# Managing Air Traffic Disruptions through Strategic Prioritization

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## Extended Abstract

In the U.S. air transportation system, congestion and resulting delays place a tremendous financial burden on airlines, passengers, and the U.S. economy as a whole. The total cost of U.S. domestic air traffic congestion has been estimated as $31.2 billion for the year 2007 (Ball et al. 2010). One obvious approach for addressing the imbalance between capacity and demand is to increase the capacity of key system resources – the airports and the air sectors. Unfortunately, this presents substantial challenges. For example, it is difficult to build new runways where they are needed most because the most congested airports are typically in costly, space-constrained, urban environments.

Outside of capacity increases, there are, broadly, two approaches to addressing congestion. The first is to manage existing capacity more effectively, while the second is to incentivize airlines to schedule fewer flights. In our work, we show how to accomplish these objectives simultaneously through the *strategic prioritization* of flights. In strategic prioritization, we propose a scheme that forces airlines to make flight priority trade-offs at the time flights are scheduled. When there is a disruption and capacity needs to be rationed, the specified priorities allow the regulator to allocate capacity more effectively. Additionally, making these strategic trade-offs causes more of the congestion-related costs to be internalized by each airline, thus reducing over-scheduling.

The mechanism we use for incorporating flight priorities is air traffic flow management (ATFM). Air traffic flow management initiatives, such as ground holding programs, are implemented on the day of operations when there are expected to be significant imbalances between capacity and demand. In a ground holding program, arrival slots for an airport or air sector are allocated to carriers, with expected arrival delays converted into ground holding at the airport of departure. These slots are allocated according to the posted flight schedule (i.e., first-scheduled, first-served) through a process known as Ration by Schedule (RBS). RBS has become the accepted view of fairness within the industry, and in the case of a single ground holding program, it has been shown to have nice theoretical properties relative to both fairness and efficiency (Vossen and Ball 2006).

A number of rationing schemes have been proposed as alternatives to RBS (e.g. Ball et al. (2010), Manley (2008)). Our approach modifies RBS by treating flights with priority as if they had been scheduled earlier than their actual time. Since airlines are able to assign priorities in advance of operations, this effectively allows airlines to trade-off congestion costs across different airports and days. Thus, our work is related to market-based mechanisms for ATFM, such as slot exchanges (Vossen and Ball 2006), auction-based slot allocation (Vazirani 2011), and day-of-flight waivers (Hoffman et al. 2011). Unlike slot exchanges and auction-based slot allocation, which are unlikely to be practically feasible due to the complexity introduced for airline recovery operations, our approach requires complex decisions in advance of operations but does not alter airline recovery approaches on the day of operations. Independent of our work, day-of-flight waivers have recently shown promise in a human-in-the-loop simulation setting. They represent another approach to prioritized slot allocation by allowing airlines to exempt individual flights.

Since airlines have a limited budget of priority to assign, if they schedule fewer flights they can assign more priority to the remaining flights. Thus, airlines that choose to schedule more flights are forced to internalize some of the costs this imposes on other airlines' operations. Because of this, our approach realizes some of the benefits of market-drive approaches to congestion reduction such as slot auctions (e.g., Ball et al. (2006), Harsha (2008)) and congestion pricing (e.g., Brueckner (2002), Brueckner (2005), Morrison and Winston (2007)) However, unlike these market-based slot allocation approaches, our scheme is non-monetary, addressing airline concerns about the imposition of additional monetary costs on their operations. Opposition to monetary costs has been a significant barrier to previous attempts to reduce congestion through mechanisms such as a now-canceled auction of landing rights at New York-area airports (United States Department of Tranportation May 13, 2009). Additionally, the fact that our approach is indirect, limiting slot allocation only when weather conditions are poor, provides another advantage with respect to industry acceptance. Because U.S. airlines make significant investments in domestic airport facilities, more direct approaches for constraining access to system resources can be easily challenged by the airlines that invest in these resources.

In our work we

- introduce the *Ration by Prioritized Schedule* (RBPS) algorithm for air traffic flow management;
- provide simulation results derived from historical data showing that RBPS allows a more efficient allocation of congestion costs;
- develop a game-theoretic model and equilibrium analysis of a system in which airlines strategically allocate these priorities; and
- provide simulation results showing that this causes airlines to internalize and reduce congestion costs.

Our first set of simulations suggest that even simple heuristics for assigning priority that could be implemented by the FAA today, for example assigning priority proportional to the number of seats on a flight, can lead to passenger delay reductions of 4.5%. Allowing airlines flexibility in allocating their priority leads to even larger improvements.

Giving airlines more flexibility in assigning priorities also introduces strategic considerations. Thus, we design a method of allocating priorities that guarantees the existence of pure strategy equilibria. Furthermore, recognizing that the existence of a priority budget may have an effect on airline decisions about the number of flights to schedule, we analyze the subgame perfect equilibria of a two stage game where in the first stage airlines determine how many flights to schedule and in the second stage they bid for priorities. While there may be multiple pure strategy equilibria, we show that the total number of flights scheduled in all equilibria (weakly) decreases as the amount of prioritization provided increases.

Our theoretical results are guaranteed to hold only for priority allocations of a limited size, but suggest that their conclusions may still hold in practice with larger allocations.

Our second set of simulations provides evidence that this is the case, as well as helping quantify the extent to which this approach can close the gap between the number of flights scheduled under RBS and the smaller, socially optimal number of flights.

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