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Optimization of assigning passengers to seats on airplanes based on their carry-on luggage

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ABSTRACT

We build upon previous work that assigns passengers to a specific numerical position in line that depends on their seat location. The assignment of seat locations to passengers depends on the number of luggage they carry aboard the plane. In particular, we propose a mixed integer programming model that determines the number of luggage to be carried by passengers assigned to each seat. Numerical results indicate that the proposed approach results in a reduction of the time to complete the boarding of the plane. The improvement is greatest when many luggage are carried onto the plane. The optimal distribution of luggage assigns passengers with few carry-on bags to the rows of the plane closest to the entrance.

1. Introduction

The total annual cost of airplane delays in 2007 in the United States alone was $29 billion (Ball et al., 2010). Jaehn and Neumann (2015) cite cost estimates of airplane delays ranging from $30 to $250 per minute. While some delays result from bad weather, mechanical issues, and congested airspace, as noted in Ball et al. (2010), other delays are due to the time to board passengers. To reduce the time it takes passengers to board their airplanes, Delta Airlines offered valet services on some flights to pre-load passengers' luggage (i.e. bags) for them (Koeing, 2015). Clearly, methods that reduce the time to board airplanes would be advantageous for the airlines and their passengers.

Skorupski and Wierzbinska (2015) determine the optimal time to wait for a late passenger to arrive at the gate. Many publications assume passengers are called to board in blocks or groups (e.g., Kuo, 2015; Bachmat et al., 2013; Bachmat and Elkin, 2008; Bazargan, 2007; Soolaki et al., 2012; Van den Briel et al., 2005) and that passengers board in a random sequence within a group. In an invited literature review, Jaehn and Neumann (2015) provide a broad overview of boarding methods and describe the 12 most relevant papers in detail. Of the methods they studied, the Steffen (2008) boarding sequence results in the fastest time to complete the boarding of all passengers.

Boarding starts when the first passenger begins entering the aisle of the airplane in row 1 and concludes when all passengers have been seated. We assume a fully loaded airplane with 20 rows and three seats on each side of a single aisle. Fig. 1 illustrates the Steffen (2008) boarding sequence. If we assume that all passengers walk down the aisle at the same speed and there is always an empty row between them, then with Steffen (2008), the first set of 10 passengers to board the plane all begin storing their carry-on luggage, if any, at the same time and occupy a window seat in every other row. For instance, as indicated in Fig. 1, the 10th passenger to board the plane sits adjacent to the window in row 2 and begins storing his or her luggage in an overhead bin at the same time that the first passenger to board begins to store his or her luggage in row 20. The first group of 10 passengers is followed by a second group of 10 passengers sitting on the opposite side of the plane. As implied by Fig. 1, the process continues until the final 10 passengers to board (passengers 111–120) take their aisle seats in the 10 odd-numbered rows of the plane.

Milne and Kelly (2014) and Qiang et al. (2014) build upon the work of Steffen (2008) by considering the amount of carry-on

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Row	Window	Middle	Aisle	Entrance	Aisle	Middle	Window
1	40		120				30
2	20						10
3	39		119				29
4	19						9
5	38		118				28
6	18						8
7	37		117				27
8	17						7
9	36		116				26
10	16						6
11	35		115				25
12	15						5
13	34		114				24
14	14						4
15	33		113				23
16	13					43	3
17	32		112				22
18	12					42	2
19	31		111				21
20	11					41	1

Fig. 1. Passengers boarding a plane in the sequence of the Steffen (2008) method.

