2022 International Mathematical Modeling Challenge

Team Control Number: 11727

Summary Sheet

In this paper, we consider possible boarding methods for three separate plane layouts. We built and used a mathematical model to determine the most efficient boarding and disembarking methods. We wrote a program in Python to calculate time spent at the gate and in the jet way. Similarly, we wrote an R program to calculate the times for randomized boarding and for seat structured boarding. Our team also created randomized identities for each passenger and used that data in our formula to calculate the total boarding time.

In our pre-model, we ran simulations to anticipate the different behaviors of passengers, such as the time they spend stowing their carry-ons, and how traffic jams can affect the total time of the boarding process. The experiments likewise taught us how troublesome passengers can delay boarding times and disrupt the gate process. We applied our model to various methods, including boarding by seats, section and randomized boarding. We also developed our own model that boards passengers faster than the three predetermined examples; we gave an abstract explanation of it, and compared it with other methods we considered.

With our cumulative findings, we wrote a letter to an airline executive explaining our model, and we recommended that they implement a more efficient boarding process–a counterpart to their inefficient front-to-back method. We asserted that the time shaved off from the boarding process will offset the cost of not having exclusive and expensive memberships currently used to finance the front-to-back procedure. We also argued that the industry-standard method of disembarking planes was uninspired and inefficient; instead we recommended a column-based plane disembarking system. This process is much faster than just letting people leave on their own, where jams prolong disembarking.

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1 Introduction

1.1 Background

As we ease into a new world after enduring a nerve-racking two year pandemic, one problem all commercial airlines must address is how to efficiently and safely board and disembark passengers. The world is trying to acclimate to a new normalcy, and many are impatient to travel for leisure, business, or just to see their loved ones. In the 21st century, air travel is the fastest way to travel internationally, and definitely the most convenient way to move between the west and east coasts of the United States. Considering the wide-reaching effect that COVID-19 has had on the entire world, such as making social distancing a regular behavior and requiring other safety measures to prevent contact between people, it is pertinent to evaluate the methods airlines use to accommodate their passengers.

Human behavior has an immense effect on departure delays and logistics issues that directly are a detriment to both the airlines and their customers. Human-influenced boarding and disembarking factors include:

- overhead storage related traffic jams,
- the inconvenience of aisle seats having to be emptied before a window seat passenger can be seated, and
- the general slowness of people to disembark their planes.

1.2 Problem Restatement

Our objective is to create a mathematical model to establish reasonable relationships between significant factors in the plane boarding and disembarking procedures, and the corresponding time efficiency. By doing so, we intend to optimize the efficiency and minimize the time consumption for passengers in these procedures. We interpret the problem as the following three fundamental questions:

a) What are the significant factors that might influence the time in the boarding and disembarking procedure?

b) How might these factors impact the overall time consumption of these procedures?

c) How can we evaluate and optimize based on the influence of these factors to create a boarding/disembarking method that best fits the situation?

The answer to the first question will define the factors in the embarking/disembarking procedure. The answer to the second question will determine the corresponding weights/significance of these factors. Answering the third question will combine all the factors and their corresponding weights into a meaningful model. This model will help the airline companies determine and create the optimal boarding and disembarking methods that are flexible and adaptable to various situations.

Dear Madam Executive,

My team and I recently took a flight with your airline company. We were excited to take to the air and enjoy a vacation in the sunny beaches of Tahiti.

We were marked as row 32 in a plane that had 33 rows in total. Once our section was called, we walked onto the jet way and stood there behind a large swathe of people that extended beyond our view. We assumed the reason for the hold-up was someone stowing their carry-on very slowly or that they were attempting to store some luggage that was simply too large to fit.

The aircraft in question only had one aisle there was no way of getting through except to wait. One person's selfishness/ignorance caused a massive delay hurting the customers (us), and most likely the airline (you). These types of bottlenecks are inescapable using your current method of boarding.

If you load from the front to the back, the flow of passengers is likely impeded by one person trying to seat themselves in the front of the plane. The other passengers that purchased seats in the back of the plane, like us, suffer because they have to wait until everyone else is settled into their spot before they can finally get to the back. We understand that even though other methods of boarding are more efficient, you profit from people that purchase priority boarding and other exclusive passes. This business makes you money at the expense of time as it takes your flights more time to board, but you generate more money from people that want the prestige of preboarding.

Based on our simulations, we have proven that a randomized boarding procedure is more time efficient (excluding the preboarding passengers). One example of a less structured boarding system is the Southwest airlines method which is whoever checks in first gets to board first. There is an initial order that the passengers line up into, but once they reach the plane and exit the jet way, it's their choice where to sit. This randomized boarding system works better, but is not perfect–many people can still create traffic jams by blocking the aisles.

We propose to solve this problem through boarding by column. Window seat passengers file in first, then middle seats, then aisle seats. This procedure would reduce back-ups since no passenger would need to re-enter the aisle to let other passengers in. This method is safer than a randomized boarding procedure since people don't have to compete with each other for a seat; instead, they get an entire column of seats to choose between. However, this method does not account for the fact that in reality people have families and typically want to sit with them.

We have considered an even more efficient procedure: boarding by a structured order of rows. This procedure allows families to sit together, and also cuts back on the inefficiencies of boarding from the front to back. Essentially, people would be sorted into groups of three and in those groups ordered by their seat position(aisle, middle, window). Then groups would fill the even number rows of seats starting from the back and work their way to the front. Then another set of groups would do the same on the other side. This, in theory, would alleviate the congestion caused by stowing delays.

Our flight also experienced issues after landing. We heard the pilot say: "Thanks for flying with us, safe travels." After that, for about 30 minutes we sat waiting for the row in front of us to leave, but the passengers were disembarking from the rows first, so it took a long time for everyone in the middle and window seats to shuffle out and leave. I propose that airlines like yours implement a disembarking procedure that's column-based. A column based method would work better since the aisle seat passengers can easily leave there seat and could swiftly exit the plane. Then the middle and window seats would do the same.

Thank you, TOT Nuclear

2 Preliminary Information

2.1 Assumptions and Definitions

Assumptions:

1. In the process of boarding and disembarking all passengers move forward and follows the trend of other passengers. This is true because it's hard to go and pass against the wave, in real scenarios each passenger will take time and pay close attention in finding their seats to make sure they won't go backward against the trend of the people.

2. The order of passengers at the gate is the exact same as the order of passengers entering the plane. During the trip through the jet way, the passengers are unlikely to pass each other. If we did not decide to void this eventuality, then we would have to factor to many possible order changes.

3. One minute after boarding the priority boarding group, the other groups are called to board. This gives us a constant amount of time to board the priority boarding groups, otherwise there would be too many factors to consider.

4. Passengers will not switch their seat because then their position would change, and accounting for how that would affect the total boarding time is unreasonable. If we consider the randomness of this happening, then we would have to consider every other possible occurrence.

Definitions:

1. A Bunch consists of three seats on the same side.
2. Normal luggage is one carry-on per person; 22" by 14" by 9".
3. Start of boarding time is when the first person's ticket is scanned.
4. A jet way or jet bridge is the connecting passage between a gate and a plane.
5. Disembarking starts when the first passenger gets up and ends when the last person leaves the plane doors onto the jet bridge.
6. Burdensome refers to someone who causes excessive delay while boarding and disembarking. For example, an argumentative passenger or a passenger who disregards the established boarding procedures.

2.2 Constants and Variables

Table 1: Assumed constants

Description	Value
Aisle width	3 feet (1 seat)
Max distance between 2 person	4 feet
Time between priority groups	50 seconds
Average of walking speed	$\frac{2.1+2.17+2.3}{3}$ ft/s
Time to go from the aisle to the seat	2 seconds
Length of cabin	96 feet
Marginal time	5 minutes
Time for sit duration	10 seconds

Table 2: Variables

Variables	Description	Units or Values
$B_{sit,\,k}$	Bunch sit time by row k	sec
$B_{urden,\,n}$	Level of burdensome for person n	Intensity: {0, 1, 2, 3, 4}
C_{length}	Length of cabin	ft
L_{num}	Number of luggage(carry-on bags)	Luggage
O_n	Order of passengers	NA
$Q_{wrong,\,n}$	Person n in wrong order	Intensity: True(1) or False(0)
Row_{num}	Row number	Rows
$Seat_{pos,\,n}$	Seat position of person n	aisle;1, middle;2, window;3
$Seat_{row,\,n}$	Distance from entrance to plane seat of person n	ft
t_{aft}	Time to get to the back of the plane	sec
$t_{bag,\,n}$	Time to put a bag for person n	sec
t_{block}	Time to block the aisle	sec
t_{bow}	Time to get to the front	sec
$t_{disembark}$	Total time of disembarking	sec
t_{gate}	Time at the gate	sec
t_{mid}	Time to get to the middle section of the plane	sec
$t_{move,\,n}$	Time to move in and out of the seat for person n	sec
t_{seat}	Time to go from the aisle to the seat	sec
$t_{sit\_duration,\,n}$	Time to put a bag and time to move in and out of the seat for person n (simplification variable)	sec
$t_{TBE,\,s}$	Time before entrance(structured)	sec
$t_{TBE,\,u}$	Time before entrance(unstructured)	sec
$t_{boarding}$	Total time of boarding	sec
$t_{tot_{plane}}$	Total time in the plane(boarding)	sec
$t_{tot_{shuf}}$	Total time for shuffling(boarding)	sec
$t_{tot_{wait}}$	Total time of waiting(boarding)	sec
$t_{tot_{walk}}$	Total time of walking(boarding)	sec
$W_{s,\,avg}$	Average walking speed	ft/s
$W_{s,\,n}$	Walking speed for person n	ft/s

3 Pre-model

3.1 Simulations and Data Collection

The main feature of the pre-model that we discussed was the passenger identities. These identities consist of boolean values (True and False) and of numerical indicators representing conditions such as Burdensome, Queue wrong, Walking speed, and Priority. These inputs allow us to evaluate the time that it takes each individual to board a plane. These values are randomly selected from a small pool, and are weighted to reflect how common each identity is. For instance, Burdensome has a 55 percent chance of being 0, and a 45 percent chance of not being 0.

Table 3: Passenger Identity

variable name	variable letter	possible values
Walk speed (ft/s)	W_s	{2.1, 2.17, 2.3} ft/s
Queue wrong	Q_{wrong}	yes(1) or no(0)
Burdensome	B_{urden}	{0, 1, 2, 3, 4}
Priority	P_{rio}	yes(1) or no(0)
Luggage number	$L_{\#}$	{1, 2, 3}
Seat row number	$Seat_{row}$	$\text{Seat}_{row} = 3 \cdot Row_{numb}$ is position in ft relative to entrance of plane
Seat column	$Seat_{spot}$	aisle{C, D}, middle{B, E}, window{A, F}
Seat position value	$Seat_{pos}$	$\text{P}_2(t) = \begin{cases} 1, & Seat_{spot} \in \{C,\ D\} \\ 2, & Seat_{spot} \in \{B,\ E\} \\ 3, & Seat_{spot} \in \{A,\ F\} \end{cases}$

Priority is a boolean value that identifies if someone has been given a preboarding pass; for example, soldiers, people with disabilities, and people who bought an expensive early boarding pass. We did not include people with priority boarding passes into our model for human behavior around boarding because they did not board with the mass population of passengers. Queue wrong is another boolean value that assesses if someone is in their assigned order in their terminal queue (line). We had to incorporate the time added when people have to be redirected to their assigned group because they try to board with higher groups.

Walking speed is used in most of our equations and is randomly selected from a list of three speeds. Seat row number represents the distance from the entrance of a plane to the individual passenger's seat, we used this to calculate the time it takes a person to reach their seat. Seat position values essentially represent the random selection between aisle, middle, and window seats and affixes the numbers 1, 2, 3 respectively. We use this value to calculate the time it takes a passenger to shuffle, and we also use it with the column boarding.

Our team performed a role-playing simulation of typical traveler behavior. We experimented with different types of people: problematic wrongdoers that try to board before their group is called; people that have physical impairments, specifically the elderly; and also the most ideal scenario where all passengers board efficiently, even though it is not realistic. The simulation included the average distance that people walk on jet ways, around 100 feet. This impromptu experience helped us create a rough idea of how the total boarding time is calculated; it is not the individual times of each passenger summed, but it is the time difference between checking the first passenger to the last sitting down. Since there is an overlap between each passenger's boarding time but each person is constrained to stand behind the person in front of them.

We collected some specific data about the boarding times of passengers with various challenges which impeded them from swiftly getting to their seat. Including the following: an old man who misplaced his ticket; an impatient man who tried to get on the plane when his section wasn't called; a person who made a queue form behind them from taking a long time to put away their luggage. We used various constants like the amount of time it takes to put away carry-on luggage into the overhead bin and how much time it takes to greet the gate agent and walk through the jet way.

