AN ANALYSIS OF BOARDING PROCEDURES ON COMMERCIAL AIRLINES

MODSIM World 2018 M&S Challenge Competition Report

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Development Platform: Eclipse (Java) and Unity 3D (C#)

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Executive Summary

PROBLEM DESCRIPTION

Our goal in this study was to observe and analyze the various boarding methods that commercial airlines implement (Front-To-Back, Back-To-Front, Random, and Outside-In). From these observations, we were able to create two programs to simulate and time each boarding process. By running our programs a total of one hundred thousand times, we identified extrema for all test cases and calculated the average run time for each method. Using a relative time scale for the compilation time and real-world data, we identified the currently implemented pattern that proved to be the fastest during every run. Although there were slight differentiations in the fastest pattern, the results remained overwhelmingly consistent. From the estimates derived from our code, we created an entirely new algorithm that is better than any in-use boarding method.

INPUTS AND ASSUMPTIONS

Each simulation was composed of passengers that represented people aboard an airplane. These passengers were assumed to walk at different speeds and wait a randomized amount of time before sitting in their respective seat. Inputs included the number of passengers aboard the aircraft, the number of seats in each row, and the number of rows. Other variables that needed to be predicted were the individual speeds of the passengers – from 1 mile per hour to 3 miles per hour – as well as the time it took for a passenger to store their luggage – a random value between 1 and 25 seconds.

MODEL

These two programs were both developed using Java through Eclipse Oxygen 1.A. After developing our algorithms and receiving substantial results from our runs, we translated the code into C# and created our simulation using Unity 3D.

VERIFICATION

Our programs in Java were used to calculate the boarding times of all currently implemented boarding procsses. These times were then compared to one another and the proposed boarding process. The results of the two programs had a difference of 1 to 2 minutes on all methods except "Random" which was more unpredictable but still fell in a reasonable range of error. In order to verify the validity of our calculations, we timed the boarding process of flights from major carriers in the United States including United Airlines, American Airlines, Southwest, and JetBlue.

CONCLUSION AND RECOMMENDATIONS

After comparing our real world and calculated results to the proposed solution, we determined that the conceptual boarding process is significantly faster than any other method. However, in order to reach maximum efficiency, the process required changes that restricted various comforts given to first class passengers, as well as a general shift in the concept of priority boarding. While we have proposed solutions to decrease boarding time while also maintaining the same level of comfort aboard airlines now, there is much more to be accomplished.

INTRODUCTION

The field of transportation reached new heights in the mid to late 20th century when commercial airlines began to rise in popularity. This was followed by the inception and privatization of airlines and after that the sky was no longer the limit. Citizens began to travel across the Pacific and Atlantic in mere hours. Gone were the days of being stranded on the ocean for weeks on end travelling via boat.

Since their establishment, commercial airlines have become much more reliable. They have increased their overall on-time percentage while simultaneously decreasing their delay and cancellation percentages. The percentage of on-time flights increased from 74.39% in 2014 to 80.97% in 2016, resulting in an increase of 117,260 on-time arriving flights. Subsequently, a staggering 98,017 delayed flights in 2014 decreased to 44,130 in 2016, a decrease in over half of delayed flights over the course of two years. ("Flight Delays at a Glance", 2017).

While there have been marked improvements in the rate of boarding airplanes, many customers still find that the current boarding processes utilized by airlines are tiring and somewhat troublesome. In some cases, flights may be several minutes late due to a slow boarding process. Addressing this issue is challenging as boarding methods tend to differ from airline to airline. For example, Southwest uses randomized boarding while United incorporates their WilMA (Window-Middle-Aisle) process.

While there are many approaches to solve our posed problem, two solutions stood out the most. The first is through the utilization of arrays, namely a two-dimensional array system. The system we created was modeled to represent a modified Boeing 737-800 composed of two columns each with thirty rows and three seats to a row.

Another solution is to create a variable-altered simulation through metric measurements of speed and distance. By inputting data for both the legroom and seat width, the program calculated randomized times based on walking speed and simulated errors in the aisle such as trouble stowing away baggage in the overhead bins.

By averaging the results from these two solutions, we determined the fastest boarding method that is currently in commercial use. After these calculations, we started to analyze specific aspects of four major contemporary boarding methods, several of which are fading into obscurity. Utilizing key aspects of each boarding process, we formulated algorithms to simplify boarding patterns and decrease the time that it took for planes to board passengers.