luggage that passengers bring aboard the plane. Both of these papers utilize the Steffen (2008) sequence of boarding in which passengers board in a specified numeric sequence determined by their seat assignments. However, Steffen (2008) ignores the volume of carry-on luggage in the seat assignments. Milne and Kelly (2014) assign passengers to seats so that the carry-on luggage is distributed evenly throughout the plane and so that passengers with the most bags sit nearest to the windows. Qiang et al. (2014) assign passengers with the most bags to seats in the rear of the plane. Qiang et al. (2014) achieve a reduction in the boarding time (versus Steffen, 2008) that they point out is “much consistent with works done by Milne and Kelly (2014).” They say that their approach is easier to understand and implement than Milne and Kelly (2014). However, a limitation of Qiang et al. (2014) is the potential for overcrowding of luggage near the rear of the plane. Suppose, for instance, that there are 30 passengers carrying two bags and they are all assigned to sit in the final five rows of the airplane. Would there be room in the overhead bins for six bags on both sides of the aisle for five consecutive rows? We suspect that applying the Qiang et al. (2014) method consistently may lead to some situations of overcrowding near the rear of the plane. This could lead to blockage in earlier rows and result in an increase in total boarding time. Milne and Kelly (2014) avoid such overcrowding. Consequently, we use Milne and Kelly (2014) as a benchmark to test against the proposed method. In our method, we propose using a mixed integer program (MIP) to determine the number of luggage to be carried by passengers assigned to each seat assignment. Similarly to Milne and Kelly (2014) and Qiang et al. (2014), we propose first assigning luggage to seats and after the luggage assignment has been completed, assign passengers carrying those amounts of luggage to those seats, and have them board the plane in the Steffen (2008) sequence. Our objective is to minimize the time to complete the boarding of the airplane.

In Section 2, we describe the assumptions we make regarding passenger flow, the storing of luggage, and sitting down. In Section 3, we describe the MIP model we propose. In Section 4, we describe numerical results comparing the proposed method with the method of Milne and Kelly (2014). Section 5 concludes our paper by highlighting insights, discussing practical considerations for implementation, and suggesting future research directions.

2. Passenger movement assumptions

We make the following assumptions on passengers flow, the storing of luggage, and the time to sit down. In the absence of interference from other passengers, we assume that the time it takes a passenger to move down the aisle from one row to the next, $Trow$, is 2.4 seconds and that the time for a passenger to sit down after storing any carry-on bags, $Tsit$, is 8 s. These times are the same as the average times used by Milne and Kelly (2014) and are based upon Van Landeghem and Beuselinck (2002)—who gathered data at Brussels National Airport—and Audenaert et al. (2009). We use average times in our assignment of luggage to seat locations because we assume we do not know the speed of individual passengers.

At time zero, the first passenger begins walking down the aisle. We assume a passenger walking or standing in the aisle consumes the aisle space of an entire row. This includes some personal space for passenger comfort. Because we assume a Steffen (2008) sequence of boarding, there will be at least one row separating the seat of a passenger from the seat of the next passenger that follows in the boarding sequence; consequently, there will not be two passengers storing their luggage at the same time in adjacent rows; this allows for further personal comfort and safety. We assume a passenger begins storing his or her carry-on bags in the overhead bin after completely entering the row in which he or she will be sitting. For instance, referring again to Fig. 1, the first passenger will begin storing any bags in the overhead bin above his or her window seat in row 20 after completing entering row 20 at time 48 s (calculated via $20 * Trow = 20 \times 2.4 = 48$). Consistent with Milne and Kelly (2014), we assume that a passenger does not begin entering a row until the row has been completely cleared of other passengers. For instance, the second passenger will wait until time 4.8 s before he or she begins to enter row 1. That is because it takes the first passenger 2.4 s to enter the first row and another 2.4 s to clear (exit) it. Time 4.8 s is the instant at which the first passenger has immediately left row 1, is standing in row 2, and is about to enter row 3. At time 7.2 s, the first passenger is standing in row 3 and the second passenger is standing in row 1. Until the final passenger begins walking down the aisle, we assume there is always a passenger waiting at the aisle's entrance for aisle space to become available to enter the first row. That first row aisle space becomes available when the previous passenger has cleared row 1 (either by completing a move into row 2 or by sitting down in a row 1 seat).

We use the same luggage storage assumptions as Milne and Kelly (2014). A passenger carries zero, one, or two bags onto the plane. Each row has an overhead bin on each side of the aisle. We assume each bin has unlimited storage space but account for the fact that a passenger takes longer to store luggage when the passenger has more luggage to store and when there is already more luggage in the bin. In particular, a passenger takes $Tstore$ seconds to store his or her luggage using Eq. (1) derived by Audenaert et al. (2009).

$$Tstore = ((Nbin + Npassenger) * Npassenger/2) * Trow \tag{1}$$

The terms in Eq. (1) are defined as follows:

Tstore Time to store the luggage (calculated)
Nbin The number of luggage in the bin prior to the passenger's arrival
Npassenger The number of luggage the passenger has
Trow Time for a passenger to walk from one row to the next