Airplane Boarding Queueing Theory

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0.1 Introduction

In this project we examine a real-world example of a queue, specifically the boarding of airplanes. The line to board an airplane is a type of queue where the "jobs" are the people standing in line and the "servicing" of jobs is passengers sitting in their seats. We implement a simulation of passengers boarding an airplane and examine the runtimes of several methods to board an airplane. We also analyze the worst-case outcome for each method as airlines are also risk-averse and a method that sometimes leads to a very bad runtime can cause scheduling difficulties.

0.2 Experimental Setup

To start, we created a simulation that models how people board an airplane. In this simulation, the user can specify various parameters. These include the total number of seats on the plane, the number of seats in each row, the time it takes for a passenger to stow their bag and sit down, the time it takes for a person to exit from the row to allow a passenger whose seat is closer to the window to sit down, and the boarding method. The two given inputs to our algorithm are a plane object, which holds all the seated passengers in memory, and a line/queue of passengers to be seated. The order of the passengers (each of which has an assigned seat number) will depend on the boarding method.

0.3 Algorithm

The general process for our boarding simulation is the following: passengers will enter the plane and be placed in a row. They will then either sit at their correct seat, walk to the next row, or stay in place depending on the given state of the boarding process.

A simplified pseudo code for this program is as follows:

1. The process will begin by boarding a passenger if there is room in the front of the plane
2. Next, starting from the first non-seated passenger to enter the plane, passengers will do one of the following:

a) Sit down if their seat is on the given row, then stow their bag (which takes some time)

b) If the passenger is in a window seat and there are passengers closer to the aisle, the time to sit is increased by a constant time

c) Walk forward to the next row if no one is in ahead or stowing in front of them

d) Pause if they can neither walk nor sit

3. Repeat the process until all passengers are seated and record the number of iterations that the loop was performed, which gives us the total boarding time.

0.4 Boarding Methods

We examine several boarding methods. The first is the simplest, where there are no boarding groups and passengers are randomly ordered to the seats they are assigned to. The second method which we dub the "American Airlines" method is where passengers are split into boarding groups, but within each group the passengers are randomized. The third method is the "Southwest Airlines" method where the passengers board in groups but within each group they are ordered front-to-back. Although this method is not exactly like how Southwest Airlines seats passengers, we make an assumption that passengers in each group choose to sit further in front for simplicity. For both the American Airlines and Southwest Airlines method, we run the algorithm with the boarding groups arriving from back-to-front and front-to-back.