RELATED WORKS

Researchers have analyzed boarding processes that are currently in use by commercial airlines, determining the fastest method overall. They continue to search for improvements (Briel, Hogg, & Villalobos, 2003). Although several programs have been created with the objective of improving airline boarding times, there is still more work to be done. A majority of past works have emphasized approaches that are focused on improving timing of already established boarding processes rather than attempts to create new methods.

Theoretical reasoning on potential boarding processes has resulted in a variety of implementations across a diverse group of airline companies. A major consequence of these processes is the less than efficient boarding times which leave many passengers frustrated. To create an accurate algorithm, certain characteristics are needed to be given to the simulated passengers. Some approaches have applied points of disturbance, such as passenger compliance, and group travel to get a far more accurate time estimation (Audenaert, Berghe, & Verbeeck, 2009). Probability distribution algorithms, such as the Markov Chain Monte Carlo method, were then incorporated into boarding methods to find the fastest possible time a plane could be boarded in a given situation (Steffen, 2008). An application of these methods results in an average decrease of approximately 20 percent of the boarding time (Mulé, 2005).

Some novel approaches move away from incorporating realistic passenger situations and instead focus on an entirely separate but linked process that slows the boarding procedure. This focuses beyond the reorganization of passengers and includes the restructuring of baggage placement. By evenly distributing baggage throughout the plane and assigning passengers to specific seats, the total boarding time decreases greatly (Kelly, Milne, 2013).

DESIGNING A SOLUTION

Input Methods

Originally our algorithms used predetermined variables to judge locations of seats, average passenger walking speeds, and the time taken to stow luggage. With the understanding of the individual differences of passengers and their personalities, we began to create a more realistic and randomized structure for each possible variable.

The first variable that we enabled for a third-party to input was the number of passengers boarding the plane. As simple as it was, there were still many more variables that needed to be considered for the program to be a success.

```
72                - Total number of passengers
Passenger 1 30A - Passengers loading by columns
Passenger 2 29A
Passenger 3 28A
…                  - Removed rows 27-1 for figure
Passenger 31 30B - Program switches to "B" column
Passenger 32 29B
Passenger 33 28B
```

Figure 1. Input for the number of passengers.

Through the incorporation of custom inputs, such as the number of passengers, randomized passenger speeds, and the ability to select seat width and legroom, we developed an exceptionally accurate method to determine airline boarding speeds.

Array Simulation Method

The first solution that we developed was that of a two-dimensional system of arrays. The design of the array system was that of a modified Boeing 737-800 that contained a total of 180 seats. The most significant modification to the simulated plane was the exclusion of two seats per aisle in first class. Rather than incorporating this into our simulation, we instead chose to simplify the interior structure of the plane with three seats per aisle even in the first class segment.

The reasoning behind this decision was because of the rapid rise in the market of budget airlines. These airlines often look for more ways to increase plane occupancy as demand grows. Following this rise in demand, budget airlines often remove the standard two-seat first class aisle, replacing it with a three-seat priority aisle.

Our calculations resulted in times that needed conversion through a particular variable we named "scale time." This variable is vital to the program as it converts the run time of each boarding method, as represented in milliseconds to real time represented in seconds. After further deliberation, we discerned that the value of scale time was equivalent to one second of real time for every one millisecond of runtime. This conversion led us to an accurate boarding time in seconds for each method, subsequently converted into minutes.

Variable Passenger Speed Method

Instead of incorporating arrays and scale time, the variable passenger speed method utilized mathematical algorithms and physics concepts to determine boarding speeds of each individual passenger. Combining these two core subjects created an equation that calculated each passenger's time to reach a specific seat.

$$T = 60\frac{(row)(width) + (|column|)(length)}{12s}$$

Figure 2. Equation for the variable speed method.

Each seat was labeled with the points of a coordinate plane with the aisle being x = 0, the front of the plane being the origin at (0,0), and the back of the plane being (0,30). Upon inputting the speed of an individual, the coordinates of the seat, and the legroom and seat width, the passenger's time was calculated. After adding the times for each seat and converting seconds to minutes, we analyzed the results and compared them to those of the two-dimensional array method. Our times proved to be nearly identical for both solutions with only minor deviations.

Modelling A Simulation

Utilizing Unity 3D, an animation and modelling program, as well as an HTC Vive virtual reality headset, we designed a playable simulation to recreate passengers reaching their seats aboard an airplane.