From here, we considered the eventuality that some people would take longer to put their luggage into the overhead bin and would create congestion. This consideration was for the narrow-body passenger aircraft, so the traffic caused by one person's sluggishness would hinder everyone from getting to there seat. This rule effectively led to our model to calculate the total boarding time. Some of the characters we artificially created had the same individual boarding times meaning that their walking speed was on average the same. In the piecewise graph we produced, this is reflected with parallel linear lines representing the movement between the passengers' gate and their seats.

3.2 More Luggage Than Normal

When the passengers carry with them more luggage and are weighed down to a greater degree, they become slower and less mobile. This has a limit on the speed that the average passenger can move at, we estimated that their average walking speed would be 2 feet per second without an excessive luggage haul. This, of course, depends on the person and their age; so, we randomized the number of feet traveled by a person in one minute between the choices 126, 130, and 138 feet. This produces a comfortable walking speed for people of various age groups and physical abilities. Realizing that their would be a few principal effects of having passenger carry more weight with them. For one, their walking speed would wane and they would be generally slower. By running a slower range of walking speeds through our model, we can visualize that the total time of boarding would be prolonged if passengers carried more luggage. This is onset by the smaller slope of the first passenger, or of any passengers attributed a slow quality by random. Also, we considered the event that with heavier luggage, it would take a passenger more time around their seat to put away their suitcases or bags. This is represented by an idle horizontal line affixed after the constant slope of a passenger walking to their seat. It would be harder for a passenger to stow away three articles of luggage than only one. Also, we thought about the inconvenience of a passenger not having enough space in the overhead bin to stow their luggage. If everyone brings more luggage than usual, then the expected volume of luggage would exceed the available space in the overhead bins. The confusion of not having enough space to store passengers' luggage would require flight attendants to empty the middle aisle and bring the luggage to the underbody of the plane. The outcome of these accommodating circumstances definitely extend the boarding time of a Narrow-body airplane.

3.3 Alternative Boarding Methods

Various methods could replace the three methods clearly outlined in the this problem's requirements. Really, there are innumerable ways to board people onto a plane. Of course, none of them would strike any sizable advantage over other procedures that have been tediously designed to garner the fastest boarding times. Our team has contemplated on a short list of possible new methods of boarding a plane. One such method would be to board the plane based off of alphabetical order of the names of each passenger. For instance, someone called Alex would board relatively quickly after the gate is opened; however, someone called Xavier would be allowed to board the plane after most of the queue will have been boarded. This mode of boarding a plane would be very difficult to undergo, the logistics of sorting people into alphabetical order would be strenuous and inefficient. Also, people are likely to lie about the letter that their name starts with if they are given early boarding.

Another unprecedented method of boarding we considered is by grouping elderly people first and moving them to the back of the plane, so that it fills efficiently and people don't have to be held up by slow, unattentive individuals affected by old age. This idea only seems reasonable and measurably effective if the elderly passengers are given priority boarding and get to board their plane earlier; they generally need more time to move. For other planes that provide multiple ways for the elderly to navigate its rows, there is enough space in the aisle allowing the elderly passengers to move without need of significant time; however, their walking speeds are slower than the average person. We are making this judgment from the perspective of an airline company that values time efficiency over ethics. Considering this, the trade-off is a net positive financial gain for the airline company.

3.4 Shuffle Time

[Appendix : Figure A]

Shuffle time is defined as the time passengers move out of their seats and into the aisle. This time is significant to consider because when the passengers move out of their seats they are blocking the aisle for other passengers, thus extending the overall time of boarding. The following diagram shows all the possible seat arrangements for passengers in different orders. The circle represents when the there are no passenger in the seat, X represent there is a passenger in that seat. t_{seat} isn't significant as it's already been considered in $t_{sit-duration}$. t_{block} which we define as 2 seconds representing the time a person spends moving in and out of between seats. For example, moving from position "OXO" to position "OXX", Passenger A sits at the window seat, but passenger B is blocking the path by sitting in the middle seat. Passenger B realizes Passenger A is being blocked thus moves to the aisle seat while Passenger A is putting their luggage in the overhead bins. After Passenger A puts their luggage up, Passenger B moves out and stays in the aisle for 2 seconds while Passenger A sits down at the aisle seat. After another 2 seconds, Passenger B moves to the aisle seat while Passenger A moves to the middle seat. Then, after another 2 seconds Passenger A sits at the window seat and Passenger B sits at the middle seat. The reason we don't consider the time Passenger B came back to their seat is because that passenger is no longer blocking the flow of the people in the aisle. Thus to go from seat arrangement "OXX" to "OXO" we only add a total of $2t_{block}$ which adds 4 seconds to the total time. Mathematically, the expected value for total shuffle time is:

$$t_{tot_{shuf}} = \frac{seat_{tot}}{3}(1/6(0t_{block}) + 1/6(2t_{block}) + 1/6(5t_{block}) + 1/6(0t_{block}) + 1/6(4t_{block}) + 1/6(2t_{block}))$$

3.5 Time Before Entrance

We define time before entrance specifically to the time passengers spent at the gate door. However, this time also include the time spent at the jet way because during the process of boarding, some passengers already pass the jet way and enters in the plane, therefore their time in the jet way will be overlap with time count at the gate. For any structured boarding procedure, we define the total time spent at the gate for all passengers as following:

$$t_{TBE_s} = 50 + \sum_{p=1}^{seat_{tot}} \left[Q_{wrong_p} \left(B_{urden}\right)_p + 5 \right]$$

The number 50 represents the estimation of 50s in between the boarding of priority groups and normal passengers. p stands for passenger, and 192 is the total number of passengers boarding the plane. Q_{wrong} as define in Passenger Identity is whether or not a passenger is in their assigned order,

$Q_{wrong} = 0$ means they are in order, $Q_{wrong} = 1$ means they are not in order. B_{urden} on the other hand is how troublesome a person may be. Thus the time for each passenger have two possible outcomes, if they are in the right order ($Q_{wrongp} = 0$) they are not going to cause any trouble, their only time spent at the gate is the 5 seconds of checking ticket. On the other hand if they are in the wrong order($Q_{wrong_p} = 1$), when the flight attendants demand them to go back, they are going to cause different degrees of trouble according to their identity B_{urdenp} extending time beyond the normal 5 seconds of checking tickets. Using $\sum$ we can find the total time of all passengers spent at the gate during structured boarding.

For unstructured on the other hand, since there are no order of entering whatsoever, it's impossible to lined up in wrong order, therefore $Q_{wrong} = 0$ is true of all passengers. Thus the total time spent for unstructured is just an constant:

$$t_{TBE_u} = 50 + \sum_{p=1}^{192} [5]$$

3.6 Marginal Time

We considered marginal time into our model to account for small amounts time where a passenger could be idle or for the eventuality where they talk for longer than anticipated. Some events include greeting the flight crew at the start of the flight and shuffle time when disembarking. This marginal time is a constant 5 minutes.

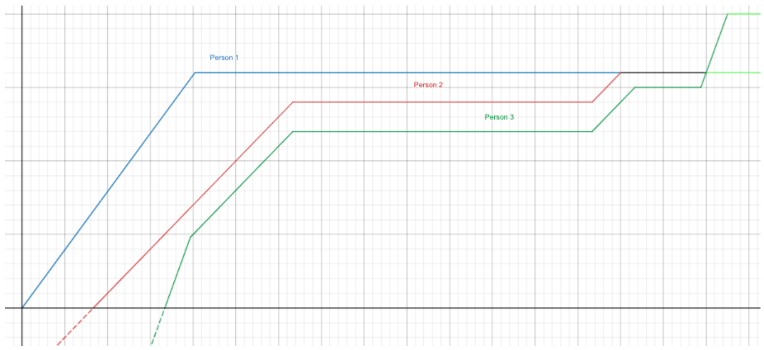
3.7 Main Concept

The principal concept of our pre-model is that a person's boarding time is predetermined by the walking speed of the person in front of them. The idea is that a passenger's speed cannot exceed that of the person in front of them; this, of course, means that our model needs to be recursive. The position of a passenger versus time is dictated directly by the person before them. This only complicates the model, but is where the idea of a piecewise function came about, it was a good visualization of how the total time could be calculated. One other notable observation we made was that the total time would be the time between when the first ticket is scanned and the last person sits down.

4 Mathematical Model

4.1 Model Overview

In the graphical interpretation of our model below, the three piecewise functions represent the distance three people are from the entrance of a plane as a functions of time. The lines are all transformed 4 units down; this models the average of 4 feet of space between the toes of one person to the toes of another person. We assumed that the space between people would not reach lower than 4 feet. Once the first person boards the plane, the person behind them has to stay at least 4 feet away. Therefore, the first person's walking speed dictates the speed of the people behind them until they reach their designated seat. The speed of the first person is a constraint for the people behind them, at least in a single aisle airplane.The logic is that if one person starts walking faster



than the other person in front of them, then they have to match their speed–this is why Person 2 and Person 3 have the same slope. However, when Person 2 finally sits down, Person 3 accelerates to their preferred speed. This is realistic to a plane boarding scenario since a passenger would be forced to slow down if there was a traffic jam in the middle aisle, not just walk through someone. Generally speaking, if you are eager to board a plane, you walk at a relatively quick speed to get to your seat; however, not everyone shares the same rationale. It is apparent that many people will saunter down the aisle and hold up many passengers from boarding efficiently. This is the case with Person 2, they are a burden on everyone around them since they take their time to get to their seat; they are not very accommodating to the other passengers. In relation to Person 2, Person 3 is conscientious that other people are trying to board and moves very quickly. This specific situation is indicative of many common human behaviors, notably conceit. Person 1 is also responsible for being selfish, they stood at their seat stowing their likely cumbersome and oversized luggage into the overhead bin for a very long time. This is expressed by the horizontal line after Person 1 walked to their seat.

4.2 Random Boarding/ Boarding By Seats

We define random boarding procedure (a.k.a. unstructured boarding) as there is no order for passengers for enter whatsoever except the priority groups.The environment of this simulation will be an "narrow-body" aircraft at full capacity (a.k.a 192 seats with 192 passengers).

We define the boarding by seats as there passengers line up at the Gate before boarding based on their seat position. Basically, the passengers who sit at seat spot "A" and "F" enters after the entrance of priorities groups. Then the passengers who sit at seat spot "B" and "E" enters second, and passengers who sit at seat spot "C" and "D" enters last.

The Random Boarding and Boarding by seats process are similar in terms of time spent in a plane as they both involve randomizes seat row number, and blocking time due to passengers putting luggage in the overhead bin correspond to their rows.

To figure out the total time in the two boarding procedure, we conduct simulations based on 7 preliminary factors: Walking speed of passenger (W_s), how troublesome each passengers are (TS), passenger's seat position ($Seat_{pos}$), passenger's row seat (Row_{seat}), number of passengers in the plane (P), the order of passengers during boarding procedure (O), and the length of the cabin of the plane (C_{length})

Combining and manipulates among the 6 preliminary factors using equations and formulas will results in two final factor: Total Walking time ($t_{tot_{walk}}$) and Total waiting time ($t_{tot_{wait}}$) in which

$$t_{tot_{plane}} = t_{tot_{walk}} + t_{tot_{wait}}$$

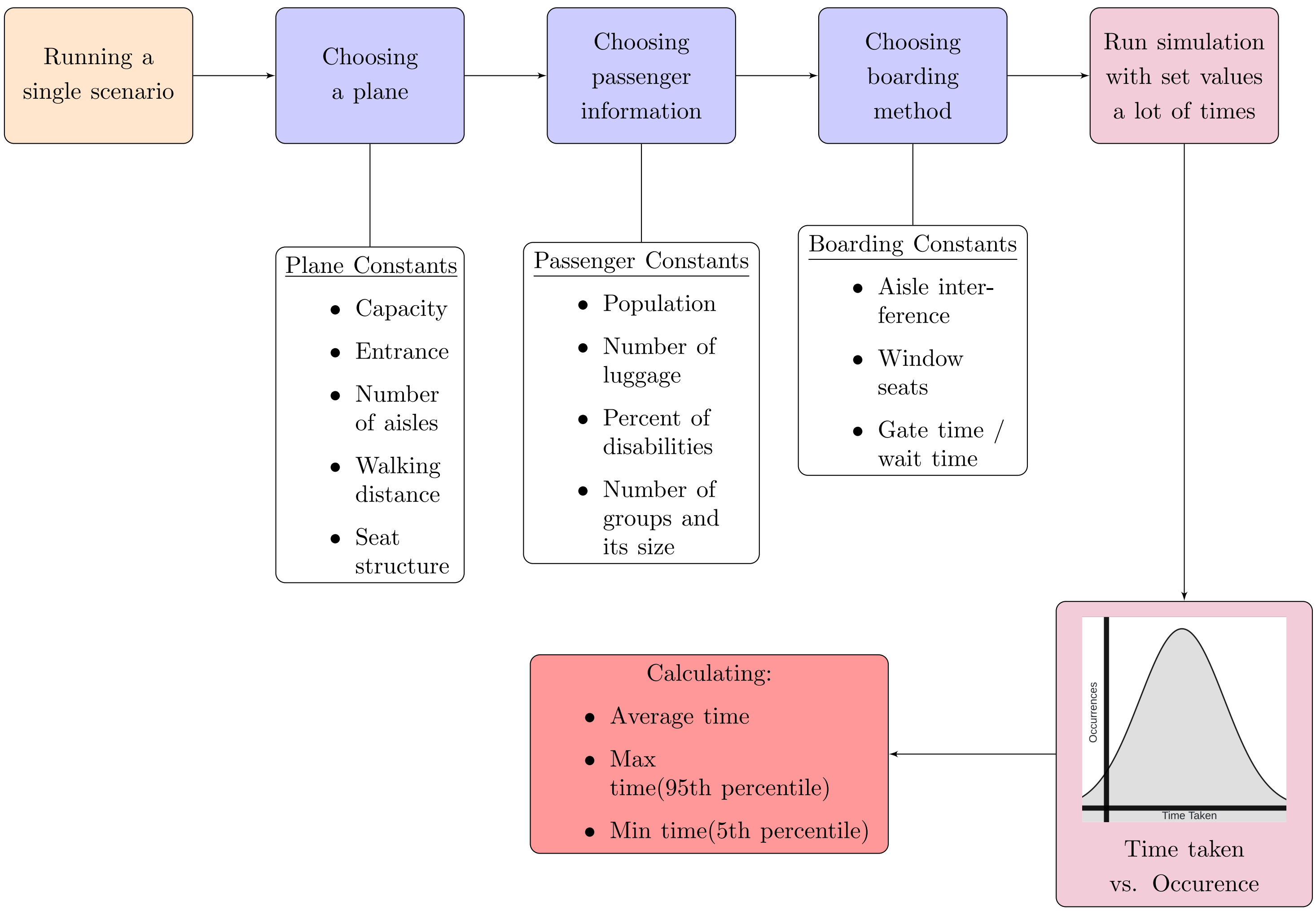


Figure 1: Boarding Flowchart

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4.2.1 Walking Time and Waiting Time

