Flight Rescheduling Decisions for Robust Passenger Itineraries

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Abstract. It has been the practice of the majority of airlines to reschedule passengers and flights so as to minimize flight delay. Some airlines are now starting to look at the problem of rescheduling from the perspective of the passenger and are trying to minimize the impact of missed and cancelled connecting flights on the consumer. In this paper we propose the algorithm Schedule Minimization foR Generalized Operational Logistics (SMRGOL) for minimizing airline passenger trip delay. Though SMRGOL is the first step in developing an algorithm for decreasing passenger trip delay, we demonstrate improvement in passenger delay.

Keywords. Decision-guidance management systems, passenger trip delay, database languages, SMRGOL.

Introduction

The airlines provide a critical service to the nation's economy, providing rapid, safe, and affordable transportation over large geographic distances. The reliability of this transportation service, defined as the difference between the ticketed arrival time and the actual passenger arrival time, translates into economic productivity. For example, in 2007, the total delays experienced by airline passengers were estimated at 30,000 years. The estimated cost of these delays to the U.S. economy was $16.1B in lost economic productivity [1]. Further, one out of five passengers experienced a disrupted trip, and the average trip disruption was 110 minutes [2][3].

The U.S. government and industry are collaborating on two approaches to improve the infrastructure required to operate the airline transportation system (ATS). First the Airport Improvement Plan [4] is working to relieve the bottlenecks at U.S. airports by increasing the flight capacity through the addition of runways, taxiways, gates, terminal buildings and service facilities at key nodes of the air transportation system. Second, the proposed $37B air traffic control modernization program, known as NextGen[5], will improve productivity and the utilization of existing airspace.

In [6], a probabilistic model was introduced to better understand the impact of improved on-time flight performance generated by the Airport Improvement Plan and the effect of NextGen on passenger trip reliability. The mains results of the analysis using this model are as follows:

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- Flight delays account for approximately 41% of the total passenger trip delays. The remaining passenger trip delays are a result of trip delays experienced by passengers due to cancelled flights and missed connections.
- The way airlines design their networks has a significant impact on total passenger trip delay. The *ratio between direct and connecting itineraries*, the *time between banks at the hubs*, the *frequency of service*, and the *selection of aircraft size* and *target load factor* play a significant role in determining passenger trip reliability.

Though the Airport Improvement Plan and NextGen do improve flight on-time performance, they do not improve passenger trip reliability and the associated improvement in lost economic productivity. In minimizing passenger trip delay, there are two questions we need to focus on:

1. Whether optimizing passenger delay as opposed to flight delay can significantly improve the quality of service to passengers within the same cost to the airlines?
2. Can we develop algorithms that are close or near to optimal, yet have manageable computational complexity?

This paper is the first step in answering the second question. In this paper we focus on developing an algorithm for creating an optimal flight schedule minimizing Passenger Trip Delay (PTD) instead of focusing on minimizing flight delay. More specifically, the contributions for this paper are as follows. We present the PTD problem including the formulation and precise computational form. We also introduce an algorithm Schedule Minimization foR Generalized Operational Logistics, SMRGOL, for rescheduling passengers while minimizing PTD. We also conduct some initial experiments with this new algorithm.

This paper is organized as follows. In Section 1, we explain the problem including the PTD formulation. In Section 2 we describe the computational form for PTD computation. In Section 3 we introduce the algorithm SMRGOL for optimally rescheduling passengers with the results of experimentation described in Section 4. Then we conclude the paper in Section 5.

1. The Problem

Passenger Trip Delay is defined as the difference between the actual time of arrival of the passenger and the ticketed time of arrival.

Passenger Trip Delay = Actual Time of Arrival – Ticketed Time of Arrival

Passenger Trip Delay can occur as a result of one or more of the following scenarios:

1. Passenger arrives on-time on the ticketed flight (i.e. less than 15 minutes after ticketed arrival time).
2. Passenger arrives late on the ticketed flight (i.e. greater than 15 minutes after ticketed arrival time).
3. Passenger arrives late when the ticketed flight is diverted.
4. Passenger arrives late after being re-booked on a later flight when the ticketed flight is cancelled.

5. Passenger arrives late, when the passenger is denied boarding on the ticketed flight and is re-booked on a later flight.
6. Passenger is on a connecting flight that arrives late at the connecting airport therefore missing the ticketed next leg in their itinerary, and is re-booked on a later flight.

Scenarios 1, 2, 3, and 4 are illustrated in the Time-Space diagrams in the Figure 1. Scenario 5 is a variant on Scenario 4.

