ABSTRACT

This paper aims to survey the aircraft boarding strategies currently adopted by major airlines in the United States. We also present a zero-one linear program for finding the optimal grouping of passengers with assigned seats to get on an aircraft so that the total amount of time required to remove all the aisle and seat interferences is minimized. We conclude by highlighting the contributions of the present study and pointing out several directions for future research.

KEYWORDS: Aircraft boarding, plane turnaround, Airline industry, Zero-one linear programming

INTRODUCTION

Today, 15 mainline and 70 regional carriers own a fleet of 7,200 passenger and cargo aircraft to provide domestic and international transportation services in the United States (Federal Aviation Administration, 2013). Many of them have been experiencing financial difficulties in recent years due to increasing fuel prices, fierce market competition, and operational inefficiency. They continue to look for ways to provide better services at lower costs in order to survive and thrive. One of the key areas identified for improvement is plane turnaround.

Plane turnaround consists of landing, taxiing, parking, passenger deplaning, baggage unloading, cargo unloading, refueling, maintenance, cabin cleaning, galley servicing, cargo loading, baggage loading, passenger boarding, taxiing, and taking off (Nyquist and McFadden, 2008). Several studies have pointed out that passenger boarding is the most time-consuming activity in the turnaround process (Marelli et al., 1988). Long boarding time often results in late departures, which in turn might cause passengers to miss connecting flights and hurt an airline’s on-time rating as well as profits.

HEURISTIC BOARDING STRATEGIES

It is a common practice in the U.S. airline industry to allow first- and business-class travelers, frequent flyers, passengers requiring special assistance, and uniformed military personnel to board first. Then a range of experience-based boarding methods are employed to get the rest of the passengers on the aircraft. Some of the most popular ones are briefly examined below (Bachmat et al., 2009; Nyquist and McFadden, 2008):
(1) Back-to-front (BF): This strategy calls for dividing the seats in the cabin into a number of zones with each zone consisting of several rows, the first zone being at the back, and the last zone being at the front. Passengers with seats in the first zone are loaded first and those with seats in the last zone are loaded last. A graphical illustration of BF is given in Figure 1, where there are eight rows of six seats each, the cells represent the seats, and the number in each cell indicates the zone number. Moreover, A, B, and C denote the left widow seat, the left middle seat, and the left aisle seat, respectively. Likewise, D, E, and F denote the right aisle seat, the right middle seat, and the right window seat, respectively.

![Figure 1: Boarding Sequence Based on BF Strategy](image)

(2) Rotating zones (RZ): This strategy divides the seats in the cabin into a number of zones with each zone consisting of several rows, the first zone being at the back, and the last zone being at the front. Passengers sitting in the first zone are loaded first, who are followed by those sitting in the last zone. This alternation process continues towards the center of the aircraft until everyone is on board. A graphical illustration of RZ is given in Figure 2.

![Figure 2: Boarding Sequence Based on RZ Strategy](image)

(3) Outside in (OI): Based on this strategy, passengers with window seats on either side of the aisle are loaded first, followed by those with middle seats, and then those with aisle seats. A graphical illustration of OI is given in Figure 3.
(4) Random (RD): Based on this procedure, passengers are loaded on a first-come-first-served basis. A graphical illustration of RD is given in Figure 4.

MATHEMATICAL MODELING APPROACH

The notation for the mathematical program to be presented is as follows:

\[ \begin{align*}
N &= \text{Number of rows of seats in a plane.} \\
G &= \text{Number of groups of passengers boarding a plane.} \\
\alpha &= \text{Fraction of passengers in a group that are not yet seated when the passengers in the next group board a plane (0} \leq \alpha \leq 1). \\
\beta &= \text{Fraction of all seats in a plane that are occupied (0} \leq \beta \leq 1). \\
U &= \text{Maximum number of passengers in a group.} \\
L &= \text{Minimum number of passengers in a group.} \\
t_a &= \text{Amount of time required to eliminate an aisle interference (either between groups or within a group).} \\
t_s &= \text{Amount of time required to eliminate a seat interference (either between groups or within a group).} \\
M &= \text{An extremely large positive number (e.g., 1,000,000).}
\end{align*} \]
\( i \) = Index of row number, \( i = 1, 2, \ldots, N \).

\( j \) = Index of seat number, \( j = 1, 2, \ldots, 6 \), where 1 = A (left widow seat), 2 = B (left middle seat), 3 = C (left aisle seat), 4 = D (right aisle seat), 5 = E (right middle seat), and 6 = F (right widow seat).

\( k \) = Index of group number, \( k = 1, 2, \ldots, G \).

\( x_{ijk} \) = 1 if a passenger is assigned to Row \( i \), Seat \( j \), and Group \( k \) and 0 otherwise, \( i = 1, 2, \ldots, N; j = 1, 2, \ldots, 6; k = 1, 2, \ldots, G \).