We calculate the total walking time for passengers' boarding as follows

$$Tot_{walk} = \sum_{k=1}^{n} \left(\frac{C_{length}}{W_s \cdot Row_{num}} \right)_k$$

.

This formula is derived from 4 analysis of the Model Overview.

Analysis 1: Since length of cabin in the plane is fixed, thus disregards the orders of the passengers when they enters the plane, and disregards the time the passengers spent in waiting for other passengers to sit down, the distance of a passenger who sit at the last row of the plane is always constant. In terms of the graph in model overview, the total sum of the vertical displacement of each segments is going to constant (96ft for "Narrow body" aircraft)

Analysis 2 : The segments that increases the overall vertical displacement are segments with positive slope.

Analysis 3: The slope of the graph is the speed of that specific passenger. Walking means the slope of the line is positive, thus increasing vertical displacement. Sitting means the slope of the line is 0, thus no change in vertical displacement.

Analysis 4: There are overlapping between passengers walking time, the only significant on time is when the passengers pass through that specific row for the first time.

Therefore to calculate the time spent for each segments we use the cabin's length (C_{length}) divided by the total number of Rows in the plane (Row_{seat}) to find the distance between each row of seats ($96/32 = 3$). Then we take the distance between each row of seat(3) and divided by the walking speed of the passenger who walk pass that segment for the first time ($3/W_s$), we will get the time spent to walk pass 1 row of seat. Then we repeat this process for 32 times to get the total time passengers spent on walking that are significant in calculating the time.

We calculate the total waiting time for passengers' boarding as follows

$$t_{tot_{wait}} = \sum_{n=1}^{\beta} (t_{sit-duration})_n$$

.

This formula is derived from 3 analysis of the Model Overview.

Analysis 1: Once people arrive at their row, that person and the people behind that person will have to wait, which means their location is not going to change until that person sits down.

Analysis 2: People who are more troublesome will takes more time to sit than people who are less troublesome.

Analysis 3: The time that this blocking and waiting time occurs only depends on the order and the rows of the passengers, the more time this blocking and waiting time occurs, the longer the total time for people complete boarding.

In addition to the three analysis we need two equations to help us:

$$\beta = \sum_{m=1}^{p} \left(\left\lceil \frac{1}{Rs_p + O_p} - \frac{1}{113} \right\rceil \right)$$

β in the final equation which is total time the blocking occurred in the process of boarding. β is calculate as the sum of the ceilings of $\frac{1}{Rs_p+O_p}$ in which Rs_p represent the row of the passenger's seat, and O_p represents the order of that passenger when enters the plane. The expression $\lceil \frac{1}{Rs_p+O_p} - \frac{1}{113} \rceil$ will give a value of 0 when $Rs_p + O_p <= 133$, a value of 1 when $Rs_p + O_p > 133$, the number 113 is calculate the mean of the maximum row number and the total passenger number. This expression explains the likelihood of blocking occurrence for a passenger sits in the front of the plan and enters earlier is greater than the likelihood of blocking for a passenger sits in the back and enters later.

$$t_{sitduration} = 2\left(B_{urden} + SP\right) + 10$$

This expression calculates the amount of time it takes one person to stow their luggage in the overhead bin, and subsequently sit down. It uses randomly generated values of B_{urden} and SP. B_{urden} represents how disruptive the passenger is, and SP represents their position: aisle, middle, and window. SP is also randomly generated, and can be any of the elements in the list, [1, 2, 3], with each element occurred 32 times to match the seats in the plane.

4.2.2 Conclusion and Comparison

Recall :

$$t_{tot_{plane}} = t_{tot_{walk}} + t_{tot_{wait}}$$

. Thus, the total time spent for passengers in the plane is express as follow:

$$t_{tot_{plane}} = \sum_{k=1}^{n} \left(\frac{3}{W_s} \right)_k + \sum_{n=1}^{B} \left(t_{sit-duration}\right)_n$$

.

The difference between Random Boarding and Boarding by seats occurred in time spent before the entrance of the plane, and the shuffle time of passengers as define in premodel.

For Random Boarding the time spent before the entrance is going to be smaller than the time spent for Boarding by seats. This is because it's impossible for passengers in Random Boarding to line themselves up wrong (queue wrong), yet it's possible in Boarding by seats thus extending the time to pass the gate.

However the shuffle time for Random boarding is going to be longer than Boarding by seats because it's possible in Random boarding a passenger who has a window found another passengers in the aisle/middle seat when reached the row, and thus the passengers in these two seats need to get out before that passenger could sit down, thus extending the overall time. Yet in Boarding by Seats, since the order is already set based on their seat spot, shuffle time would be 0 in the case of Boarding by Seats.

Mathematically, the total boarding time for Random Boarding is:

$$t_{tot_{plane}} + t_{tot_{shuf}} + t_{TBE_u}$$

The total boarding time for Boarding By Seats is:

$$t_{tot_{plane}} + t_{TBE_s}$$

4.2.3 Distributions

Simulating Random Boarding using R programming with 5000 random trials will give us a graph following [[Appendix : Figure B].

The 5, 50, and 95 percentile of this empirical distribution is 3054 seconds, 3096 seconds, and 3140 seconds which is about 50.9 minutes, 51.6 minutes, 52.3 minutes respectively.

Simulating Boarding By Seats using R programming with 5000 random trials will give us a graph following [Appendix : Figure C].

The 5, 50, and 95 percentile of this empirical distribution is 2683 seconds, 2725 seconds, and 2770 seconds which is about 44.7 minutes, 45.4 minutes, 46.1 minutes respectively.

In the piecewise above, the disembarking time of one person is defined with two equations. For the passengers in the rows less than 15, it is considerably faster; whereas, the people in rows greater than 15 have to spend more time waiting, so their disembarking time is greater. Note that this is for one boarding method, rows.

Column:

$$T_{disembark} = \begin{cases} \frac{1}{2}x(Row_{num})^2 + 30\{Seat_{pos} = 1\} \\ \\ x(Row_{num})^2 + 30\{Seat_{pos} = 2\} \\ \\ 2x(Row_{num})^2 + 30\{Seat_{pos} = 3\} \\ \end{cases}$$

The piecewise function above calculates the disembarking time of an individual passengers by rows, it assumes that their is some shuffle time, and more overall congestion in the aisle. The main idea is that the closer you are to the window the longer it takes to disembark.

4.3 Boarding by Section

Boarding by Section (a form of structured boarding) is boarding by Bow, Middle, Aft sections.

1) bow section (rows 1-11)

2) middle section (rows 12-22)

3) aft section (rows 23-33)

We must first find all of the cases that are considered in this section. These are the 2 most important combinations of Bow, Middle (which we will call Mid), Aft. It is more reasonable to consider these 2 cases will likely give a 2 extreme cases. Either the optimal or the most efficient.

1. Aft, Mid, Bow
2. Bow, Mid, Aft

Instead of using probability to predict the motion of people, we will instead calculate the average time taken by **Bunches** (see definitions).

4.3.1 Boarding by: Bow, Mid, Aft

We will calculate the time taken by a **Bunch** (one side of a row) by taking the average time of the worse seat shuffling time with the best seat shuffling time.

Table 4: 3 person seat shuffle

steps	value
P_1 walks P_1 puts bag P_1 sits in aisle	time=$t_{sit,\,1}$
P_2 puts bag	time=$(t_{bag})_2$
P_1 moves out	time=$(t_{move})_1$
P_2 and P_1 sit in middle and aisle respectively	time=$(t_{move})_2$
P_3 puts bag	time=$(t_{bag})_3$
P_1 and P_2 move out	time=8 sec
P_3 and P_2 and P_1 sits in window, middle, aisle respectively	time=$(t_{move})_3$

The table above lists the steps the movement of 3 arbitrary passengers all seating in the same **Bunch**. They are ordered in a way which each person has to get up to let the person in. We assume that passengers may not coordinate with others, therefore giving the worst time. [Appendix: Figure D] models those steps in a position vs time graph.

$$B_{sit,1} = (t_{bag})_2 + (t_{move})_1 + (t_{move})_2 + (t_{bag})_3 + 8 + (t_{move})_3$$

The total time time after person 1 (P_1) sits is $B_{sit,1}$, which is the sum of the time ranges in the image above. The 1 indicates that this is the sit time (of all 3 people) in bunch 1.

$$(B_{sit,\,k})_{worst} = (t_{bag})_{i-1} + (t_{move})_{i-2} + (t_{move})_{i-1} + (t_{bag})_i + 8 + (t_{move})_i$$

We can now generalize the Sit time of any **Bunch** ($B_{sit,k}$) –see[Appendix: Figure E]–in terms of k, the row number. Where $i \in \{3x \mid x \in \mathbf{N}\}$, where $k = 2x$, in other words, 2 bunches makes up a row, and x is a bunch.

We calculated the worst possible time for a bunch to sit, and now to find the best time to sit. We go through the same methodology to find the best possible time.

$$(B_{sit,\,k})_{best} = (t_{bag})_{i-1} + (t_{move})_{i-1} + (t_{bag})_i + (t_{move})_i$$

The equation above is similar but shows the best time possible for a bunch to sit. Refer to [Appendix: Figure F] for explanation.

$$(B_{sit,k})_{avg} = \sum_{k=start}^{end} \left(\frac{(B_{sit,\,k})_{worst} + (B_{sit,\,k})_{best}}{2} \right)$$

4.3.2 Boarding by: Aft, Mid, Bow

See [Appendix: Figure G] for the position of each **bunch** (Bunch 1 represented as red) for the worst time taken by the Bow, Mid, Aft scenario. Unlike the other scenarios the Bow, Mid, Aft has big clog up. All of the bunches will pile up no matter what. This is why we must consider this case shown in [Appendix: Figure G].

$$t_{(bow,mid,aft),\,avg} = (B_{sit,k})_{avg} + t_{sit,\,1} + (16)(8W_{s,avg})$$

First we have to add the sit time of the first person, $t_{sit,1}$If we look at Figure (Multiple Dotted lines) we will notice the parts of the equation being summed. The $\lfloor \frac{1}{2}(32) \rfloor$ is the extra walking times there, which occurs 16 times.

Now we can add one the gate/jet way and marginal time.

From section 3.3 (Time Before Entrance) we can add on 965 seconds, and add on 300 seconds (5 minutes) from Marginal time.

$$t_{(bow,mid,aft),tot} = t_{(bow,mid,aft),\,avg} + 965 + 300$$

This is the total boarding time of the Bow, Mid, Aft ordering.

Now we are going to consider the Aft, Mid, Bow

The figure above shows the position of the bunches as time increases. The bunches are lined up correctly in order so that no row needs to wait for the other. The diagram above shows all of the B_{sit}, but we only want to add up a certain amount of them. We want to add up $B_{sit,k}$ for values of $\{1, 2, 4, 6...\}$. There is an overlap.

$$t_{(aft,mid,bow),\,avg} = \sum_{j=1}^{16} ((B_{sit,j})_{avg}) + B_{sit,1} + t_{sit,1}$$

$$t_{(aft,mid,bow),tot} = t_{(aft,mid,bow),\,avg} + 965 + 300$$

Using j for $j \in \{2k\}$ allows us to take every 2 rows and add on the first Sit time to keep the pattern.

