American Airlines' Next Top Model

Introduction

Airlines employ several distinct strategies for the boarding and deboarding of airplanes in an attempt to minimize the time each plane spends idle on the ground. The airlines' objectives are to maximize the amount of time planes are in the air, thereby increasing their revenue by increasing the number of passengers they can move in a given time period. Given this, the objectives in our study are:

- To board (and deboard) various sizes of plane as quickly as possible.
- To find a boarding plan that is both efficient (fast) and simple for the passengers.

With this in mind, our approach entails:

- We investigate the time required for an individual to stow their luggage and clear the aisle.
- We investigate the time required for a passenger to clear the aisle when another passenger is seated between them and their seat
- We review the current boarding techniques being implemented by airlines.
- We study the floor layout of planes of 3 different sizes to compare any difference between the efficiency of a given boarding plan as plane sizes increase and layouts vary.
- We construct a simulator which mimics typical passenger behavior during the boarding processes under different techniques.
- We realize that there is not very much time savings possible in deboarding while maintaining customer satisfaction.
- We calculate the time elapsed for a given plane to load under a given boarding plan by tracking and penalizing the different types of interferences which occur during the simulations.
- As an alternative to the boarding techniques currently employed by the industry, we suggest an alternative boarding plan not currently in practice and assess it using our simulator.
- We make recommendations regarding the algorithms that proved most efficient for small, medium, and large planes.

Interferences and Delays for Boarding

There are two basic causes for interference – someone blocking a passenger in an aisle and someone blocking a passenger in a row.[1] *Aisle interference* is caused when the passenger ahead of you has stopped moving and is preventing you from continuing down the aisle towards the row with your seat. *Row interference* is caused when you have reached the correct row but already seated passengers between the aisle and your seat are preventing you from immediately taking your seat. Note that a major cause of aisle interference is a passenger experiencing row interference.

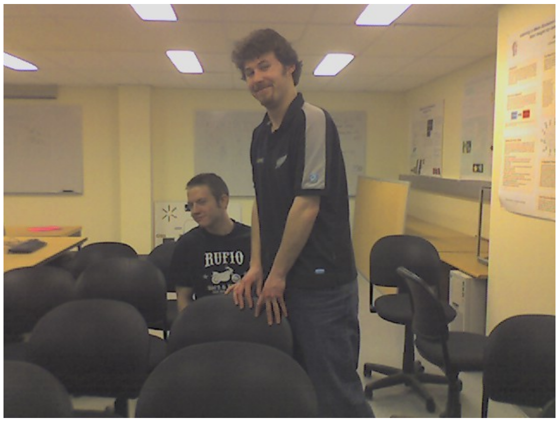

Photo 1. Row Interference

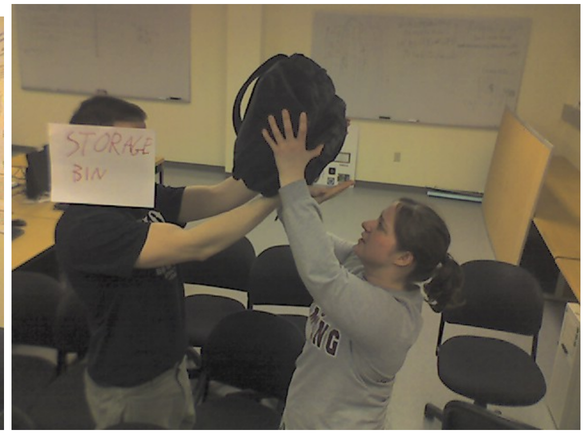

Photo 2. Aisle Interference

We conduct experiments using lined up rows of chairs to simulate rows in an airplane and a team member with outstretched arms to act as an overhead compartment to estimate parameters for the delays cause by these actions., The times we find through our experimentation for the following common boarding activities are given in Table 1.