The zero-one linear program for the aircraft boarding problem developed by us is shown below:

Minimize 
\[
Z = t_a \sum_{i=1}^{N} \sum_{j=1}^{6} \sum_{k=1}^{G} AB_{ijk} + t_a \sum_{i=1}^{N} \sum_{j=1}^{6} \sum_{k=1}^{G} AW_{ijk} + t \sum_{i=1}^{N} \sum_{k=1}^{G} \left( SB_{i1k} + SB_{i2k} + SB_{i5k} + SB_{i6k} \right) + t \sum_{i=1}^{N} \sum_{k=1}^{G} \left( SW_{i1k} + SW_{i2k} + SW_{i5k} + SW_{i6k} \right)
\]

subject to:

\[
AB_{ijk} \geq -M(1 - x_{ijk}) + \alpha \sum_{u=1}^{i} \sum_{v=1}^{6} x_{u,v,k-1}, \quad i = 1, 2, \ldots, N; j = 1, 2, \ldots, 6; k = 2, 3, \ldots, G
\]

\[
AW_{ijk} \geq -M(1 - x_{ijk}) + 0.5 \sum_{u=1}^{i} \sum_{v=1}^{6} x_{u,v,k-1}, \quad i = 1, 2, \ldots, N; j = 1, 2, \ldots, 6; k = 1, 2, \ldots, G
\]

\[
SB_{i1k} \geq -M(1 - x_{i1k}) + \sum_{w=1}^{k-1} x_{i2w} + \sum_{w=1}^{k-1} x_{i3w}, \quad i = 1, 2, \ldots, N; k = 2, 3, \ldots, G
\]

\[
SB_{i2k} \geq -M(1 - x_{i2k}) + \sum_{w=1}^{k-1} x_{i3w}, \quad i = 1, 2, \ldots, N; k = 2, 3, \ldots, G
\]

\[
SB_{i5k} \geq -M(1 - x_{i5k}) + \sum_{w=1}^{k-1} x_{i4w}, \quad i = 1, 2, \ldots, N; k = 2, 3, \ldots, G
\]

\[
SB_{i6k} \geq -M(1 - x_{i6k}) + \sum_{w=1}^{k-1} x_{i4w} + \sum_{w=1}^{k-1} x_{i5w}, \quad i = 1, 2, \ldots, N; k = 2, 3, \ldots, G
\]

\[
SW_{i1k} \geq 0.5[-M(1 - x_{i1k}) + x_{i2k} + x_{i3k}], \quad i = 1, 2, \ldots, N; k = 1, 2, \ldots, G
\]

\[
SW_{i2k} \geq 0.5[-M(1 - x_{i2k}) + x_{i3k}], \quad i = 1, 2, \ldots, N; k = 1, 2, \ldots, G
\]

\[
SW_{i5k} \geq 0.5[-M(1 - x_{i5k}) + x_{i4k} + x_{i5k}], \quad i = 1, 2, \ldots, N; k = 1, 2, \ldots, G
\]

\[
SW_{i6k} \geq 0.5[-M(1 - x_{i6k}) + x_{i4k} + x_{i5k}], \quad i = 1, 2, \ldots, N; k = 1, 2, \ldots, G
\]

\[
\sum_{k=1}^{G} x_{ijk} \leq 1, \quad i = 1, 2, \ldots, N; j = 1, 2, \ldots, 6
\]

\[
\sum_{i=1}^{N} \sum_{j=1}^{6} x_{ijk} \geq L, \quad k = 1, 2, \ldots, G
\]

\[
\sum_{i=1}^{N} \sum_{j=1}^{6} x_{ijk} \leq U, \quad k = 1, 2, \ldots, G
\]
\[
\sum_{i=1}^{N} \sum_{j=1}^{6} \sum_{k=1}^{G} x_{ijk} = \left\lfloor \beta(N) \right\rfloor
\]

(15)

\[x_{ijk} = 0 \text{ or } 1, \ i = 1, 2, ..., N; \ j = 1, 2, ..., 6; \ k = 1, 2, ..., G\]

(16)

In the above formulation, (1) indicates that the objective is to minimize the time required to eliminate the total number of interferences among all passengers, which is equal to the sum of between-group aisle interferences, within-group aisle interferences, between-group seat interferences, and within-group seat interferences. (2) - (11) are definitional constraints. The purpose of (12) is to ensure that each passenger will be assigned to no more than one boarding group, (13) and (14) are imposed so that the size of each boarding group will fall within the desirable range, and (15) states that the total number of seats taken is equal to the total number of passengers to board the plane. Lastly, (16) indicates that all decision variables are binary.

CONCLUSIONS

Loading travelers on the aircraft quickly will not only generate more revenues, but also lead to increased customer satisfaction. This paper contributes to the existing literature by reviewing the traditional heuristic approaches to boarding passengers on an aircraft adopted in the U.S. airline industry. It also presents a mathematical model for speeding up the enplaning process, which is more efficient than those suggested in van den Briel et al. (2005), Bazargan (2007), and Soolaki et al. (2012).

There are several directions for our future research endeavors. First and foremost, we plan to use a software package (e.g., LINDO) to solve a realistic aircraft boarding problem in which there are N = 23 rows of seats and up to G = 5 groups of passengers are considered. Another avenue that seems worth pursuing is to build a mathematical program similar to the one proposed in this paper under each of the following two scenarios: (1) the cabin door is located in the middle of the plane and (2) one door is at the front and the other door is at the back. We hope to analytically prove that the boarding process in each of the two cases is more efficient than that with one door at the front.

REFERENCES