Comparing the (Aft, Mid, Bow) and (Bow, mid,aft).

$$t_{(aft,mid,bow),tot} > t_{(bow,mid,aft),tot}$$

We notice that Aft, Mid, Bow is strictly greater than Bow, Mid, Aft using the same passenger identities.

After many trials with varying passenger identities we found that the 95th percentile of time taken was 34.0 **minutes**, and the 5th percentile was 32.0 **minutes**.

In the next parts of the paper the $t_{(aft,mid,bow),tot}$ will be referred to as the function, $t_{section}(start, end)$.

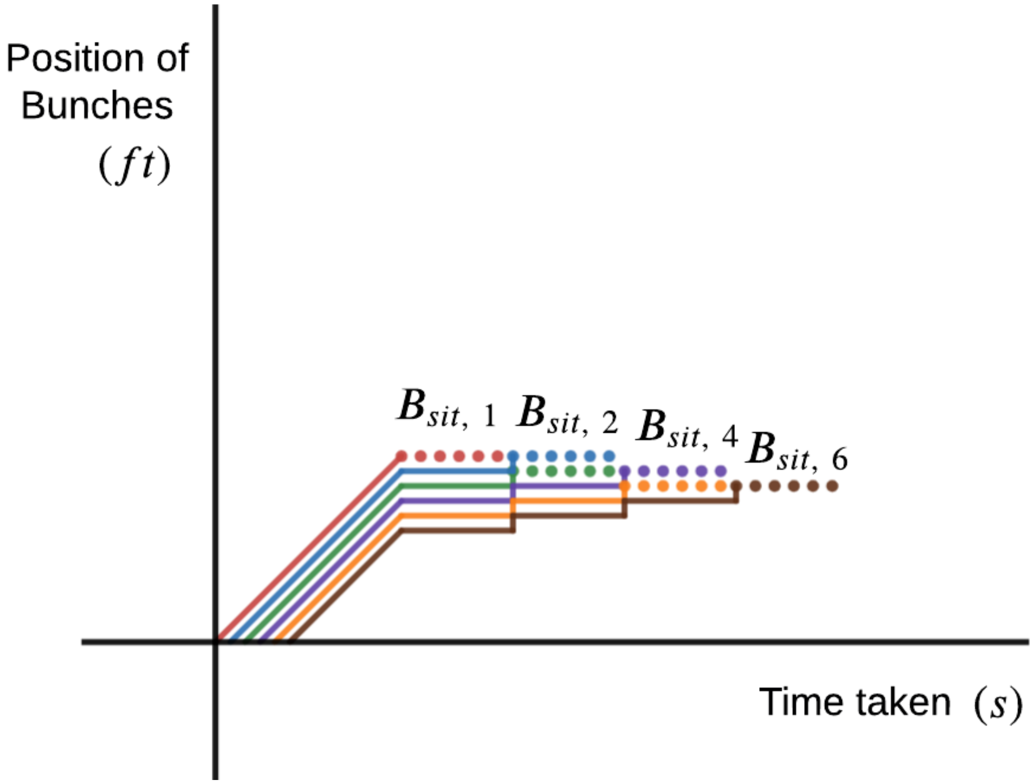


Figure 2: Bunches loading in plane in a nice order

$$t_{section} = \sum_{j=start}^{end/2} ((B_{sit,j})_{avg}) + B_{sit,1} + t_{sit,1}$$

4.4 Disembarking

[Appendix : Figure H]In short, this program calculates the time that a passenger would have to wait before disembarking. This time is based off of the passenger seat's row and a margin of randomness since no one time can be generalized to all situations.

$$T_{disembark} = \begin{cases} 3x(Row_{num})^{1.5} + 60\{x(Row_{num}) \leq 15\} \\ \\ 1.1x(Row_{num})^{1.5} + 60\{15 < x(Row_{num})\} \end{cases}$$

Our team considered two main methods of disembarking a plane, first by rows, and second by columns. Between those two procedures, there are benefits and shortcomings. For instance, disembarking by row can be effective for the people in front, but the passengers towards the aft of the plane have o wait until all the other rows in front of them have deplaned. Whereas with disembarking by column, the lines move much faster and there tends to be less congestion. Not to mention, there is a lot of shuffling time for disembarking by row, and if one person holds up the line by taking excessive time to collect their carry-on(s) then everyone has to wait. Disembarking by column is just more efficient and less time consuming, saving the airline and the passengers money in the process.

5 Model Application

5.1 Flying Wing Passenger Aircraft

Random Boarding

For Random Boarding in Flying Wing Passenger Aircraft, the overall equation for overall time remains the same.

$$t_{tot_{plane}} + t_{tot_{shuf}} + t_{TBE_u}$$

However, since the structure within the plane is different, the equation to calculate $t_{tot_{walk}}$, $t_{tot_{wait}}$ and $t_{tot_{shuf}}$ will be different than the one use in "narrow-body" aircraft.

Recall the graph in overview where we define the y axis as the position of the passengers across the cabin rows, so that there is only one direction of moving. The position and distances of passengers in "Flying Wing" air-crafts is calculated using Pythagorean distance between the passenger's seat and the entrance. In addition to the position, the equation for this specific passenger Aircraft also considers the influence of blocking for seats in specific regions. Referred to the diagram above, area "A", "B", "C" and "D" will have a greater influence than the blocking occurred in area "D","E","F" and "G" [Appendix : Figure I]. Therefore we determines whether the blocking and waiting occurs in a position is significance to the extension of overall time using the following equation:

$$Sit_{duration-consid} = \left\lceil \left(\frac{p_{influence} + \sqrt{9R^2 + 9C^2}}{2\,(262)} \right) \right\rceil$$

In this equation, $p_{influence}$ represents the total people that a blocking position might influence. R represents rows, and C represents Column, therefore a blocking is only being considered if it is further away from the entrance. This may influence many passengers and will add to the overall time.

Recall: $t_{tot_{wait}} = \sum_{n=1}^{\beta} (t_{sit-duration})_n$

The value of β is going to be the sum of all $Sit_{duration-consid}$ for all 318 passengers.$t_{sit-duration}$ on the other hand, which is equal to $2\,(B_{urden} + seat_{pos}) + 10$ is not going to change much. Only the $seat_{pos}$ will adjust based on the number of aisle seats, middle seats, and window seats (the 3rd seat count from the aisle in a row).

$t_{tot_{walk}}$ is also going to change due to the different structure of the plane. The difference occurs in the walking distance, which uses the taxicab distance $(3(|row| + |col|))$ divided by the walking speed to find the total walking time.

Finally, $t_{tot_{shuf}}$ is calculated using the level of influence. The area D will have a smaller impact than area E, than area F, than area G.

We ran thousands of trials to get the distribution graphs for random boarding placement of the Flying Wing Aircraft [Appendix : Figure J] . The 50^{th} percentile is 3720s (62 minutes). Add on the margin of 5 minutes to give us a total of 67 minutes for 318 passengers to board the Flying Wing Aircraft randomly.

Boarding By Seats

Recall: $t_{tot_{plane}} + t_{TBE_s}$ in the Mathematical Model Section. The only difference between random boarding and boarding by seats is shuffle time and Time before Entrance. For Boarding By Seats, shuffle time is 0 and the passenger who has the farthest to scoot boards first. t_{TBE_s} for the Flying Wing Air crafts follows the exact same calculation as defined in the Time Before Entrance section in Pre-Model. The empirical distribution for Boarding is in the Appendix, Figure K. The 50 percentile of this distribution is 3535 seconds (59 minutes). Add on the marginal of 5 minutes to give us a total of 64 minutes for 318 passengers to board the Flying Wing Aircraft by seats.

Sectional Boarding

In order to solve this problem of boarding by sections we must first determine what rows fall into Aft, middle and bow section. The reference lines can be seen in [Appendix: Figure L]

Aft) Rows 9-14

Middle) Rows 4-8

Row) Rows 1-3

In order to simply the model we divided the plane into sections as can be seen in the [Appendix: Figure L].

Using the function created in 4.4 Boarding by Section,

$$t_{section}(start, end) = \sum_{j=start}^{end/2} ((B_{sit,j})_{avg}) + B_{sit,1} + t_{sit,1}$$

With this function we can quickly define the times taken by each section in each A area (A1,A2,A3...). The only varying differences between these sections is $t_{sit,1}$ because the distances change.

See [Appendix: Figure M] (Times for each A section), Now with all of these timed areas we can simply add up all of the numbers by Aft, Mid and Bow.

$$t_{aft,flying-wing} = (A1)_{aft} + (A2)_{aft} + (A3)_{aft} + (A4)_{aft}$$
$$t_{mid,flying-wing} = (A1)_{mid} + (A2)_{mid} + (A3)_{mid} + (A4)_{mid}$$

$$t_{bow,flying-wing} = 1.5\text{min} \cdot \frac{60\text{s}}{1\text{min}} + (A2)_{bow} + (A3)_{bow} + 1.5\text{min} \cdot \frac{60\text{s}}{1\text{min}}$$

The equations above compile the boarding times by sections.

$$\text{Boarding time } = t_{aft,flying-wing} + t_{mid,flying-wing} + t_{bow,flying-wing} + 1672\text{sec} + 5\text{min} \cdot \frac{60\text{sec}}{1\text{min}}$$

The equation above is the final sectional boarding time for the "Flying-wing" aircraft. The 1672 seconds is the time before entry (gate/jetway time), see [Appendix: Figure B]. The 5 minutes is the marginal time.

5.2 Two-Entrance, Two Aisles Passenger Aircraft

Random Boarding and Boarding By Seats

Again the general equation for Random Boarding and Boarding by Seats still holds true.

$$t_{tot_{plane}} + t_{tot_{shuf}} + t_{TBE_u}$$

In addition, since the structure within the plane is different, the equation to calculate $t_{tot_{walk}}$, $t_{tot_{wait}}$ and $t_{tot_{shuf}}$ will be different than the one use in "narrow-body" aircraft.

$t_{tot_{walk}}$ depends on the walking distance and walking speed. Walking speed is fix as we defines in passenger Identity. Walking distance is determine as longest walking distance between an passenger's seat and the entrance that passenger enters.

$t_{tot_{shuf}}$ changes since the structure of the plane switch from an 3-3 structure for an row to an 2-3-2 structure for an row. We can find the possibilities of shuffle time within this plane structure, which is (0,0,4,4) for the 2 seats and (0,4,0,0,4,0) for the three seats in the middle.

$t_{tot_{wait}}$ follows the similar calculation in the "narrow-body" Air crafts. Conduct simulations 5000 times for both boarding methods will results in the two following empirical distributions.

[Appendix : Figure N]The 50 percentiles of Random Boarding is 2949 seconds, converts to 49 minutes, add the total of 10 minutes of marginal time and business boarding results in total time of 59 minutes for random boarding .

[Appendix : Figure O]The 50 percentiles of Boarding by Seats is 2849 seconds, converts to 47 minutes, add the total of 10 minutes of marginal time and business boarding results in total time of 57 minutes for boarding based on seats.

Sectional Boarding

Assumptions made:

1) No passengers can cross into the middle section (where the lavatories are located).
   Justisfication: With 2 entrances it makes sense for the airline to not allow passengers to go through as it will disrupt the passengers on the other side.

2) There is negligible blocking near the turn areas that diverge the groups into the 2 aisles.
   Justification: There is a bigger area for passengers to move through.

3) Business class (the wider seats at the front) will add on an extra 5 minutes (300s) (including walk time, sit time etc.)
   Justification: Business class has a less chance to be more chaotic as there is usually enough luggage and maneuver room.

This "Two-Entrance, Two-Aisle" Aircraft is special because it has 2 entrances. We only need to consider the walk and path times of the passengers boarding in the selected section [Appendix: Figure P].

$$(t_{twoseat,k}) = (t_{bag i-1} + 2(t_{move})_{i-1} + (t_{bag})_i + (t_{move})_i$$

This time is similar to $B_{sit,k}$, this equation has 2 seats on each side instead of the usual 3. For $i \in \{4k-1|k \in \mathbf{N}\}$

$$t_{TwoAisle} = \sum_{j=1}^{10}((t_{twoseat,j})) + t_{twoseat,1} + t_{sit,1} + 1313 + 300 + 300$$

This equation is used the same method as in 4.4. 1313 seconds is the time taken by the gate for the "Two-Entrance , Two-Aisle" Aircraft. 300 is added from priority assumption, and 300 more from assumption listed at the beginning of this chapter.

In the end the best boarding method for both the "Flying Wing" and the "Two-Entrance, Two-Aisle" Aircraft is sectional boarding.The column method of disembarking holds as the most efficient procedure, even for the the last two planes.