Boarding Activity	**Time (Seconds)**
Walking 1 row of seats	1
Carry-on stowage	6
Clearing aisle when you must get by someone seated in the aisle seat	4
Clearing aisle when you must get by people seated in the aisle seat and adjacent seat	4
When person seated on the aisle must get up	6
When person seated in middle seat must get up	6
When two people must get up	7
When no one is in the aisle and you can squeeze by the middle person	1

Table 1. Delays cause by common boarding activities

We use these times in our simulation to model the speed at which a plane can be boarded. We model separately the delays caused by aisle interference and row interference. Both are simulated using a mixed distribution defined as follows:

$$f(x) = \min\{2, X\} \qquad (1)$$

where X is a normally distributed random variable with such that the mean (μ) and standard deviation (σ) are determined by our experiments. We opt for our distribution being partially normal with a minimum of 2 after reasoning that other alternative and common distributions (such as the exponential) are too prone to throw a small value, which is unrealistic.

We find that the average row interference time is approximately 4 seconds with a standard deviation of 2 seconds, while the average aisle interference time is approximately 7 seconds with a standard deviation of 4 seconds. These values are slightly adjusted based on our team's cumulative experience on airplanes.

Typical Plane Configurations

Essential to our model are the current industry standards regarding the common layouts of passenger aircraft of varied sizes. We use an Airbus 320 plane to model a small plane (85-210 passengers). The Airbus 320 is in use by United Airlines and Lufthansa.[2] We base our model of the midsize plane (210-330 passengers) off of the Boeing 747, commonly employed by United Airlines.[3] Because of the lack of large planes available on the market, we modify the design of the Boeing 747 by eliminating the first class section and extending the coach section to fill the entire plane. This puts the Boeing 747 close to its maximum capacity.[4] For the modified Boeing 747, our model for the large plane has 55 rows, all with the same dimensions as the coach section in the standard Boeing 747. Airbus is in the process of designing planes that can hold up to 800 passengers. The Airbus A380 is a double-decker with occupancy of 555 people in three different classes. We choose to exclude double-decker models from our simulation because it is the larger, bottom deck which is the limiting factor, not the smaller upper deck.

Current Boarding Techniques

There are several different boarding procedures currently in use. We examine the following industry boarding procedures:

- *Random, Ordered Boarding*
- *Outside-In Boarding*
- *Back-to-Front Boarding* (for several group sizes)

Additionally, we explore this innovative technique not currently used by airlines:

- *"Roller Coaster" Boarding*- Passengers are ordered before they board the plane in a style much like those implemented by theme parks when they fill their roller coasters. Passengers are ordered back of the plane to front and board in seat letter groups. This is a modified Outside-In technique, the difference being that passengers in the same group are ordered before boarding. Figure 1 shows how this ordering could take place. By doing this, most interferences are avoided.

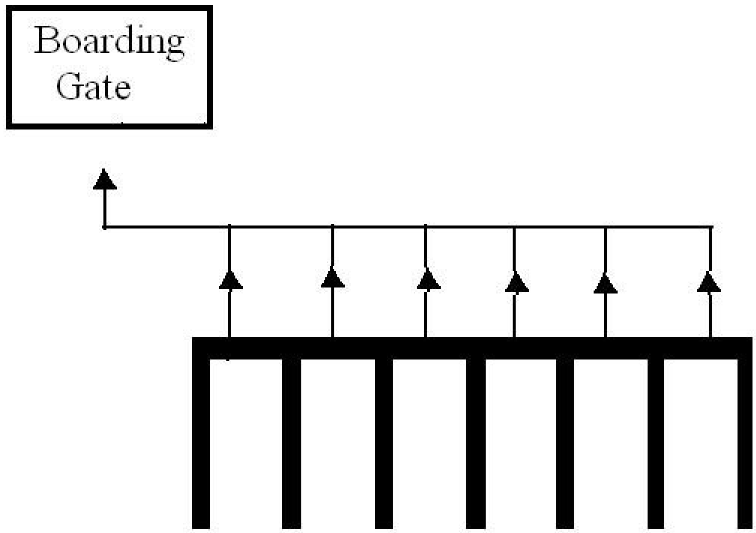

Figure 1. Roller coaster boarding before passengers reach the boarding gate

Current Deboarding Technique

Planes are currently deboarded in an aisle-to-window and front-to-back order. This deboarding method comes out of the passengers' desire to be off the plane as quickly as possible. Any modification of this technique could lead to customer dissatisfaction as they may be forced to wait while other passengers seated behind them on the plane are deboarding.

Boarding Simulation

We chose to search for the optimal boarding technique by designing a simulation that models the boarding process and running the simulation under different plane configurations and sizes along with different boarding algorithms. We then compare which algorithms yielded the most efficient boarding process.