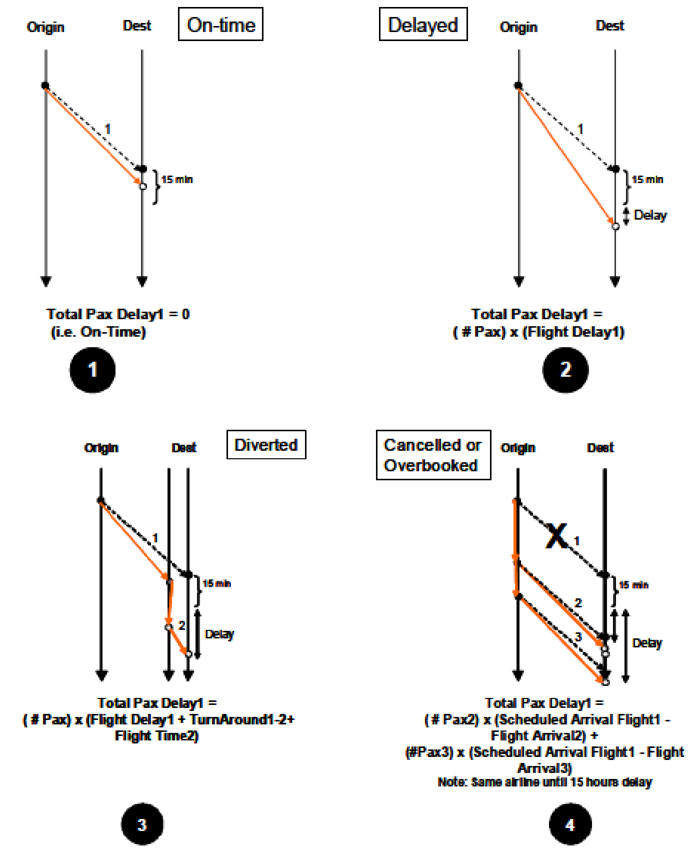

Figure 1. Passenger Trip Delay (solid) is determined by one of the scenarios described in Space-Time diagrams. The dashed line corresponds to the scheduled arrival time of the flight.

The trip delays experienced by passengers on late flights and on diverted flights are proportional to the magnitude of the delay of these flights. The trip delays experienced by passengers that have to be re-booked due to cancelled flights, denied boarding, or missed connections are a function of the frequency and load factors (i.e. seats available) on other flights to the ticketed destination. As the frequency of the flights decreases and/or the load factor of candidate re-booked flights increases, the “reservoir” of seat capacity is reduced and the trip delay experienced by these passengers increases non-linearly.

2. PTD Computation

The algorithm for estimating Passenger Trip Delays uses the Airline On-Time Performance (AOTP) data-base to compute passenger trip delays. The AOTP data-base contains on-time arrival data for non-stop domestic flights.

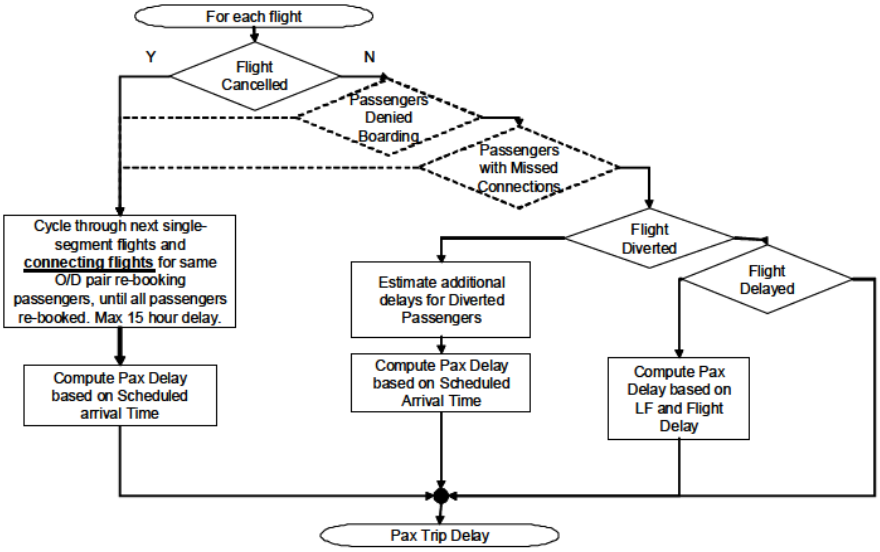

Figure 2. Algorithm used to compute Passenger Trip Delays. Dashed elements identify limitations of the algorithm that are under development.