5.3 Covid-19 Impact

Recall the equation for Boarding time by Random placements:

$$t_{tot_{plane}} + t_{tot_{shuf}} + t_{TBE_u}$$

And the total boarding time for Boarding By Seats:

$$t_{tot_{plane}} + t_{TBE_s}$$

We realised the only difference between the two boarding procedures is the time spent before entrance and the total shuffle time in the plane. Thus, in order to make a comparison between Random and Boarding by Seats, we need to compare the sum of $t_{tot_{shuf}}$ and t_{TBE_u} with the value of t_{TBE_s} If $t_{tot_{shuf}} + t_{TBE_u} > t_{TBE_s}$, Boarding By Seats is better. If $t_{tot_{shuf}} + t_{TBE_u} < t_{TBE_s}$, Random Boarding is better.

Similarly for Sectional Boarding, in addition to shuffle time, we need to consider time before entrance. Boarding by Sections saves time by reducing the occurrences of blocking (Reduce β value).

In general, as the population decreases due to the limitation of capacity, the time spent for all three boarding methods will decrease. Boarding by section is still going to be the best as the time saved in blocking is more significant to the overall time than the extra time spent at the gate due to passengers queuing wrong or the time spent in shuffle time.

6 Conclusion

Through this paper, we constructed a model to identify superior boarding and disembarking methods. Our team used programming and data analysis with R and Python to defend our claims. The model is realistic and considers passenger identities. We used our specific model for a narrow-body aircraft and generalized it for two larger planes; we proved that our model is flexible to multiple constraints.

6.1 Sensitivity Analysis

As the number of passengers increases, the time for all three boarding methods will all increase. The time spent for sectional boarding will increase more than the random boarding because the number of people queuing wrong will increase, thus increasing the time spent before entry (gate time). As the percentage of Burdensome people increase, the prescribed boarding method time will increase for both sectional boarding and boarding by seats. However as said in the previous paragraph, sectional boarding will still be better boarding option because the time for blocking will still be more significant than the time increase for the reasons stated above.

6.2 Strength and Weaknesses

1. One of our strengths was being able to test our model with R and Python. We inputted random passenger identities and our programs produced predicted boarding and disembarking times. This helped us because we cross-checked our results to assure that our figures were realistic

2. Our model was very specific to each part of boarding and disembarking, and making sure that most scenarios were accounted for. Our model reflects the most likely boarding time depending on the three boarding methods we applied to our equations.

3. One of our weaknesses was that our formula was not versatile for the second and third plane figures, but our generalized model was adaptable.

4. Another pitfall of our model is that we didn't consider a diverse range of identity values for each passengers. If we considered categories like flight status: Business, First-class, and coach then our model would be more realistic and applicable to the real world. In terms of time, however, our model compensated for its shortcomings by accurately calculating boarding times.

7 Appendices

Figure A - Shuffle Time

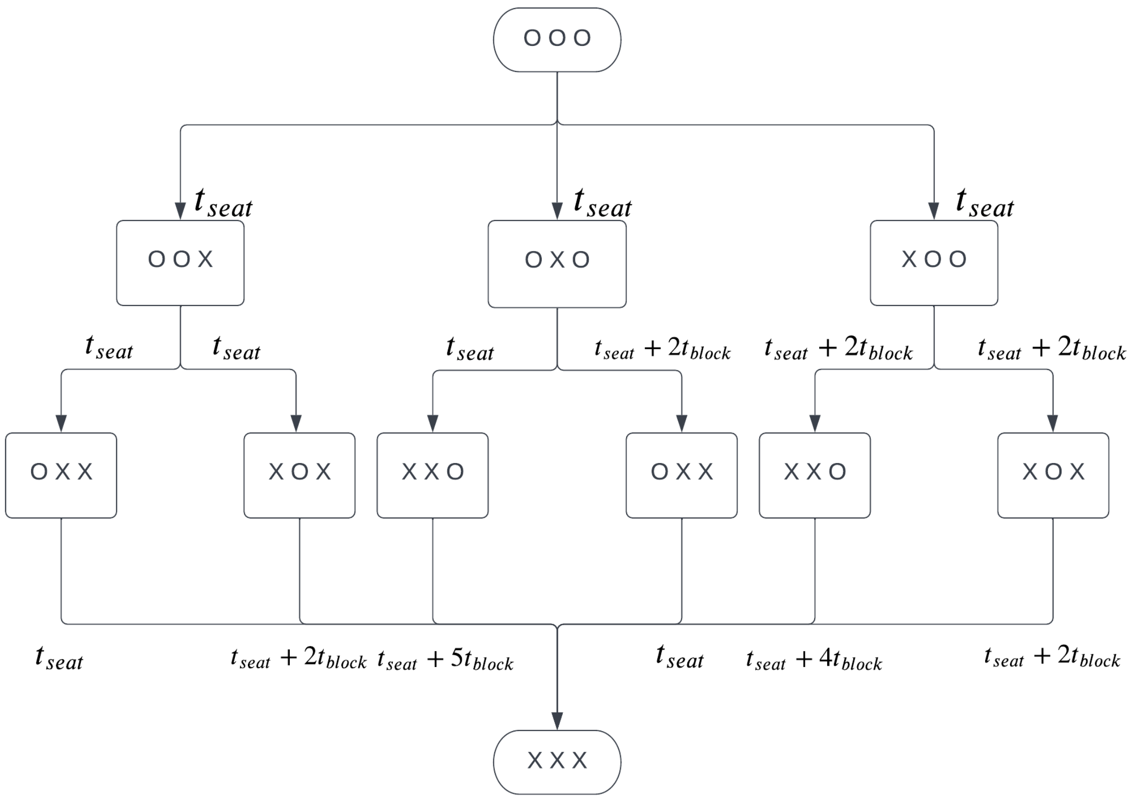
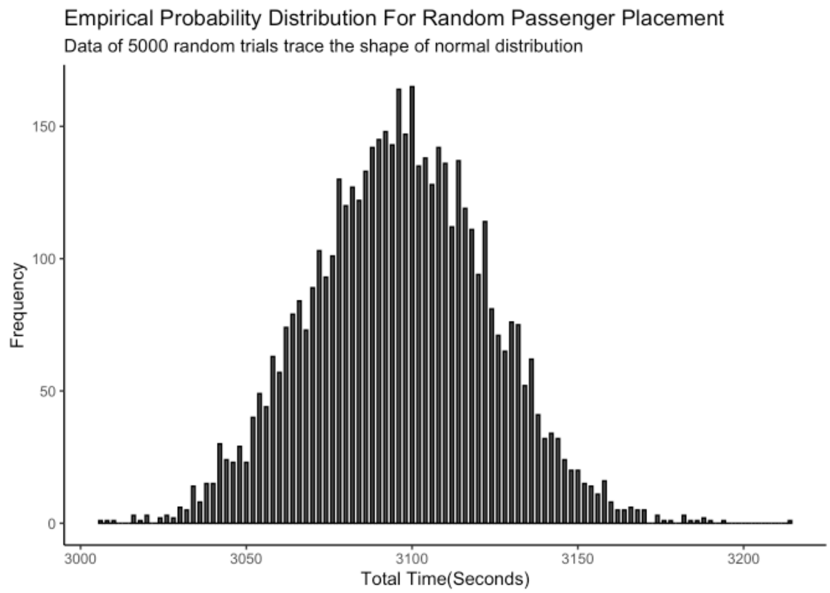


Figure B - Distribution




```
set.seed(1)

time_gate_seats_tot <-
tibble(walking_speed = sample(x= c(130, 138, 126),
size = 192,
prob = c(0.35, 0.40, 0.25),
replace = TRUE),
       priority = sample(x = c(0,1),
       size = 192,
       prob = c(0.95,0.5), replace = TRUE),
       trouble_some = sample(x = c(0,1,2,3,4),
       size = 192,
       prob = c(0.70, 0.15, 0.08, 0.05, 0.02),
       replace = TRUE))%>%
  mutate(queue_check = ifelse(priority == 1,
                              0,
                              1)) %>%
  mutate(queue_wrong = ifelse(queue_check == 1,
        ifelse(trouble_some == 0,
        sample(x= c(1,0),size = 192,
        replace = TRUE, prob = c(0, 1)),
        ifelse(trouble_some == 1,
         sample(x= c(1,0),size = 192,
         replace = TRUE, prob = c(0.1, 0.9)),
         ifelse(trouble_some == 2,
         sample(x= c(1,0),size = 192,
         replace = TRUE, prob = c(0.3, 0.7)),
         ifelse(trouble_some == 3,
         sample(x= c(1,0),size = 192,
         replace = TRUE, prob =c(0.5,0.5)),
        sample(x= c(1,0),size = 192,
```

```
        replace = TRUE, prob = c(0.7, 0.3)))))), 0))%>%
  mutate(gate_time = queue_wrong*trouble_some+5)%>%
  summarise(gate_tot = sum(gate_time)+50)%>%
  pull(gate_tot)
```

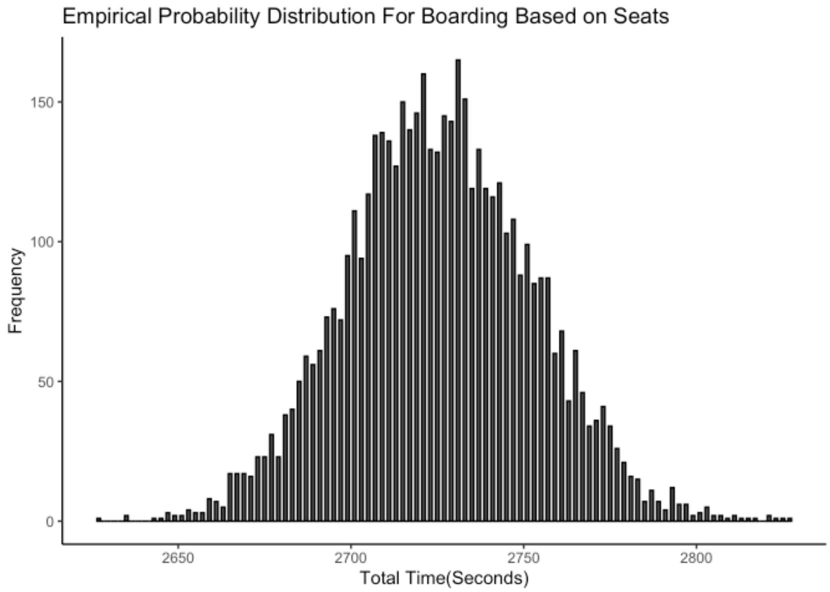
```
time_gate_random_tot <-
tibble(walking_speed = sample(x= c(130, 138, 126),
size = 192,
prob = c(0.35, 0.40, 0.25),
replace = TRUE),
       priority = sample(x = c(0,1),
       size = 192,
       prob = c(0.95,0.5), replace = TRUE),
       trouble_some = sample(x = c(0,1,2,3,4),
       size = 192,
       prob = c(0.70, 0.15, 0.08, 0.05, 0.02),
       replace = TRUE))%>%
  mutate(queue_check = ifelse(priority == 1,
                              0,
                              1)) %>%
  mutate(queue_wrong = 0)%>%
  mutate(gate_time = queue_wrong*trouble_some+5)%>%
  summarise(gate_tot = sum(gate_time)+5)%>%
  pull(gate_tot)
```

```
Walking_time_tot <- tibble(row_seat = 1:33,
walking_speed = sample(x= c(2.17, 2.3, 2.1),
size = 33, prob = c(0.35, 0.40, 0.25),replace = TRUE), walk_time1 = 1/walking_speed,
walk_time_fin = 3*sum(walk_time1))%>%
  summarise(walking_time_fin =
  sample(walk_time_fin, size =1))%>%
  pull(walking_time_fin)
```

```
Tsd_tot <-
tibble(TS = sample(c(0:4),
prob = c(0.55, 0.75, 0.45, 0.35, 0.10),
size = 192, replace = TRUE),
SS = sample(c(rep(1,64),
rep(2,64),
rep(3,64)),
size =192),
Tsd = 2*(TS+SS)+10)%>%
  summarise(Tsd)%>%
  pull(Tsd)
```

```
T_shuffle_tot <- tibble(row3seats = 1:64,
T_shuffle = sample(c(0,4,10,4,12,8),
 size = 64, prob = c(16.67,16.67,16.67,16.67,16.67,16.67),
replace = TRUE))%>%
  summarise(T_shufflefin = sum(T_shuffle))%>%
  pull(T_shufflefin)

B <- tibble(RS = sample(rep(c(1:32),6)),
order = sample(1:192, size = 192),
RS_O = RS+order,
Bp = ceiling(1/RS_O - 1/113))%>%
  summarise(B = sum(Bp))%>%
  pull(B)



random_simulation <- replicate(
  5000,
  {
    expand.grid(time_tot =
    sample(x = Tsd_tot, size = B, replace = TRUE))%>%
  summarise(time_tot = Walking_time_tot +
  sum(time_tot) +T_shuffle_tot+
  time_gate_random_tot)%>%
  pull(time_tot)
  }
)

as.data.frame(random_simulation)%>%
  ggplot(aes(x=random_simulation))+
  geom_histogram(aes(y=after_stat(count)),
  binwidth = 1,
                    color = "black")+
  labs(title =
  "Empirical Probability
  Distribution For Random Passenger Placement",
    subtitle = "Data of 5000 random
    trials trace the shape of normal distribution",
          x = "Total Time(Seconds)",
          y = "Frequency")  +
    theme_classic()
}
```