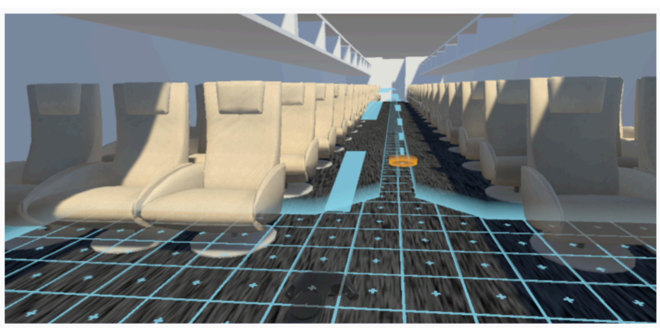


Figure 3. Picture of movement down the aisle.

By using navigation meshes and teleportation vectors, the player was granted free-reign to traverse the modeled airline. This primary segment of the simulation was mainly designed to provide a game-like aspect to the topic. Upon reaching the correct seat, the scene resets, but with slight alterations.

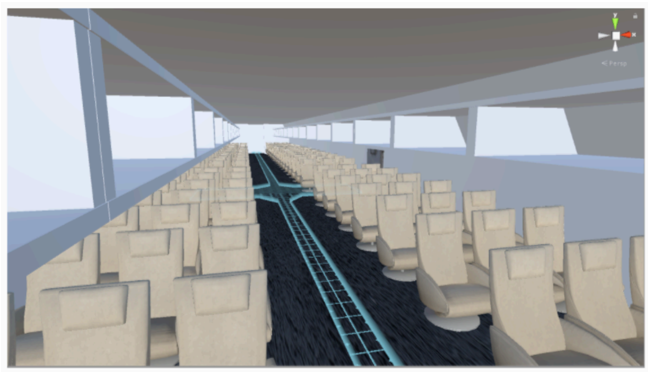


Figure 4. Navigation path in the plane.

In the newly loaded scene, the player is among a group of fellow passengers steadily boarding the plane. After reaching a new seat, the player is left to watch other passengers reach their individual seats. The representation of this boarding simulation is to demonstrate, through a simple medium, the structure and flow of airplane boarding. Displaying areas of conflict and design flaws in currently implemented boarding procedures, the player is better able to comprehend the severity of the boarding dilemma. To further this concept of disorganized boarding, each movement the player makes is monitored and affects a final boarding time that is calculated at the end of the program.

PERFORMANCE STUDY

Apparatus

We conducted our experiment on an iMac with an Intel Core i5 processor and 8 Gigabytes of RAM. Both the array simulation and variable speed methods were designed and coded originally in Java. However, with the transition to Unity 3D we programmed the simulation in C#. Our programs utilized random inputs for passenger speeds and seating locations to facilitate the boarding of a maximum of 180 passengers.

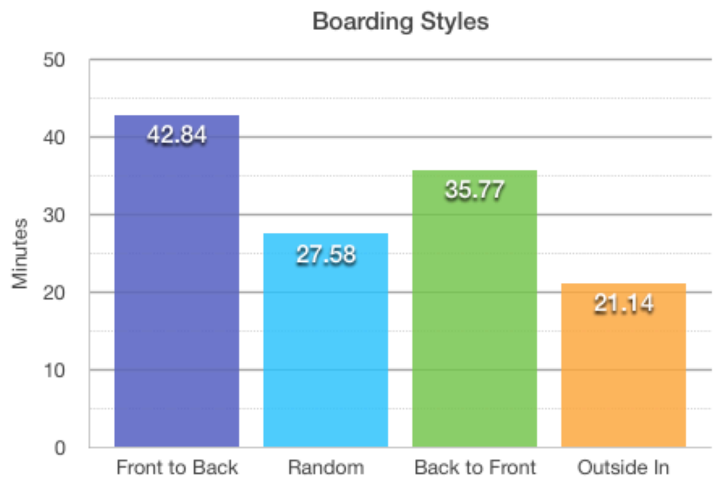
Experiment Design

In order to reach a sound conclusion, we utilized both the array simulation and variable speed methods combining and averaging the results from each run. To provide for a wide range of results, we ran each solution a total of 100,000 times for each of the four boarding processes. This means that we calculated the average time that it took to board a plane a total of 800,000 times.

RESULTS

Data and Interpretation

While there were a few outliers, particularly from the "Random" boarding method, both the array simulation and variable speed method calculated similar results. The typical variation of time difference between the two solutions was approximately 1 to 1.5 minutes. After compiling our data and analyzing the results, we began to see a trend. The methods that proved to be the fastest were those that were either fading from service or were already replaced by slower, more obsolete boarding patterns.



