in these respective areas.

The typical objective of a centralized GDP design optimization problem is to minimize the sum of ground and airborne delay costs, when facing an anticipated demand-capacity imbalance at an airport, by assigning departure delays to flights. Literature on optimization models for GDP decision-making can be broadly classified into two streams: the *single airport ground delay problem* (SAGDP) (Richetta and Odoni, 1993, 1994; Ball et al., 2003; Mukherjee and Hansen, 2007; Kuhn, 2013) and the *multi-airport ground delay problem* (MAGDP) (Vranas et al., 1994a,b). SAGDP optimizes ground delay assignment assuming a single, isolated airport with reduced capacity, while MAGDP considers network effects such as delay propagation along an aircraft flying through multiple airports. Literature can also be classified into *deterministic* and *stochastic* models depending on whether future capacity information at the airport(s) of interest is deterministic or probabilistic. The third dimension along which we can divide the literature is the nature of the decision-making process: *static* and *dynamic*. The static approaches solve the GDP design problem once and then implement that plan for the rest of the day (Richetta and Odoni, 1993; Vranas et al., 1994b; Ball et al., 2003). On the other hand, the dynamic approach allows updates to the GDP design decisions when more accurate weather and/or capacity information becomes available (Richetta and Odoni, 1994; Vranas et al., 1994a; Mukherjee and Hansen, 2007).

Although the literature on optimal GDP design can be classified into different categories, they all share a common characteristic: they all present *centralized* methods, wherein the central aviation authorities (e.g., Federal Aviation Administration (FAA), Eurocontrol, etc.) almost completely decide the GDP design. GDP design, however, involves tradeoffs and the central authority often does not have access to all relevant information about each airline's business objectives, operational characteristics and network strategy while making these decisions in a centralized manner. Therefore, centralized methods are likely to make decisions under insufficient information about airline operations and hence, might result in suboptimal decisions.

Let us delve deeper into some of the factors that should be considered when planning GDPs. A useful example is the decision between *aggressive* and *conservative* GDP designs, which is necessitated by the uncertainty around our knowledge of future capacity. Setting GDP duration aggressively short (thus assigning less ground delays to flights) might incur unexpected additional airborne delays due to last-minute GDP extensions if adverse weather continues longer than anticipated. On the other hand, setting GDP duration conservatively long (thus assigning lengthy ground delays to flights) might lead to unused capacity and unnecessary delays. One might argue that this trade-off is accurately captured by the stochastic centralized models with the airborne-versus-ground delay trade-off driving the solution to the appropriate balance. However, such characterization of the trade-off ignores airline reactions and their recovery operations in response to a GDP. These recovery operations significantly modify the nature of these trade-offs in ways that are not currently modeled in the centralized optimization approaches.

When the operations of an airline are disrupted, due to a GDP or otherwise, a number of actions are taken to try to bring operations back on track as soon as possible and with as little cost as possible. This is achieved by using a number of alternative recovery actions including intentional flight departure delays, flight cancellations, aircraft reassignments, crew swaps, passenger rebookings, etc. Different airlines have different recovery capabilities due to the differences in their network structures, fleet compositions, recovery flexibilities, and other operational characteristics, to name a few. This variation causes airlines to have different preferences toward alternative GDP designs. For example, an airline operating a frequent shuttle service with low load factors and a single fleet type can often rebook disrupted passengers easily and can often also swap aircraft easily. For such airlines, operating under a conservative but more predictable GDP design allows full utilization of the airline's recovery capability to mitigate adverse operational impacts. For an airline with lower schedule frequency and higher load factors, however, recovery is relatively more difficult. For such airlines, aggressive GDP designs may be preferred so that less initial ground delays are assigned and the flights are allowed the best chance to land as soon as possible. Centralized models either completely ignore airline recovery actions, or model only the simplest of the recovery actions, such as delaying of flight departures. However, any accurate performance metric for a GDP design needs to account for the effects of that GDP design on the airlines and all the passengers that are impacted by the airlines' recovery actions in response to the GDP. Thus the performance of the air transportation system should be measured in terms of the actual operational performance (flight delays, passenger delays, etc.) of all airlines instead of a simple metric such as the sum of ground and airborne delay costs calculated assuming simplified or no recovery actions. We thus argue that a GDP planning method should take airlines' preferences and reactions to a GDP into consideration and strive to better support the airlines' business objectives. This approach could improve the air transportation system's performance from the perspectives of its various stakeholders.

In fact, several recent research studies have already been focusing on developing these "airline-driven" GDP decision-making approaches. Evans et al. (2016) evaluate several approaches for systematically collecting preferences from airlines and conclude that voting is the most promising among their tested methods with respect to airline profitability, system optimality and equity. They also suggest exploring the effectiveness of other variants of voting/grading mechanisms, including a newly developed method called Majority Judgment (Balinski and Laraki, 2010). Swaroop and Ball (2013) and Yan et al. (2017) apply the Majority Judgment method to the airline-driven GDP design problem and report promising performance based on their analytical and computational studies. In both approaches, the underlying idea is for the FAA to provide an initial list of candidate GDP designs, and then for all involved airlines to grade these candidate designs. Consistent with the Majority Judgment paradigm, the candidate with the highest median

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