Figure C - Distribution




```
seats_simulation <- replicate(
  5000,
  {
    expand.grid(time_tot =
    sample(x = Tsd_tot, size = B,
    replace = TRUE))%>%
  summarise(time_tot =
  Walking_time_tot + sum(time_tot)+
  time_gate_seats_tot)%>%
  pull(time_tot)
  }
)

as.data.frame(seats_simulation)%>%
  ggplot(aes(x=seats_simulation))+
  geom_histogram(aes(y=after_stat(count)), binwidth = 1,
                    color = "black")+
  labs(title =
  "Empirical Probability Distribution For Boarding Based on Seats",
          x = "Total Time(Seconds)",
          y = "Frequency")  +
    theme_classic()
```

Figure D - Boarding By Section

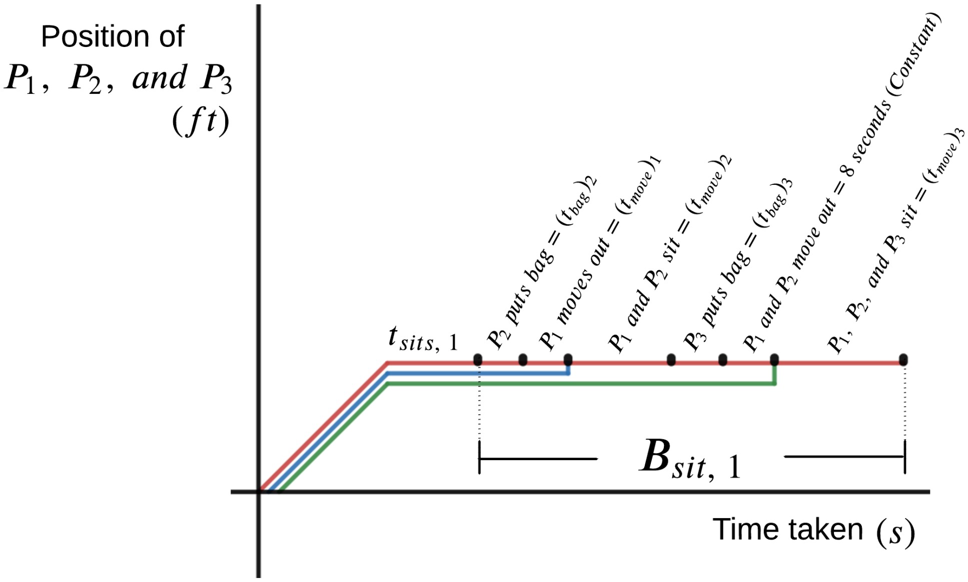
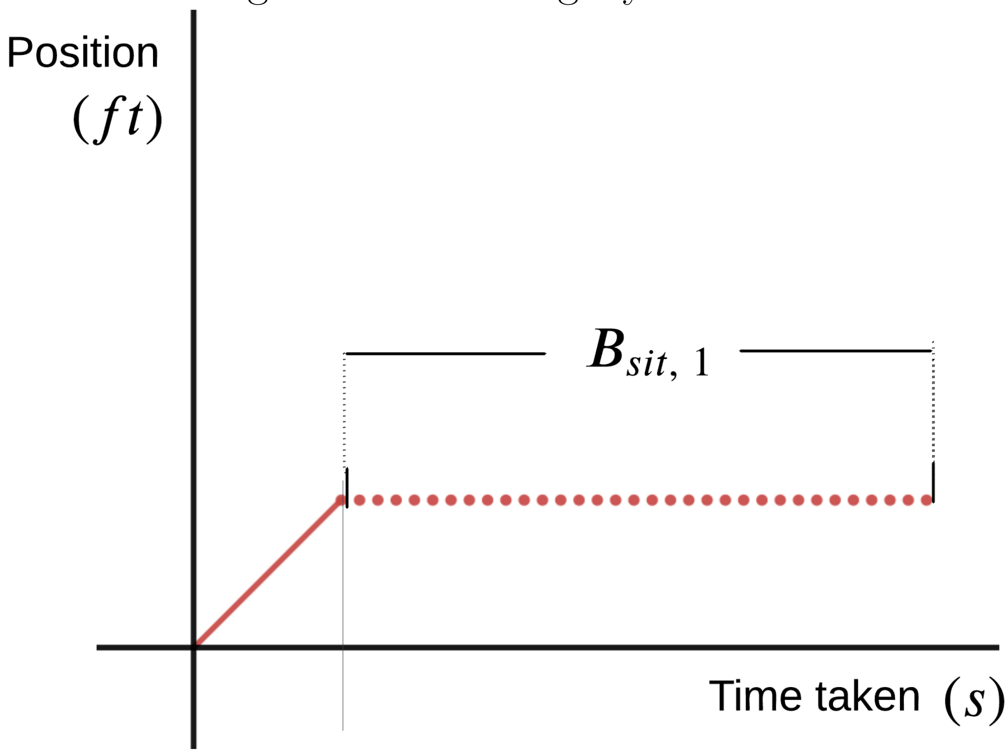


Figure E - Boarding By Section



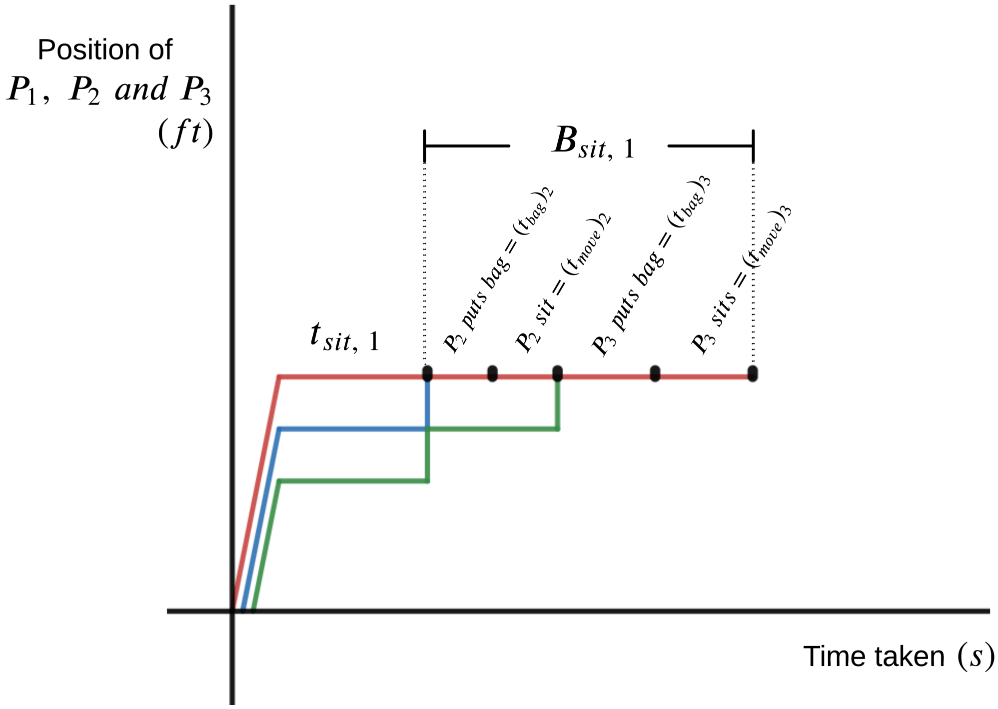


Figure F (shown above)- Boarding By Section

Figure G - Boarding By Section

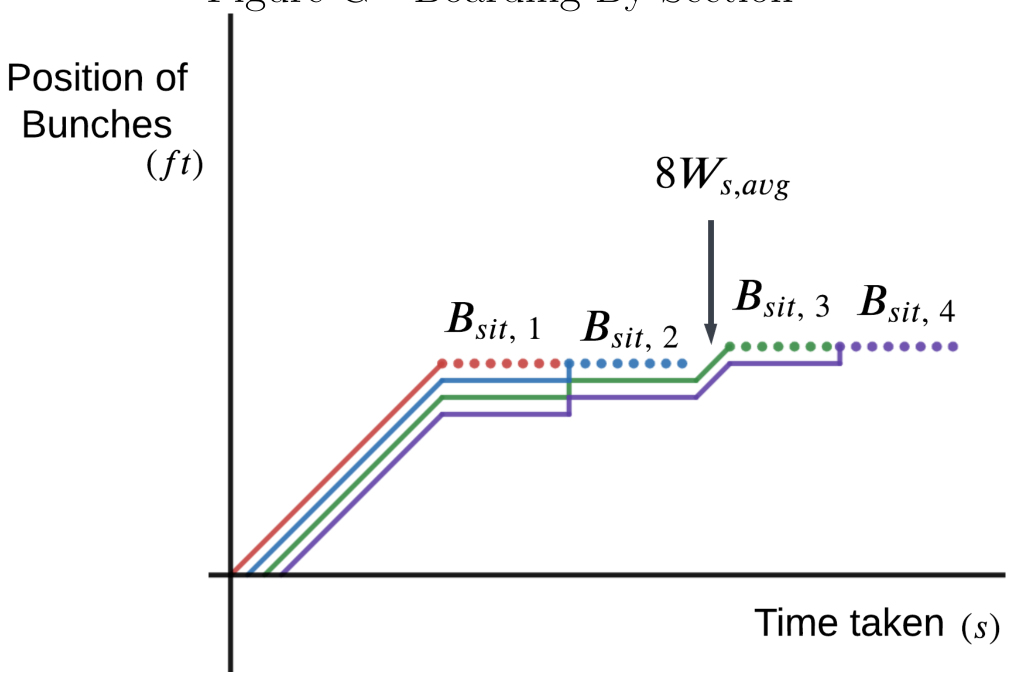


Figure H - Disembarking

```
import random
time_disembark = 0
import math

int = time_disembark
row_number = random.choice(range(1,33))
if row_number >= 15:
    time_disembark = time_disembark +
    3.5*row_number**1.5 + 120 + random.randint(1, 20)


elif row_number < 15:
    time_disembark = time_disembark +
    1.2*row_number**1.5 + 120 + random.randint(1, 20)
time_disembark = round(time_disembark)
print(time_disembark)

print(row_number)
```

Figure I - Flying Wing

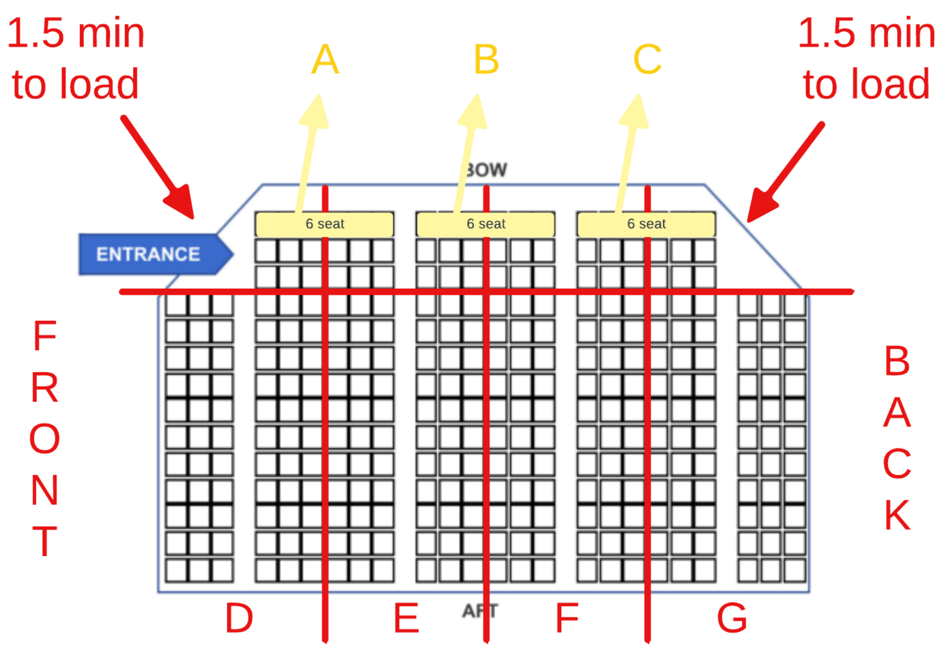
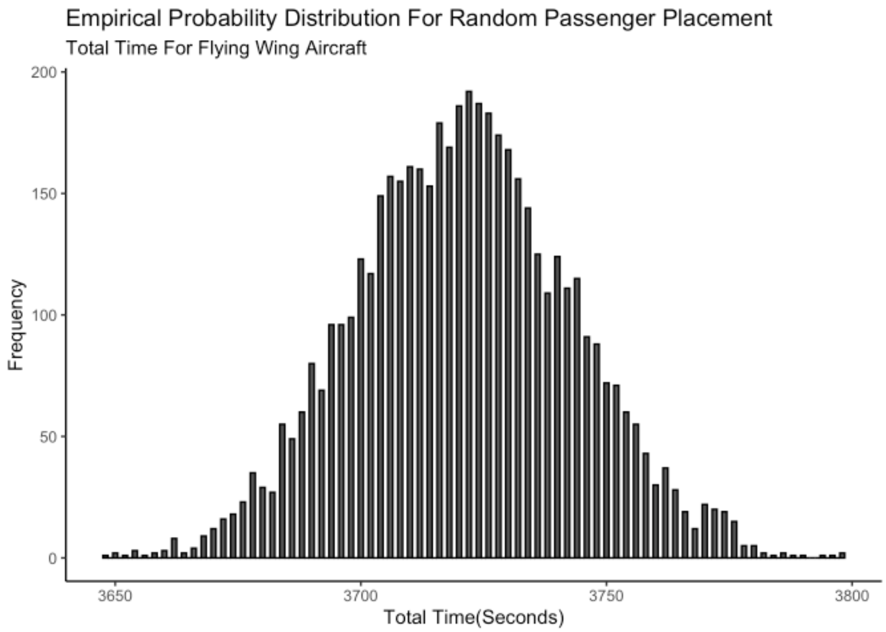