STYLE	TIME
Front to Back	42.84
Random	27.58
Back to Front	35.77
Outside In	21.14

Figure 5. Graph and table for boarding averages

The slowest method that appeared in our test data was "Front-to-Back". As the name suggests, airplane boarding starts at the front of the plane, progressively moving back until eventually reaching the rear. This method is one of the most popular in-use boarding systems as it gives primary seating to those in first class and other priority boarding groups. Because of this slow process, the boarding time is far greater than other methods at an average of 42.84 minutes.

Improving the boarding time by approximately 7 minutes, the aptly named "Back-to-Front" method greatly surpasses the "Front-to-Back" pattern. This process, resulting in 35.77 minutes of boarding time, is one of the other most commonly used boarding patterns for airlines. The algorithm for boarding is inverted to that of "Front-to-Back", boarding from the rear of the plane and steadily moving towards the cockpit. Unfortunately, the current application of "Back-to-Front" is being implemented as a hybrid, applying "Front-to-Back" to priority areas like first and business classes. After these priority passengers have boarded, economy and other lower-class passengers follow the "Back-To-Front" design.

Oddly enough, the "Random" boarding method, used by airlines such as Southwest, proved to be one of the fastest at 27.58 minutes. As the name implies, "Random" has no true structure, resulting in outliers between 30 and 33 minutes in the array simulation and variable speed methods, respectively. Regardless, the times proved to be some of the fastest from any method that we had tested so far.

With an average of 21.14 minutes, exactly 21.70 minutes less than that of the "Front-to-Back" method, the "Outside-In" algorithm proved to be the fastest. "Outside-In" incorporates a boarding pattern that starts at the rear of the plane, boarding all window seats, then middle seats, and finally aisle seats. While this method is fastest, there are a handful of issues that need to be addressed, specifically families and disabled patrons. Even so, the time that the plane boarded was significantly less than any other method and cannot be ignored. With these times in mind, we began to piece together a conceptual boarding process that would be even faster than "Outside-In".

CONCEPT

Summary

It is no surprise that one of the biggest issues with airline boarding times is the prevalence of a group system. These systems divide planes into separate sections thus increasing the time that it takes to board a plane. By separating an airplane into two groups separated by the aisle (Group ABC and Group DEF), we found that all programs ran significantly faster. The implementation of this strategy on the "Outside-In" method led to computational results determining roughly 18 to 20 minutes to board a full Boeing 737-800.

Family Boarding

The functionality of this modified "Outside-In" process relies on individual behavior and cannot function properly without the introduction of irregular groups. To appeal to these patrons, the simulation must consider their situation, such as group travel or handicapped status. Theoretically we would hope to appeal to these groups through the usage of rules and restrictions that our program would follow. For any travelling families, the method of "Outside-In" would briefly switch to "Back-to-Front" in order to allow for the family to board to the plane at the same time. Upon the family reaching their seats, the method would revert to "Outside-In". While there is a slight increase in time when switching methods for families, the change is relatively minor. Reverting back to the "Outside-In" method occasionally allows other passengers to board the plane faster, as there may be an entire row already filled by a family. This leads the simulated passengers to immediately move to the next row and board their seat without waiting for someone in front of them.

Disabled Patrons

The other group, disabled passengers, would board last instead of first, as this would prevent any congestion in the aisle. Furthermore, disabled patrons would be given priority seating, located at the front of the coach cabin for economy passengers. This location allows for better seating and offers storage for any medical necessities or belongings, such as wheelchairs and EPAP machines.

First Class Boarding

Making our hypothetical process a reality requires much work, as reaching maximum efficiency when boarding would require first class passengers to board the aircraft at the end of their group.

This is a seemingly insane statement to many, as the premium that is paid by first class passengers does not reasonably justify such treatment. However, after conducting a survey of 67 businesspersons from conglomerates including American Express, Sony Entertainment, and Marriot, a majority stated such a change would not be too improbable.

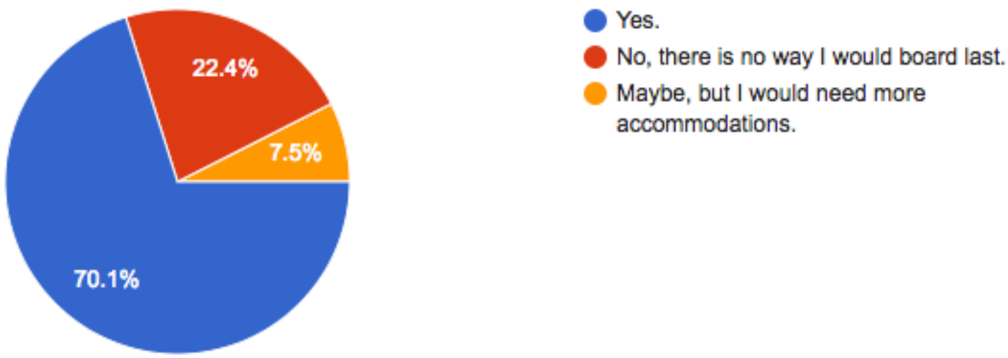


Figure 6. Survey results

In our study, 70.1% of those surveyed accepted that, given reserved overhead baggage, access to club lounges, and early drink and food service, boarding last in each group (ABC and DEF) was acceptable. In contrast, 22.4% stated they could not accept such conditions as first class passengers who already pay a premium to board first. However, 7.5% of respondents stated that, given certain accommodations not mentioned, they would likely opt to board last in their group.

