Selective Boarding to Minimize Airplane Boarding Time

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1 Introduction

As globalization has increased over the last thirty years, there has been a significant increase in air travel. With this increase, airport traffic has become a nightmare to the airline industry. In 2007, the airline industry lost approximately $24 billion due to airline delays. Of that $24 billion, the airline customers are consuming about $17 billion of cost [**1**]. Therefore, there is a monetary benefit in reducing airline delays. This issue identifies a need for decreasing wait time at the airline gates to prevent delays and save both the airlines and their customers money. This paper will focus on the boarding process.

There are several main types of boarding processes currently in use by major airlines. Back-to-front boarding is the most common. In back-to-front boarding, passengers in the back of the plane are loaded first. This is often outperformed by outside-in boarding wherein passengers in the window seats board first, followed by passengers in the middle seats, and lastly by aisle seat passengers. Perhaps surprisingly, the random boarding order used by Southwest Airlines also outperforms back-to-front boarding on average. In this method, passenger are loaded in by zones typically arranged from back-to-front; however, there is not notion of seating assignment[**2**].

The first process considered was the back-to-front loading. The initial thought was that if the back of the plane was loaded first, there would be few stalls in the line as people in the back of the plane are less likely to affect the people in front of the plane. Unfortunately, previous research suggest that this barely outperforms front-to-back loading [**3**]. Although this method boards passenger onto the plane quicker, it simply shifts the passenger traffic from the gate the to aisle of the plane.

There is one noteworthy observation when evaluating the back-to-front model: If two passengers are adjacent in seating order, the first will interfere with the second as the second passenger is still required to wait for the first passenger to stow away their luggage before they may be seated. This introduces the notion that most airlines follow a serialization method. Serialization focuses on seating a single passenger at a time; parallelization is the concept of loading multiple passengers at a time.

Shifting focus to parallelized boarding methods, the outside-in approach was evaluated. With outside-in boarding, row traffic that may affect the aisle traffic can be avoided given the proper arrangement. Furthermore, it is possible through this approach to position multiple passengers into their correct seating assignment and, ideally, would not stagger the line. Since this method loads passengers by seating position relative to the windows, it does not consider overhead luggage spacing and how two passengers adjacent to each other would affect each other's abilities to stow their respective luggage. That is, while boarding two passengers with luggage such that one is seated directly behind the other, the two passengers ability to stow their luggage will be affected by each other.

Since random barding drops the notion of seating assignment, it was not considered.

2 Modeling Implementation

2.1 Assumptions

In the model's infancy, certain assumptions were made to create a simple model such that it may be built up and grow in complexity over several iterations. The first assumption was that passengers board at the same rate. This assumption is quite large; however, it is easy to replace. Since boarding time can vary from one individual to the next, the idea to simplify speed for the first iteration of the model allows us to focus on the most basic requirements of the equation. In addition, this allowed us to more easily create a simulator to observe our model compared to others. Changing the passenger speed later on to be dependent on several other variables is the next step to creating a well rounded model.

The next set of assumptions is related to carry-on luggage. It was assumed that each passenger had one carry-on bag and that all bags fit in the overhead bin above each individual's seat. This removes any time needed to be considered for finding overhead space and placing the luggage into the overhead bin. That is, the rate of storing luggage was assumed to be constant.

Another assumption was that adjacent passengers boarding in different rows and on opposite sides of the aisle will not interfere with one another. This assumption eliminates any variables that represent how passengers interact and may affect one another.

The final and largest assumption was that all passengers are timely in arriving to their gate and are lined up in the order specified by the airline—in this case, an alternating back-to-front, outside-in seating order.

2.2 Original Model

In the first iteration of the model, the plane is divided into n partitions with r rows each. For each partition, two passengers whose seating position are the opposite corners of the given partition are loaded at a time. The pair seated farthest in the back of the plane enter first, followed by the next farthest pair, and so on. These pairs are staggered such that by the time the first pair arrives at the back partition, the last pair arrives at the front partition. Since each partition is independent of every other partition, no pair can affect another partition's pair. Furthermore, since each pair is seated at opposite corners of the plane and the farthest is entering first, there are no collisions within each partition unless r is odd. For this reason, we assumed each partition to have an even number of rows.

Figure 1 – Image of first model, where plane is divided into partitions. Solid Blue squares indicate first group of passengers seating arrangements

Given the set of assumptions listed in section 2.1, the most passengers that can be boarded at a given moment would be $2n$. This model appears more feasible than current boarding methods as it does not attempt to control the total ordering of all passengers boarding the plane; rather, it prescribes only a partial ordering that must be followed. While this does not strictly matter under the given assumptions, it does make the model more feasible as it is more likely that an airline can order a few passengers than it is the with all passengers.

2.3 Improved Model

In the original model, there was an upper bound of $2n$ for the number of passengers that could be seated on the plane in parallel. To increase this limit, m passengers were loaded, where m is the number of rows in the plane. Each adjacent passenger would be seated at the opposite side of their respective row. That is, if one passenger was seated at the left window seat, the next passenger would be seated at the right window seat of the next row. Under the assumptions listed in section 2.1, no collisions would occur as the passengers would be facing opposite sides when loading their luggage.

This modification removes the notion of partitions in order to increase parallelism. This modification also has implications for feasibility, as it assumes further control of the ordering of passengers. Since there are no buffers, we expect that if the rate at which each passenger are not equal, there would be some staggering in the aisle.

