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Preemptive rerouting of airline passengers under uncertain delays

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ABSTRACT

An airline's operational disruptions can lead to flight delays that in turn impact passengers, not only through the delays themselves but also through possible missed connections. Since the length of a delay is often not known in advance, we consider *preemptive rerouting* of airline passengers before the length of the delay is realized. Our goal is to reaccommodate passengers proactively as soon as it is known that a flight will be delayed instead of waiting until passengers have missed connections. We consider the simplified version of the real-world problem in which only a single flight is delayed. We model this problem as a two-stage stochastic programming problem, with first-stage decisions that may preemptively assign passengers to new itineraries in anticipation of the delay's impact, and second-stage decisions that may further modify itineraries for any passengers who still miss connections after the delay has been realized. We present a Benders Decomposition approach to solving this problem and give computational results to demonstrate the reasonable run time in solving our model. This research lays the groundwork for the more-realistic case in which multiple flights in the network may experience concurrent delays.

1. Introduction

Airlines often face unexpected disruptions of their scheduled flight times, frequently caused by inclement weather, maintenance problems, and system congestion. A delay in one flight often propagates to other flights through delayed aircraft and crews. These operational disruptions can lead to flight delays that in turn impact passengers, not only through the delays themselves but also through resulting missed connections.

According to http://www.transtats.bts.gov (n. d.), in the period from January 2014 to February 2015, about 24% of flights in the US were delayed or canceled (based on reporting carriers). Specifically, in the first two months of 2015, which represent the current available data for this year, 21.26% of flights were delayed and 3.61% were canceled. It is clear that this high percentage of flight delays and cancellations causes passengers to miss many flight connections.

Passenger reaccommodation is commonly handled on an ad hoc basis, where each passenger is considered separately and only after a connection has been missed. Some airlines may watch for passengers who will be most affected when flights are delayed, especially those who have flights that are international or are at the end of the day, but reaccommodation is often done manually.

Unlike many other airline recovery problems, little research has been done on passenger reaccommodation. In this paper, we propose an approach to improve the recovery of passengers impacted by delays. In particular, we focus on doing so proactively, anticipating and addressing a possible missed connection, rather than waiting until after the missed connection has occurred.

Before looking at an example, we explain the idea of an itinerary. An itinerary is a passenger's plan consisting of one of more flights in a relative short time period that will end in the desired destination. Thus, an itinerary may be just one flight, and normally not more than 2 or 3. Also, this means that passengers on a given flight usually represent at least several different itineraries and therefore possible missed connections.

In particular, the length of a delay is often not known in advance, presenting challenges in making decisions for passengers, as illustrated by the following example. Suppose that a passenger has an itinerary consisting of two flights:

- Flight A from EWR to DTW, departing at 12:00 pm and arriving at 2:10 pm
- Flight B from DTW to LAX, departing at 3:40 pm and arriving at 6:25 pm

Further suppose that there is a mechanical delay on Flight A. The delay will either be 45 minutes, if the necessary part is available on site, or three hours, if the part must be flown in from another airport.

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Other itineraries that have available capacity are the following:

- Itinerary 1:
  - Flight C from EWR to CMH, departing at 12:30pm and arriving at 2:30pm
  - Flight D from CMH to LAX, departing at 5:30pm and arriving at 8:00pm
- Itinerary 2:
  - Flight A from EWR to DTW, departing at 12:00pm and arriving at 2:10pm
  - Flight E from DTW to LAX, departing at 7:10pm and arriving at 9:55pm

Consider two possibilities. In the first, the passenger remains on her original itinerary. If the delay on her first flight turns out to be 45 minutes, then she will make her second flight and reach her destination on time. Conversely, if the delay is three hours, then she will miss her second flight. In this case, she will receive a new itinerary consisting of Flight E arriving at 9:55pm, 3 hours and 30 minutes later than planned.

Alternatively, if the passenger proactively switches to Flight C when the delay on her first flight is discovered, she will arrive at her destination at 8:00pm, 1 hour and 35 minutes later than planned.

In this example, keeping the original itinerary with the delayed flight leads to the passenger arriving either on time or 3.5 hours late, depending on the duration of the delay. Alternatively, changing itineraries proactively when her first flight's mechanical delay is discovered ensures that the passenger will arrive one hour and 35 minutes late. The optimal choice depends on the probability of each possibility for the length of delay and on the passenger's individual preferences. A passenger's priorities may depend on her destination, reason for travel, schedule once at her destination, and other considerations.