Those who chose the option of "maybe" were asked to extrapolate on what they would like in addition to aforementioned benefits, with all of the responses providing tame additions that could likely be implemented. Such additions include bonus frequent flyer miles, an expanded menu on board, or food and drink service at the gate which would likely be provided by a nearby restaurant. Assuming all of the stipulations given by those who responded "maybe" were met, the total amount of those who would board the airplane last increases to 77.6%.

Environmental Effects
As a result of the shorter boarding times, planes would spend less time on the tarmac and use much less fuel while remaining idle, producing less greenhouse gas emissions. Furthermore, the profit that will be retained by airline companies is significant, as less money will be spent on refueling. The increased profit can then be redirected to improve other aspects of air travel, such as customer service.

Aircraft	Burn Rate (l/hr)	Fuel Consumed (current, liters)	Fuel Consumed (proposed changes, liters)	Current Fuel Burned - Loading (gallons)	Proposed Fuel Burned - Loading (gallons)	Current CO2 Emissions (lbs/CO2)	Proposed CO2 Emissions (lbs/CO2)
737.00	2.85	1.925	0.868	0.51	0.23	10.73001339	4.838260585
757.00	4	3.333	1.6	0.88	0.42	18.57825176	8.918452691
767.00	5.8	3.383	1.643	0.89	0.43	18.85695341	9.158136107
A320	2.9	1.93343	1.02176667	0.51	0.27	10.77700249	5.695361067
MD-90	2.9	1.624	1.02	0.43	0.27	9.052229481	5.68551359

Figure 7. Breakdown of current vs. estimated CO_2 emissions with the proposed method

Using Delta's fleet as an example, we found that there was a significant reduction in CO_2 emissions upon switching to the modified Outside-In solution. By calculating the current burn rate of fuel and applying the rate to the proposed method, we determined a decrease in carbon emissions of around 54.9% for 737 flights, 52.0% for 757 flights, 51.4% for 767 flights, 47.2% for A320 flights, and 37.2% for MD-90 flights.

Aircraft	Ttl. Owned	Current Fuel Burned - Loading (gallons)	Proposed Fuel Burned - Loading (gallons)	Current Idle Cost (ttl fleet)	Proposed Idle Cost (ttl fleet)	Percent Savings
737.00	171	86.96	39.2	$604.36	$272.51	45.09%
757.00	118	103.90	49.9	$722.09	$346.64	48.01%
767.00	83	74.18	36.0	$515.53	$250.37	48.57%
A320	65	33.20	17.5	$230.74	$121.94	52.85%
MD-90	65	27.89	17.5	$193.81	$121.73	62.81%

Figure 8. Breakdown of current vs. estimated savings with proposed method

The decrease in carbon emissions is not only beneficial to the environment but also to the airline companies. After averaging the cost of jet fuel to $6.95 per gallon, we applied the cost of refueling airplane models with current times to the proposed time. We found that the estimated minimum saving would be 45.09%.

FUTURE WORKS

Our concept aims to improve lifestyles as more people begin to use air travel. By incorporating new designs to decrease turnaround times, airlines will make a greater profit. As the airline industry develops over the next decade, there will be many more improvements that will be vital for the further growth of airline companies. The introduction of new plane designs will lead to an even more in-depth analysis of the effects of boarding times on airline companies, particularly from an economic standpoint. It would be beneficial to apply our programs and concepts to analyze the further effects that changes in the airline industry will have on both the passenger and the company. Using new methods, such as our modified "Outside-In" concept, would also allow aviation to succeed in a new era of transportation.

LESSONS LEARNED

During the development of our program we expanded our knowledge on two-dimensional arrays and variable-altered metric measurements in Java. These programs helped us to better understand the different boarding methods, the benefits and pitfalls of each, and how slight variations in each process affects the final boarding time. The Unity simulation that we developed expressed this data visually thus enabling for an ease of viewing and conceptual comprehension.

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