Figure 2. "Flying Wing" Passenger Aircraft

Figure J- Flying Wing




```
set.seed(10)

time_gate_seats_tot2 <-
tibble(walking_speed =
sample(x= c(2.17, 2.3, 2.1), size = 318,
prob = c(0.35, 0.40, 0.25), replace = TRUE),
       priority = sample(x = c(0,1),
       size = 318, prob = c(0.95,0.5),
       replace = TRUE),
       trouble_some = sample(x = c(0,1,2,3,4),
       size = 318,
       prob = c(0.70, 0.15, 0.08, 0.05, 0.02),
       replace = TRUE))%>%
  mutate(queue_check = ifelse(priority == 1,
                              0,
                              1)) %>%
  mutate(queue_wrong = ifelse(queue_check == 1,
    ifelse(trouble_some == 0,
    sample(x= c(1,0),size = 318,
    replace = TRUE, prob = c(0, 1)),
    ifelse(trouble_some == 1,
    sample(x= c(1,0),size = 318,
    replace = TRUE, prob = c(0.1, 0.9)),
    ifelse(trouble_some == 2,
    sample(x= c(1,0),size = 318,
    replace = TRUE, prob = c(0.3, 0.7)),
    ifelse(trouble_some == 3,
    sample(x= c(1,0),size = 318,
    replace = TRUE, prob =c(0.5,0.5)),
    sample(x= c(1,0),size = 318,
```

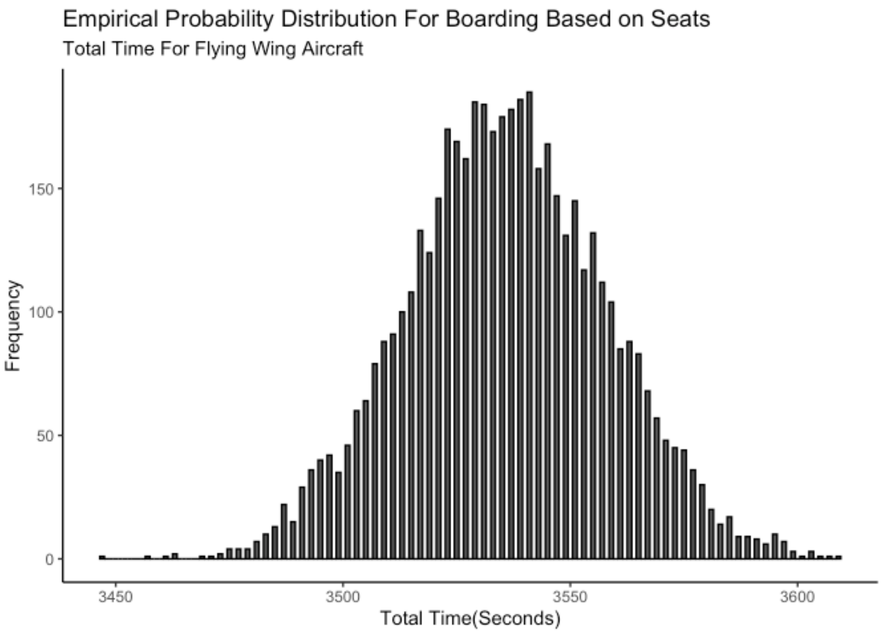
```
    replace = TRUE, prob = c(0.7, 0.3)))))),0))%>%
  mutate(gate_time = queue_wrong*trouble_some+5)%>%
  summarise(gate_tot = sum(gate_time)+50)%>%
  pull(gate_tot)



time_gate_random_tot2 <-
tibble(walking_speed = sample(x= c(2.17, 2.3, 2.1),
size = 318, prob = c(0.35, 0.40, 0.25), replace = TRUE),
       priority = sample(x = c(0,1), size = 318,
       prob = c(0.95,0.5), replace = TRUE),
       trouble_some = sample(x = c(0,1,2,3,4),
       size = 318, prob = c(0.70, 0.15, 0.08, 0.05, 0.02),
       replace = TRUE))%>%
  mutate(queue_check = ifelse(priority == 1,
                              0,
                              1)) %>%
  mutate(queue_wrong = 0)%>%
  mutate(gate_time = queue_wrong*trouble_some+5)%>%
  summarise(gate_tot = sum(gate_time)+5)%>%
  pull(gate_tot)
B <- tibble(order = sample(1:318),
       Area = sample(c(rep("A",6),
       rep("B",6),rep("C",6),rep("D",72),
       rep("E",78), rep("F",78),rep("G",72))),
       Row = ifelse(Area == "A" | Area == "B" |
       Area == "C", -3, sample(c(rep(-2,18),
       rep(-1,18),rep(1,24),
       rep(2,24),rep(3,24),
           rep(4,24),rep(5,24),rep(6,24),
           rep(7,24),rep(8,24),rep(9,24),rep(10,24),
           rep(11,24))))))%>%
  mutate(Column = ifelse(Area == "A", sample(c(2,3,4,5,6,7)),
       ifelse(Area == "B", sample(c(9,10,11,12,13,14)),
         ifelse(Area == "C", sample(c(16,17,18,19,20,21)),
   sample(c(rep(-3,11),rep(-2,11),rep(-1,11),
   rep(2,13),rep(3,13),rep(4,13),
     rep(5,13),rep(6,13),rep(7,13),rep(9,13),rep(10,13),rep(11,13),
            rep(12,13),rep(13,13),rep(14,13),rep(16,13),
            rep(17,13),rep(18,13),rep(19,13),rep(20,13),
            rep(21,13),rep(23,11),rep(24,11),rep(25,11)))))))%>%
  mutate(P_influence = ifelse(Area == "A", 240,
         ifelse(Area == "B",156,
         ifelse(Area == "C",72,
           ifelse(Area == "D"|Area == "G", 72,78)))))%>%
  mutate(entrance_dist = sqrt(Row*Row*9 + Column*Column*9))%>%
  mutate(Factor_combine = P_influence+1/entrance_dist)%>%
  mutate(Sit_duration_consid =
  ceiling((Factor_combine - mean(Factor_combine))/262+1/order-1/159))%>%
  summarise(B = sum(Sit_duration_consid))%>%
  pull(B)

TSD <- tibble(Passengers = 1:318,
```

```
        Area = sample(c(rep("A",6), rep("B",6),rep("C",6),
        rep("D",72), rep("E",78), rep("F",78),rep("G",72))),
        Row = ifelse(Area == "A"| Area == "B"|
        Area == "C", -3, sample(c(rep(-2,18),
        rep(-1,18),rep(1,24),
        rep(2,24),rep(3,24),
         rep(4,24),rep(5,24),rep(6,24),
         rep(7,24),rep(8,24),rep(9,24),
         rep(10,24),rep(11,24))))))%>%
  mutate(Column = ifelse(Area == "A", sample(c(2,3,4,5,6,7)),
   ifelse(Area == "B", sample(c(9,10,11,12,13,14)),
       ifelse(Area == "C", sample(c(16,17,18,19,20,21)),
        sample(c(rep(-3,11),rep(-2,11),
        rep(-1,11),rep(2,13),rep(3,13),rep(4,13),
         rep(5,13),rep(6,13),rep(7,13),
         rep(9,13),rep(10,13),rep(11,13),
         rep(12,13),rep(13,13),rep(14,13),
         rep(16,13),rep(17,13),rep(18,13),
          rep(19,13),rep(20,13),rep(21,13),
          rep(23,11),rep(24,11),rep(25,11)))))))%>%
  mutate(P_influence = ifelse(Area == "A", 240,
         ifelse(Area == "B",156,
           ifelse(Area == "C",72,
            ifelse(Area == "D"|Area == "G", 72,78)))))%>%
  mutate(entrance_dist = sqrt(Row*Row*9 + Column*Column*9))%>%
  mutate(Factor_combine = P_influence+entrance_dist)%>%
  mutate(Sit_duration_consid =
  ceiling((Factor_combine - mean(Factor_combine))/262))%>%
  mutate(TS = sample(c(0:4),
  prob = c(0.55, 0.75, 0.45, 0.35, 0.10)
  ,size = 318, replace = TRUE),
  SS = sample(c(rep(1,122),rep(2,98),rep(3,98))),
  Tsd = 2*(TS+SS)+10)%>%
  pull(Tsd)


T_shuffle_tot2 <- tibble(row3seats = 1:106,
T_shuffle = sample(c(0,4,10,4,12,8),size = 106,
prob = c(16.67,16.67,16.67,16.67,16.67,16.67),
replace = TRUE))%>%
  mutate(significant = ifelse(row3seats == 1|row3seats ==2|
  row3seats ==3|row3seats ==4|row3seats ==5|row3seats ==6|
  row3seats ==7|row3seats ==8|row3seats ==9|row3seats ==10|
  row3seats ==11|row3seats ==12|row3seats ==13|row3seats ==14|
  row3seats ==15|row3seats ==16|row3seats ==17|row3seats ==18|
  row3seats ==19|row3seats ==20|row3seats ==21|row3seats ==22,
   sample(c(0,1),size = 22, prob= c(0.9,0.1), replace = TRUE),
     ifelse(row3seats == 23|row3seats ==24|
     row3seats ==25|row3seats ==26|
     row3seats ==27|row3seats ==28|
     row3seats ==29|row3seats ==30|
     row3seats ==31|row3seats ==32|
     row3seats ==33|row3seats ==34|
     row3seats ==35|row3seats ==36|
```

```
    row3seats ==37|row3seats ==38|
    row3seats ==39|row3seats ==40|
    row3seats ==41|row3seats ==42|
    row3seats ==43|row3seats ==44,
      sample(c(0,1),size =22 ,
      prob = c(0.7,0.3), replace = TRUE),
        ifelse(row3seats  ==45|
        row3seats ==46|row3seats ==47|
        row3seats ==48|row3seats ==49|
        row3seats ==50|row3seats ==51|
        row3seats ==52|row3seats ==53|
        row3seats ==54|row3seats ==55|
        row3seats ==56|row3seats ==57|
        row3seats ==58|row3seats ==59|
        row3seats ==60|row3seats ==61|
        row3seats ==62|row3seats ==63|
        row3seats ==64|row3seats ==65|row3seats ==66,
       sample(c(0,1),size = 22, prob = c(0.5,0.5), replace = TRUE),
       ifelse(row3seats == 67|row3seats ==68|
       row3seats ==69|row3seats ==70|
       row3seats ==71|row3seats ==72|
       row3seats ==73|row3seats ==74|
       row3seats ==75|row3seats ==76|
       row3seats ==77|row3seats ==78|
       row3seats ==79|row3seats ==80|
       row3seats ==81|row3seats ==82|
       row3seats ==83|row3seats ==84|
       row3seats ==85|row3seats ==86|
       row3seats ==87|row3seats ==88,
        sample(c(0,1),size = 22,
        prob = c(0.3,0.7), replace = TRUE),
       ifelse(row3seats == 89|row3seats ==90|
       row3seats ==91|row3seats ==92|
       row3seats ==93|row3seats ==94|
       row3seats ==95|row3seats ==96|
       row3seats ==97|row3seats ==98|
       row3seats ==99|row3seats ==100|
       row3seats ==101|row3seats ==102|
       row3seats ==103|row3seats ==104|
       row3seats ==105|row3seats ==106,
       sample(c(0,1),size = 18,
       prob = c(0.1,0.9), replace = TRUE),NA))))))%>%
  summarise(T_shufflefin = sum(T_shuffle*significant))%>%
  pull(T_shufflefin)


Walking_time_tot2 <- tibble(Passengers = 1:318,
      Area = sample(c(rep("A",6),
      rep("B",6),rep("C",6),
      rep("D",72), rep("E",78), rep("F",78),
      rep("G",72))),
      Row = ifelse(Area == "A"| Area == "B"|
      Area == "C", -3, sample(c(rep(-2,18),
      rep(-1,18),rep(1,24),
```

```
        rep(2,24),rep(3,24),
        rep(4,24),rep(5,24),rep(6,24),rep(7,24),
        rep(8,24),rep(9,24),rep(10,24),rep(11,24)))))%>%
  mutate(Column = ifelse(Area == "A",
  sample(c(2,3,4,5,6,7)),
           ifelse(Area == "B",
           sample(c(9,10,11,12,13,14)),
             ifelse(Area == "C", s
             ample(c(16,17,18,19,20,21)),
             sample(c(rep(-3,11),rep(-2,11),
             rep(-1,11),rep(2,13),rep(3,13),rep(4,13),
             rep(5,13),rep(6,13),rep(7,13),rep(9,13),
             rep(10,13),rep(11,13),
             rep(12,13),rep(13,13),rep(14,13),
             rep(16,13),rep(17,13),rep(18,13),
             rep(19,13),rep(20,13),rep(21,13),
             rep(23,11),rep(24,11),rep(25,11)))))))%>%
  mutate(P_influence = ifelse(Area == "A", 240,
           ifelse(Area == "B",156,
          ifelse(Area == "C",72,
              ifelse(Area == "D"|Area == "G", 72,78)))))%>%
  mutate(entrance_dist2 = abs(Row) + abs(Column))%>%
  mutate(walking_speed =
  sample(x= c(2.17, 2.3, 2.1),
  size = 318,
  prob = c(0.35, 0.40, 0.25),replace = TRUE),
  walk_time1 = (entrance_dist2/walking_speed)/3,
  walk_time_fin = sum(walk_time1))%>%
  summarise(walking_time_fin =
  sample(walk_time_fin, size =1))%>%
  pull(walking_time_fin)
random_simulation2 <- replicate(
  5000,
  {
    expand.grid(time_tot = sample(x = TSD,
    size = B, replace = TRUE))%>%
  summarise(time_tot = Walking_time_tot2 +
  sum(time_tot) +T_shuffle_tot2+
  time_gate_random_tot2)%>%
  pull(time_tot)
  }
)

as.data.frame(random_simulation2)%>%
  ggplot(aes(x=random_simulation2))+
  geom_histogram(aes(y=after_stat(count)), binwidth = 1,
                     color = "black")+
  labs(title = "Empirical Probability
  Distribution For Random Passenger Placement",
          subtitle = "Total Time For Flying Wing Aircraft",
          x = "Total Time(Seconds)",
          y = "Frequency") +
    theme_classic()
```