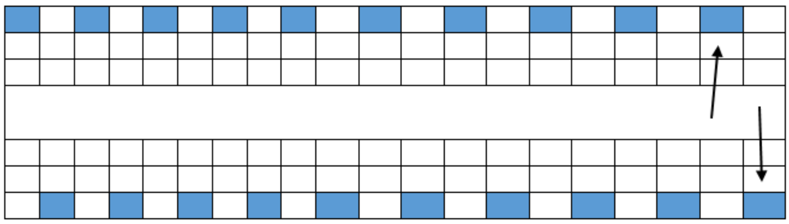


Figure 2 – Image of improved model, where an alternating seating arrangement from outside-in, back to front boarding process is followed

We formed the queue for boarding the plane with a couple things in mind. That is, when the first passenger to board the plane is aligned with their row, then the last passenger to board the plane will be as well.

To model the time for any passenger to find their respective seat, we use a basic linear equation:

$$T(x, y) = Ax + By + C$$

where x is the number of rows between the destination row and the plane door and y is the number of seats to cross to get to the proper seat (i.e. $y = 0$ for an aisle seat, $y = 2$ for a window seat). A is a constant representing the rate at which the passenger moves down the aisle, B is a constant representing the rate at which the passenger moves across seats within their row, and C is a constant representing the time it takes the passenger to load their luggage into the overhead bin.

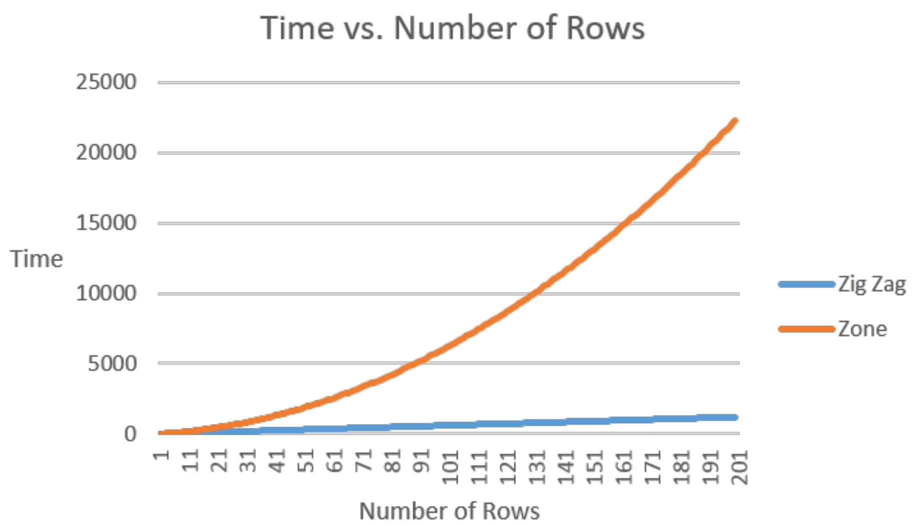
So the total time to board the plane is given by:

$$TotalTime = 2\sum_{y=0}^{2} T(R, y)$$

where R is the number of rows on the plane. The constant 2 outside of the summation is because passengers are ultimately loaded by pairs of rows, and the summation is the time it takes to board half of the farthest row and the opposite half of the adjacent row.

3 Results

The model developed in section 2.3 showed linear growth as the number of rows to board increased. This is to be expected, since the model is linear. The pure back-to-front loading scheme described in the introduction grew considerably faster, as shown below.



4 Conclusions

There are many areas of the model that could be made more complex in order to more precisely model the boarding process. Most of these improvements involve loosening or removing assumptions listed in section 2.1.

The first assumption, that all passengers move at the same rate down the aisle and seats is fairly straightforward to remove from a modeling perspective; however, this is potentially difficult to simulate and gather data. To model the boarding process without this assumption, it would be natural to assign each passenger a rate (or rates) randomly generated from some probability distribution. This allows for calculation of ranges of boarding times and confidence intervals on these ranges. The problem with this addition is that looking at a single distribution for all passengers may not provide much more clarity than just assuming the average rate. Furthermore, looking at different distributions for different demographic groups could become cumbersome quickly as more granularity is added to the model.

Removing the assumption that each passenger has exactly one carry-on bag is similar. We could assign each passenger a certain number of carry-on luggage using a select probability distribution with a randomly associated stowing rate.

The final assumption that would be interesting to remove is that all passengers are on time and in the proper order. Of course, this does not occur regularly in reality; rather, passengers arrive late and in no particular order. To model this, a Poisson distribution of the arrival of passengers would be natural. There are a few ways you could extend the model from there. Blindly keeping the current back-to-front, outside-in boarding algorithm would be the simplest to model, but it also would not make sense to hold up passengers who are ready to board in order to wait for people who are "supposed" to board before them but have not arrived. A more realistic model, then, would mean a modified algorithm which handles randomly arriving passengers more gracefully. Modifying the algorithm could be done in any number of ways. One way we have considered is to maintain the current boarding process of the model and skipping over late arrivals. Late arrivals will then all be processed later in a separate queue. This would essentially keep the current model and add another boarding group at the end, which would ideally have a small number of passengers relative to the size of the other boarding groups.

References

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[2] Trip Advisor Seat Guru's Guide to Airline Boarding Procedures 4-14-2017

[3] Jason H. Steffen *Optimal Boarding Method of Airline Passengers, Journal of Air Transport Management Vol 14* 2008.