Assumptions

The environment within a plane during the boarding process is far too unpredictable to be modeled accurately. In order to make our model more tractable, we make the following simplifying assumptions:

- *There is no first class or special needs seating*. Because the standard industry practice is to board these passengers first, and because they generally make up a small portion of the overall plane capacity, any changes in the overall boarding technique will not apply to these passengers due to their special needs.
- *All passengers board when their boarding group is called*. No passengers arrive late or try to board the plane early.

- *Passengers do not pass each other in the aisles*. Airplane aisles on commercial passenger aircraft are too narrow for passengers to try and squeeze past each other if a passenger in the front of a line is walking slowly or stowing baggage.
- *There is no gap between boarding groups*. Airline staff call a new boarding group before the previous boarding group has finished boarding the plane. This assumption is justifiable given the condition of lines at a given gate during the boarding process.
- *Passengers do no travel in groups*. Often, airlines allow passengers boarding with groups, especially with younger children, to board in a manner convenient for them rather than in accordance with the boarding plan. These events are too unpredictable to model accurately.
- *Airplanes are filled to capacity with passengers*. By having the planes filled to capacity, we are able to compare results between different boarding techniques without other causal forces (such as a random number of passenger on a plane) interfering with our analysis. A plane at full capacity would typically cause the most passenger interferences, allowing us to view the worst case scenario in our model.
- *Every row in an aircraft contains the same number of seats*. In reality, the number of seats in a row changes due to engineering reasons or to accommodate luxury class passengers.

Implementation

We formulate the boarding process as follows:

- The layout of a plane is represented by a matrix, with the rows representing each row of seats on the plane, and each column describing whether a row is next to the window, aisle, etc. The specific dimensions vary with each plane type. Integer parameters track which columns are aisles.
- The line of passengers waiting to embark is represented by an ordered array of integers which shrinks appropriately as they board the plane.
- The boarding technique is modeled in a matrix identical in size to the matrix representing the layout of the plane. This matrix is full of positive integers, one for each passenger, assigned to a specific submatrix, representing each passenger's boarding group location. Within each of these submatrices, seating is assigned randomly to represent the random order in which passengers line up when their boarding groups are called.
- Interferences are counted in every location they occur within the matrix representing the plane layout. These interferences are then cast into our probability distribution defined above, which gives us a measurement of time delay.
- Passengers wait for interferences around them before moving closer to their assigned seats; if an interference is found, the passenger will wait until the time delay has finished counting down to 0.
- The simulation ends when all delays caused by interferences have counted down to 0 and all passengers have taken their assigned seats.

Strengths and Weaknesses of the Model

Strengths

- It is robust for all plane configurations and sizes. The boarding algorithms we design can be implemented on a wide variety of planes with minimal effort. Furthermore, the model yields reasonable results as we adjust the parameters of the plane, e.g., larger planes require more time to board, while planes with more aisles can load more quickly than similarly sized planes with fewer aisles.
- It allows for reasonable amounts of variance in passenger behavior. While with more thorough experimentation a superior stochastic distribution describing the delays associated with interferences could be found, our simulation can be readily altered to incorporate such advancements.
- It is simple. We made an effort to minimize the complexity of our simulation, allowing us to run more simulations during a greater time period and minimizing the risk of exceptions and errors occurring.
- It is fairly realistic. Watching the model execute, we can observe passengers boarding the plane, bumping into each other, taking time to load their baggage, and waiting around as passengers in front of them move out of the way. Its ability to incorporate such complex behavior and reduce it are key to completing our objective.

Weaknesses

- It cannot account for possibilities in altering boarding plans for passengers other than economy class passengers. Because of the structural differences that often accompany luxury class seating, our model cannot account for all possible classes at once.
- It cannot simulate structural differences in the boarding gates which could possibly speed up the boarding process. For instance, some airlines in Europe board planes from two different entrances at once, which could speed up the boarding process.
- It cannot account for people being late to the boarding gate.
- It does not account for passenger preferences or satisfaction.

Results and Data Analysis

For each plane layout and boarding algorithm we run 500 boarding simulations so that our results are statistically significant. Table 2 shows the mean time it takes to load each plane layout and boarding algorithm. The standard deviation is included because the reliability of plane loading is important for scheduling multiple flights in a day. A large standard deviation forces an airline to allow extra boarding time in scheduling.