The Passenger Trip Delay Algorithm for computing the PTD is summarized in Figure 2. For each day in the period under analysis, each passenger itinerary is processed. If the itinerary is a connecting itinerary, the algorithm follows the left branch (shaded). If the passenger itinerary is a direct itinerary, the algorithm follows the right branch. The algorithm checks for cancelled flight, diverted flight and delayed flight, rebooking and/or assigning passenger delays as described above. For more details on the algorithm, see [7].

3. SMRGOL: Schedule Minimization foR Generalized Operational Logistics

Currently, when one of the flights of a passenger is late, the passenger may miss the connecting flights and have to be rescheduled on subsequent flights. This domino effect can quickly add to the passenger's frustration and increase his trip delay. SMRGOL takes a flight schedule as input and generates a schedule that minimizes passenger trip delay. This can be done either by rescheduling the passenger or by holding the connecting flight for a period of time to allow for the passenger to make the flight.

The flights are broken into two groups, or tiers, with the next tier depending on the previous tier. One group of flights, referred to as soft constraint, is flights that are dependent on each other for flight connections (as opposed to depending on the aircraft). The second group of flights,, referred to as hard constraint, consists of flights where the flight is dependent on the physical plane of the previous flight. With the soft constraint group, the flights of the next tier dependent on a previous flight can still meet its departure time as a flight leaving before the flight in the previous tier has arrived results in passengers missing the flight. For the hard constraint group, the flight in the next tier cannot leave because it is dependent on the plane itself.

Table 1. SMRGOL Algorithm

```
Input: init_schedule – Initial Schedule
Output: best_schedule - New Flight Schedule with minimum PTD

Structures:
    min_PTD – minimum passenger trip delay
    best_schedule – the schedule with the minimum PTD
Initialization:
    schedule := apply_hard_constraint_reschedule (init_schedule);
    best_schedule := schedule;
    min_PTD := PTD (best_schedule);

    For Every tier = 1 to num_tiers Do
        schedule := soft_reschedule_tier (tier);
        schedule := hard_reschedule_tier (schedule);
        PTD := PTD (schedule);
        If PTD < min_PTD Then
            best_schedule := schedule;
            min_PTD := PTD;
        End If
    End For
```

Table 2. soft_reschedule_tier Algorithm

```
Input: tier – a tier of the flight schedule
Output:
   schedule – the soft constraint flights rescheduled so connections are made

Structures:
    new_departure – max arrival time of pre-flights of a flight

For Each flight In tier  Where constraint = 'soft' Do
   new_departure := flight.departure_time;

   For Each pre_flight In flight Do
      If pre_flight.arrival_time > new_departure Then
         new_departure := pre_flight.arrival_time;
      End If
   End For
   flight.departure_time = new_departure + 30 minutes;
End For
```

Table 3. hard_reschedule_tier Algorithm

```
Input: schedule –the flight schedule
Output: schedule – new flight schedule
```

```
Structures:
   new_departure – max departure time for a plane so that it arrives at the
                   destination before its next flight
For Each tier In schedule Where constraint = 'hard' Do
   new_departure := flight.departure_time;

   For Each plane In tier Do
      If plane.arrival_time > plane.next_depature_time Then
         plane.departure_time :=
               plane.next_depature_time – plane.flight_time – 30 minutes;
      End If
   End For
   plane.departure_time = new_departure;
End For
```

4. Initial Experimental Results

For our experiment, we used a 131 airport hub-and-spoke network with Dallas, Texas as the hub and 130 spoke airports gleaned from airline transportation system statistics from 2007. Using data for a 24 hour period, we compared the PTD of SMRGOL to rescheduling passengers on the next available flight to their destination. If there was not a new connecting flight for a passenger during the twenty-four hour period, a 900 minute PTD was assumed. For rescheduling of passengers, the total PTD for the 24 hour period was 13358 hours. With SMRGOL, the PTD was reduced to 11836 hours giving an 11.4% improvement.

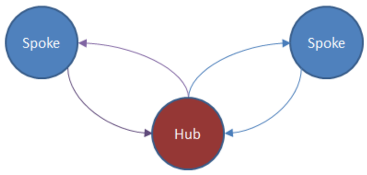

Figure 3. Hub and spoke network with flights going into and out of the hub

5. Conclusions and Future Work

SMRGOL minimizes PTD, but it is just a first step. In future iterations, we intend to extend the optimization with stochastic simulation to increase accuracy, model trade-offs between passenger delay and airline costs, and extend the class of scheduling problems for which to develop SimQL [8][9] algorithms based on the optimization of model approximation.

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