In actuality, airlines often have passengers keep their original itineraries until the delay length is realized, instead of considering the option of proactively moving the passengers onto different flights. If that is the case, after the delayed flight reaches its destination, recovery decisions are made and disrupted passengers are reaccommodated one-by-one.

This method has limitations in that, since passengers are not given new itineraries until they have already missed connections, alternate flight possibilities may be lost. Conversely, if reaccommodated proactively, passengers may be able to take itineraries that would otherwise no longer be available. This is the focus of our approach.

The remainder of the paper is arranged as follows. In Section 2, we review the literature, discussing work in passenger routing and, more broadly, airline recovery in general. Next, in Section 3, we present the *PRP (Preemptive Rerouting of Passengers)* model. In Section 4, we discuss the implementation of the model, including how Benders Decomposition is used to find solutions in tolerable run times. Last, Section 5 contains a summary and discussion of future research plans.

The contribution of our research is in introducing a new approach to passenger reaccommodation that proactively handles passenger delays before misconnections occur. We present the PRP model and investigate a Benders Decomposition-based approach to finding tractable solutions. Our computational results show the approach's effectiveness for reducing the length of passenger delays. Thus, the model lays the groundwork for studying the more realistic problem in which multiple flights may experience concurrent delays.

2. Literature review

When a flight is delayed or canceled, its passengers must be reaccommodated and the flow balance for the aircraft and crew must be preserved. Although there has been substantial research on recovery methods in passenger aviation, not much research has been done specifically in the area of passenger reaccommodation after a delay, and we did not find any other papers addressing preemptive rerouting of passengers. Below, we briefly discuss some models that route passengers, recovery of other factors, and recovery of multiple system resources including passengers.

2.1. Models that route passengers

There have been several papers that address routing of passengers, though not specifically re-routing after delays.

For example, within the fleet assignment model (FAM), it is necessary to consider not only assignment costs but also passenger revenues (often modeled through *spill costs,* the revenue loss associated with an aircraft that is too small to accommodate all demand for the flight). In Rexing (1997) and Rexing et al. (2000), the authors allow small changes in an original flight schedule in order to give better options while solving the fleet assignment problem and minimize operating costs and spill costs. To capture this, the model must explicitly consider the assignment of passengers to itineraries.

In Barnhart et al. (2002), the authors create the Itinerary-Based Fleet Assignment Model that approximates spill costs and recapture of passengers, producing better solutions for fleet assignments. The Passenger Mix Model is also described, where decisions are made as to what fraction of passengers from each itinerary to spill to each other itinerary given a solution to FAM. The authors of Jacobs et al. (2008) use origin and destination network effects and expected passenger flows in their fleet assignment model.

2.2. Schedule robustness and recovery of factors other than passengers

Although recovery models for passengers do not appear heavily in the literature, there is much published research on other types of recovery. In particular, recovery of aircraft, crews, and flight schedules has been studied in great depth. In addition, important research has been done on the topic of creating more robust schedules that respond better under delay situations in order to create schedules that perform better in practice. Various topics on robustness of schedules and recovery after delays are discussed in this section. Our goal is to give some context to reaccommodation of passengers and to see how techniques studied in the papers relate to passenger recovery.

For example, Lapp et al. (2008) study how robust a given flight schedule is, determining how delays can be propagated from one flight to others. In Ahmad Beygi et al. (2010), the authors redistribute slack already existing in the system in order to lessen delay propagation. They allow small changes in the flight departure times, but do not allow changes in the fleet assignment solution or the crew scheduling solution, so that planned costs do not change, but operational performance can improve.

Delays still occur even with well-designed robust schedules. The Crew Recovery Model presented in Lettovsky (1997) and Lettovsky et al. (2000) gives solutions to the problem of creating new schedules for crews after flight delays. In Abdelghany et al. (2004), the authors present a tool for decision-making that proactively handles reaccommodation of crews. Their goal is to minimize cost from reassignments and delays. An example of a stochastic integer programming problem with recourse is given to solve the airline crew scheduling problem in Yen and Birge (2006). In the objective function of the model is the cost if the problem was deterministic, and there is also a term for the expected cost of recourse in case of disruptions.