0.5 Results and Discussion

0.5.1 Average Boarding Time

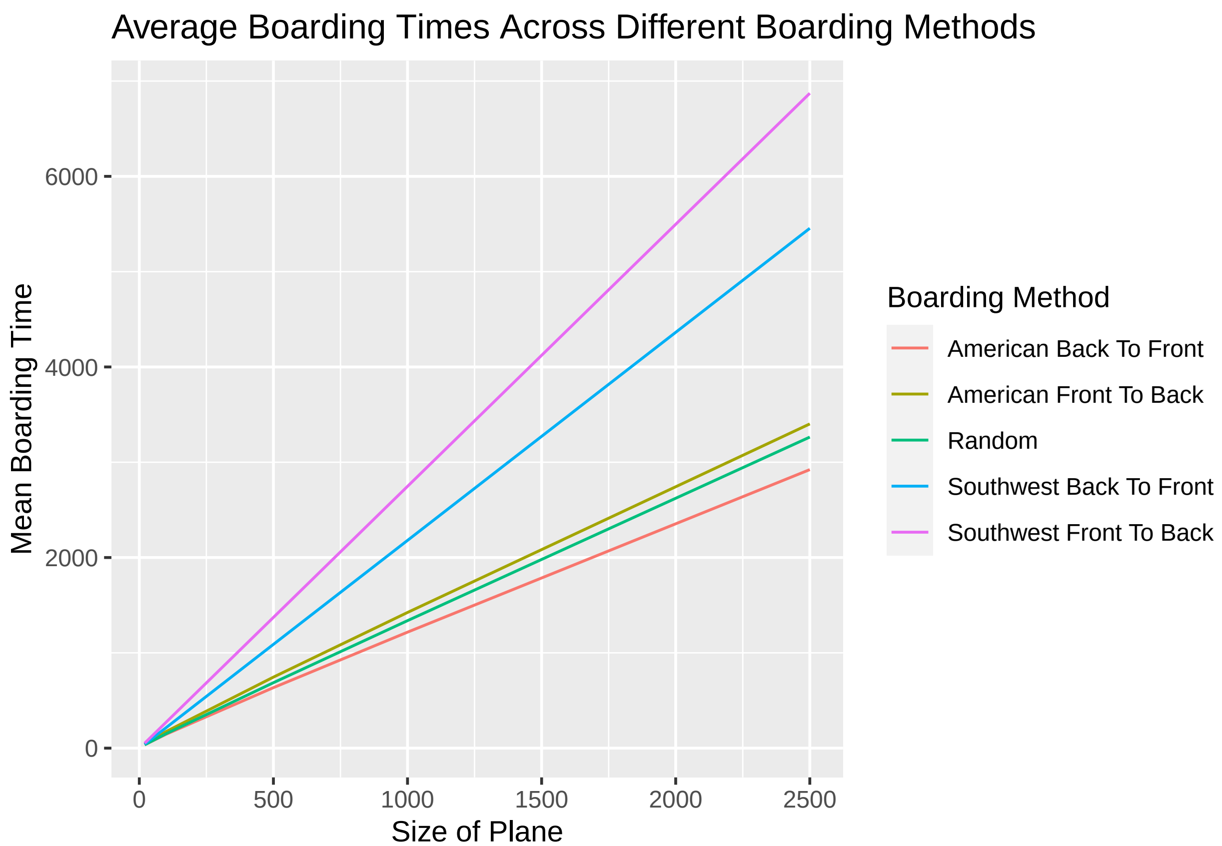

Table 1: Average Boarding Time Values

Plane Size	Random	Southwest F To B	Southwest B To F	American F To B	American B To F
20	34.89	52	41	41.75	34.82
100	151.22	272	215	174.33	145.86
500	686.82	1372	1089	745.33	634.68
1000	1337.98	2747	2180	1423.81	1217.01
2500	3264.24	6872	5455	3402.34	2922.59

We examine the average boarding time for each algorithm by boarding the plane 10,000 times for each plane size and boarding method. With the graph above, we can see that the "Southwest" front-to-back method had the slowest average boarding time while the "American" back-to-front method was the fastest, followed by completely random and American front-to-back. As expected, boarding back to front is faster than boarding front-to-back as more people are able to stow their bags and sit down at the same time. What is interesting is that the difference between completely random and American back-to-front and American front-to-back is not very large, especially given the size of the planes we use in our analysis. For a reasonably-sized plane (say 200 seats), the difference is even less significant. Meanwhile, using boarding groups requires the extra effort of assigning people group numbers, making sure the people boarding are in the same group, and other logistical difficulties. As such, it seems as though airlines could just randomly board people and save a significant amount of pre-flight logistics.