The Back-to-Front method was simulated for several possible group sizes. Because of the difference in the number of rows in the planes, not all group size possibilities could be implemented on all planes, as seen below.

500 Simulations	Plane Size					
	Mean Time (seconds)			Standard Deviation (seconds)		
Boarding Pattern	**Small**	**Medium**	**Large**	**Small**	**Medium**	**Large**
Random	600.24	546.46	976.34	31.68	24.88	35
Outside-In	652.55	590.848	959.97	21.38	21.52	27.73
Back-to-Front - 2	*	659.39	*	*	31.61	*
Back-to-Front - 3	717.57	707.88	*	30.28	30.44	*
Back-to-Front - 5	*	*	1130.53	*	*	36.41
Back-to-Front - 6	*	818.76	*	*	32.77	*
Back-to-Front - 9	941.08	903.19	*	36.53	35.24	*
Back-to-Front - 11	*	*	1346.43	*	*	37.47
Back-to-Front - 12	*	971.26	*	*	34.71	*
Back-to-Front - 27	1313.22	*	*	31.91	*	*
Roller Coaster	198	341.84	616.70	0	1.92	1.88

Table 2. Boarding times for various airplane sizes and various boarding algorithms

Small Plane

For the small plane, Chart 1 shows that all boarding techniques except for the Roller Coaster slowed the boarding process compared to the Random boarding process. As more and more structure is added to the boarding process, while passenger seat assignments continue to be random within each of the boarding groups, passenger interference backs up more and more. When passengers board randomly, gaps are created between passengers as some move to the back while others seat themselves immediately upon entering the plane, preventing any more from stepping off of the gate and onto the plane. These gaps prevent passengers who board early and must travel to the back of the plane from causing interference with many passengers behind them. However, when we implement the Roller Coaster algorithm, seat interference is eliminated, with the only passenger causing aisle interference being the very last one to board from each group.

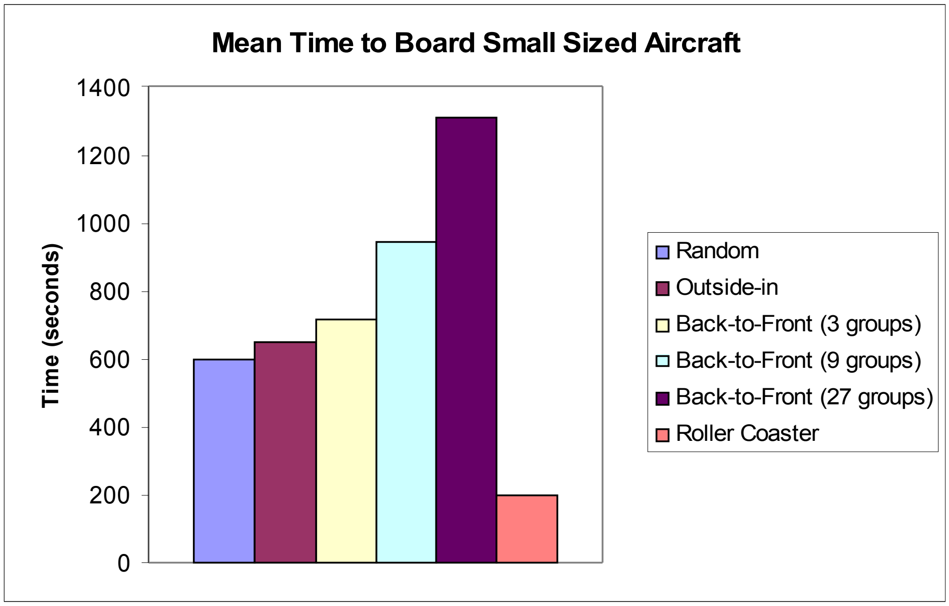

Chart 1. Results of Boarding Plans on Small Aircraft

Interestingly, the small plane's boarding times for all algorithms are greater than their respective boarding time for the medium plane. This is because the number of seats per row per aisle is greater in the small plane than in the medium plane. That is, the second aisle in the medium plane allows passengers to keep boarding the plane if one aisle is blocked, reducing overall interference.

Medium Plane

The results experienced from the simulations of the mid-sized plane are shown in Chart 2 and are comparable to those experienced by the small sized plane. As the structure imposed by a given algorithm increased, the efficiency of the boarding plan decreased. However, as the amount of structure increased for each algorithm, the amount of delay created increased at a slower rate compared to the small plane. We account for this again by the fact that the mid-sized plane has two aisles, allowing passengers to board continuously without interruption. Again, the Roller Coaster method proved the most effective.

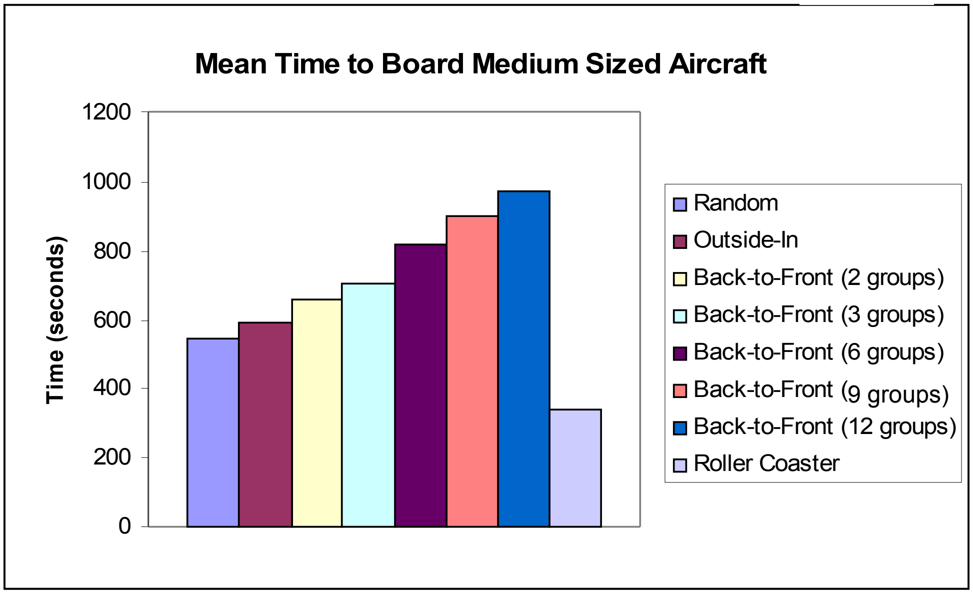

Chart 2. Results of Boarding Plans on Medium Aircraft

Large Plane

Chart 3 shows that, unlike the other plane configurations, the boarding time for a large aircraft experienced a drop off when moving from the Random boarding algorithm to the Outside-In boarding algorithm. Observing the movements by the passengers in the simulation, it is clear that because of the greater number of passengers in this plane, gaps are more likely to form between passengers in the aisles, allowing passengers to move unimpeded by those already on board the plane. However, both instances of Back-to-Front loading created too much structure to allow these gaps to form again. Again, because of the elimination of row interference it provides for, Roller Coaster proved to be the most effective boarding method.