0.5.2 Worst-Case Boarding Times

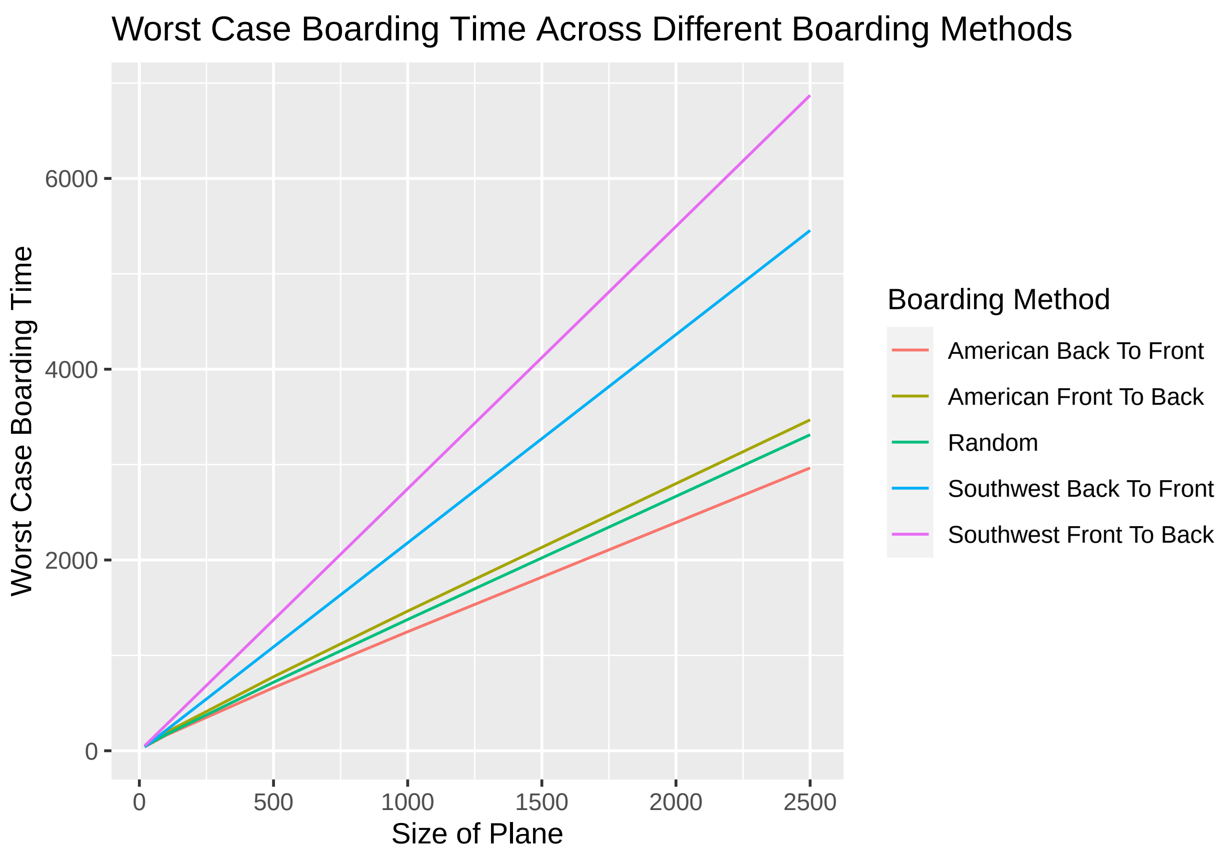

Table 2: Worst Case Boarding Time Values

Plane Size	Random	Southwest F To B	Southwest B To F	American F To B	American B To F
20	45	52	41	50	42
100	170	272	215	193	163
500	718	1372	1089	776	661
1000	1376	2747	2180	1464	1248
2500	3313	6872	5455	3469	2965

In this worst-case runtime scenario analysis where we ran each boarding method 10,000 times, we can observe that the worst-case runtimes seem to track similarly to the average case runtime. For each plane size, the order of the worst-case runtime for the different boarding methods is the same as the average case runtime. Therefore, for the different boarding methods airlines can mostly ignore the worst case scenario as they are not too far different from the average case scenario. Even in the completely random boarding method the randomization does not cause a significant shift in the worst-case runtime relative to the American front-to-back and back-to-front methods.

0.6 Conclusion

In this project, we created a simulation to analyze different ways to board an airplane. We find that the most popular way to board an airplane, back-to-front with randomized boarding groups, is the fastest way to board the airplane out of the different methods we analyzed. This supports the idea that for the most part, airlines use a relatively efficient boarding method. In general, the American Airlines method is faster compared to the Southwest method because in the Southwest method the passengers are ordered front-to-back within the boarding group, leading to fewer people being able to sit down at the same time.

We also find that the average runtime for the completely random boarding method is not much slower than this back-to-front method. In addition, the completely random boarding method has a couple advantages over boarding methods using groups. First, it has the additional bonus of not needing to group the passengers before boarding. Second, there is often a delay between boarding groups when entering a plane. We did not take this delay into account, but such a delay would make the completely random boarding method a more attractive option. As such, even though the completely random method is slower than the American Airlines method in our simulation, it still may be worthwhile for the airline to implement.

For further research, we could examine more types of boarding methods such as window-middle-aisle. In addition, results might differ if the time to stow a bag is longer, or if the time to sit varies significantly from person to person. These modifications will allow for an even more realistic simulation which may capture aspects that were not taken into consideration in this method. Changing the amount of seats per row or having more "columns" like in a 747 with two aisles would also be interesting to examine. Another method to allow for more realism is the introduction of "classes" as first class and business class board before economy and are boarded front-to-back. Lastly, we realized with this project that the slowest way to board an airplane, Southwest front-to-back, is the way people disembark from an airplane. As such, finding an implementation to deboard an airplane should be considered to save time for both passengers and the airline.