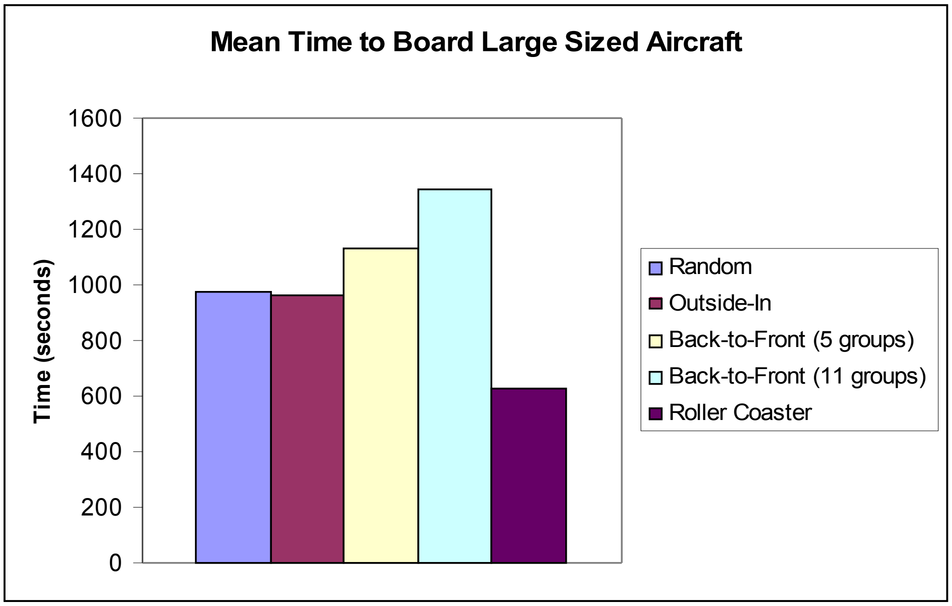

Chart 2. Results of Boarding Plans on Large Aircraft

Overall

Table 2 clearly shows that the Roller Coaster boarding algorithm is the fastest algorithm for each plane size. The Roller Coaster boarding procedure is 35% faster for a large plane than the next fastest boarding procedure. For a medium plane, it is 37% faster than the next best method. For a small plane it is 67% faster than the next fastest boarding procedure. The Roller Coaster boarding procedure also has the added benefit of very low standard deviation. Thus it allows the airlines to have a more reliable boarding time.

The boarding time for the back to front algorithms increases with the number of boarding groups and is always slower than a random boarding procedure. The idea behind a Back-to-Front boarding algorithm is that interference at the front of the plane is avoided until passengers in the back sections are already on the plane. A flaw in this procedure is that having everyone line up in the plane can cause a bottleneck that actually increases the loading time.

The Outside-In ("Wilma", or window, middle, aisle) algorithm performs better than the random boarding procedure only for the large plane. The benefit of the random procedure is that it evenly distributes the interferences that are occurring throughout the plane, and so these interferences are less likely to impact very many passengers.

Validation and Sensitivity Analysis

We develop a Test Plane configuration with the sole purpose of implementing our boarding algorithms on planes of all sizes, varying from as small as 24 passengers to as large as 600 with both 1 and 2 aisles for passengers to walk down. We also examine situations where the plane is not at full capacity. We model capacities of as low as 70% and the trends we see at full capacity are reflected at these lower capacities. The Back-to-Front and Outside-In algorithms do start to perform better, but this increase in performance is relatively small, and the Roller Coaster algorithm still substantially outperforms them. Under all circumstances, the algorithms we test are robust. That is, they assign passenger to seats in accordance with the intention of the boarding plans used by airlines and move passengers in a realistic manner.

Recommendations

Which plan should be used?

We recommend that the Roller Coaster boarding plan be implemented by airlines for planes of all sizes and configurations for the boarding of non-luxury class and non-special needs passengers. As planes increase in size, its margin of success in comparison to the next best method decreases, but given the large parameters of the large sized aircraft we simulate, we are confident that the Roller Coaster method will prove robust for all planes currently in use by passenger airlines. We recommend boarding groups traveling together before boarding the rest of the plane, as groups would cause interferences that would slow the entire boarding process. Ideally, groups would be ordered before boarding just like the rest of the boarding process.

Future Work

For further examination, it would be useful to explore the same boarding algorithms for different models of aircraft. The specific aircraft seating layout in use directly impacts the different types and number of interferences. For example, it is inevitable that some passengers will arrive late and not board the plane at their scheduled time. Additionally, we believe that the amount of carry-on baggage permitted on the plane would have a larger effect on the boarding time than the specific boarding plan implemented – modeling this would prove insightful. We also recommend modifying the simulation to reflect groups of people traveling (and boarding) together. This is especially important to the Roller Coaster boarding procedure. This is why we recommend boarding groups first before boarding the rest of the plane.

Alternative Approaches to the Problem

Simulation is the most common way to analyze the boarding problem. A less common, but equally valid method is to use mathematics, specifically conditional probabilities. Using different conditional probabilities corresponding to each specific boarding algorithm, one could calculate the expected value of time it takes for the passengers to load the plane.

References

[1] \van den Briel, Menkes; Villalobos, Rene; Hogg, Gary. *The Aircraft Boarding Problem*. http://www.public.asu.edu/~dbvan1/papers/IERC2003MvandenBriel.pdf.
[2] http://www.airbus.com/en/aircraftfamilies/a320/
[3] http://www.boeing.com/commercial/747family/index.html
[4] http://en.wikipedia.org/wiki/Boeing_747