Figure K - Flying Wing




```
seats_simulation2 <-
replicate(
  5000,
  {
    expand.grid(time_tot = sample(x = TSD,
    size = B, replace = TRUE))%>%
  summarise(time_tot =
  Walking_time_tot2 +
  sum(time_tot)+time_gate_seats_tot2)%>%
  pull(time_tot)
  }
)

as.data.frame(seats_simulation2)%>%
  ggplot(aes(x=seats_simulation2))+
  geom_histogram(aes(y=after_stat(count)),
  binwidth = 1,
                    color = "black")+
  labs(title = "Empirical Probability D
  istribution For Boarding Based on Seats",
       subtitle = "Total Time For Flying Wing Aircraft",
         x = "Total Time(Seconds)",
         y = "Frequency")  +
    theme_classic()
```

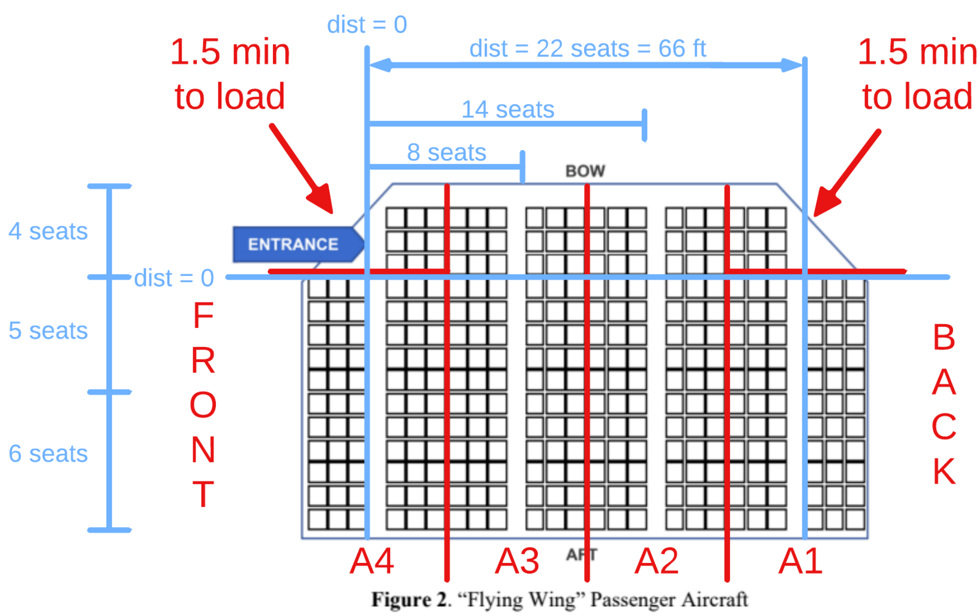


Figure L (shown above)- Flying Wing - Sectional

Figure M - Flying Wing - Sectional

$A1$ and $A4$

$$t_{aft} = t_{section}(9,\ 14)$$

$$A1 : t_{sit,\,1} = 3\left(\frac{4+22+14}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

$$A4 : t_{sit,\,1} = 3\left(\frac{4+1+14}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

The 4 represents their walk distance (in rows) from the entrance to the hallway along the Bow. The 22, and 1 is the walk distance (in rows) traveled in parallel with the Bow, with A1 having to travel much further from the entrance than A4. The 14 is the distance they must walk from the Bow all the way to the Aft section.

$$t_{mid} = t_{section}(4,\ 8)$$

$$A1 : t_{sit,\,1} = 3\left(\frac{4+22+8}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

$$A4 : t_{sit,\,1} = 3\left(\frac{4+1+8}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

The 4 and 22 are the same as stated above. The 8 is the row distance from the Bow of the aircraft to the middle of the aircraft.

$$A1 : t_{sit,\,1} = 3\left(\frac{4+22+4}{W_{s,\,1}}\right) + 1.5\text{min} \cdot \frac{60\text{s}}{1\text{min}}$$

$$A2 : t_{sit,1} = 3 \cdot (\frac{1}{W_{s,1}})1.5\text{min} \cdot \frac{60\text{s}}{1\text{min}}$$

Because A1 and A4 have seats cut out at the end, we considered their $t_{sit_duration,1}$ to be a constant. By experimentation we found that value to be 1.5 minutes.

For $A2$ and $A3$

$$t_{aft} = t_{section} \quad (9,\ 14)$$

$$A2 : t_{sit,\,1} = 3\left(\frac{4+15+14}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

$$A3 : t_{sit,\,1} = 3\left(\frac{4+8+14}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

The 4 is held constant again because it travels up to the bow, the 15 and the 8 is the distance traveled (in rows) parallel to the bow. The 14 is held constant because they are travelled to the aft.

$$t_{mid} = t_{section}(4,\ 8)$$

$$A2 : t_{sit,\,1} = 3\left(\frac{4+15+8}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

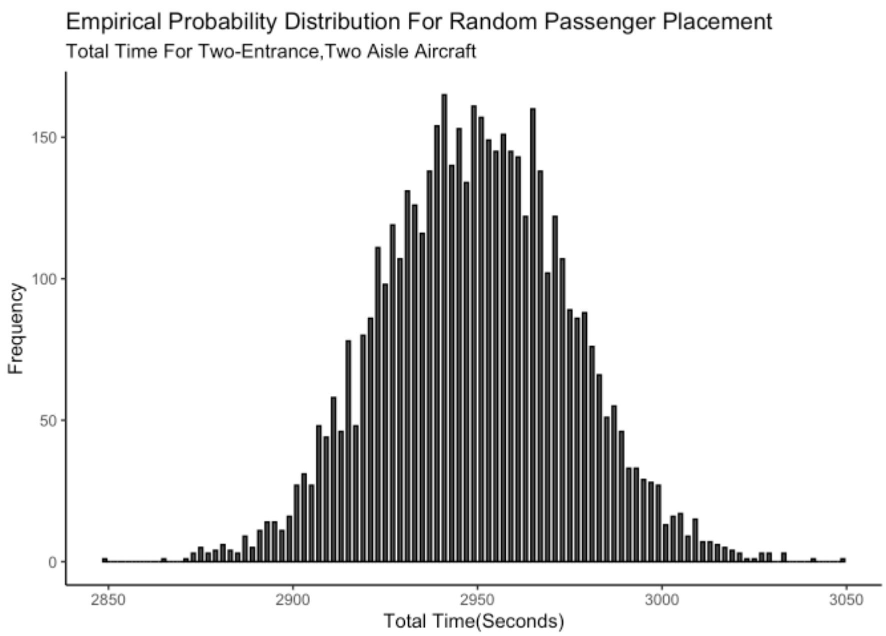
$$A3 : t_{sit,\,1} = 3\left(\frac{4+8+8}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

$$t_{bow} = t_{section}(1,\ 3)$$

$$A2 : t_{sit,\,1} = 3\left(\frac{4+15+1}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

$$A3 : t_{sit,\,1} = 3\left(\frac{4+8+1}{W_{s,\,1}}\right) + t_{sit\_duration,\,1}$$

Figure N - 2E2A

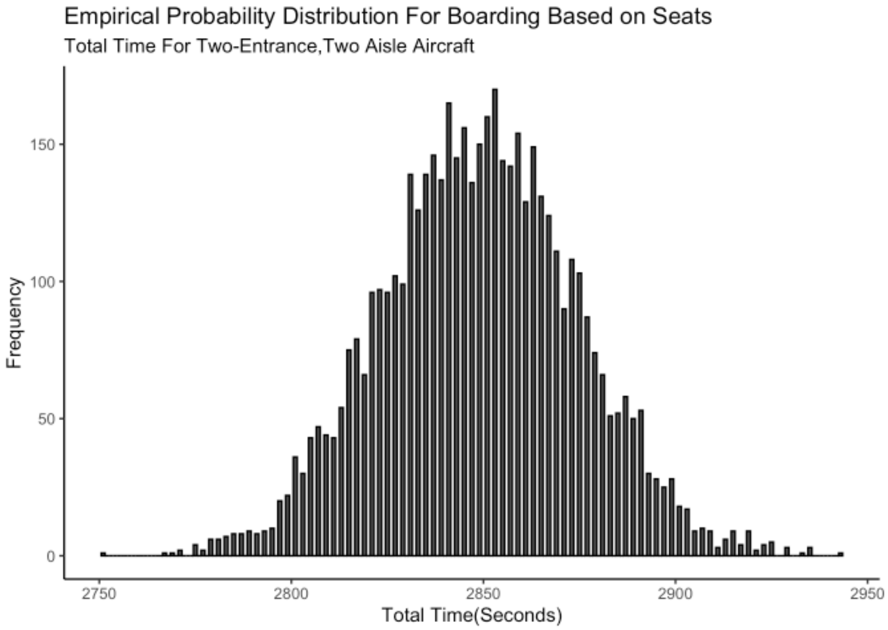



```
set.seed(10)

time_gate_seats_tot3 <-
tibble(walking_speed = sample(x= c(2.17, 2.3, 2.1),
size = 245, prob = c(0.35, 0.40, 0.25), replace = TRUE),
        priority = sample(x = c(0,1), size = 245,
        prob = c(0.95,0.5), replace = TRUE),
        trouble_some = sample(x = c(0,1,2,3,4),
        size = 245,
        prob = c(0.70, 0.15, 0.08, 0.05, 0.02),
        replace = TRUE))%>%
  mutate(queue_check = ifelse(priority == 1,
                                      0,
                                      1)) %>%
  mutate(queue_wrong = ifelse(queue_check == 1,
         ifelse(trouble_some == 0,
            sample(x= c(1,0),size = 245,
            replace = TRUE, prob = c(0, 1)),
            ifelse(trouble_some == 1,
            sample(x= c(1,0),size = 245,
            replace = TRUE, prob = c(0.1, 0.9)),
             ifelse(trouble_some == 2,
             sample(x= c(1,0),size = 245,
             replace = TRUE, prob = c(0.3, 0.7)),
              felse(trouble_some == 3,
              sample(x= c(1,0),size = 245,
              replace = TRUE, prob =c(0.5,0.5)),
               sample(x= c(1,0),size = 245,
               replace = TRUE, prob = c(0.7, 0.3)))))),0))% >%
  mutate(gate_time = queue_wrong*trouble_some+5)%>%
  summarise(gate_tot = sum(gate_time)+50)%>%
```

```
  pull(gate_tot)



time_gate_random_tot3 <-
tibble(walking_speed = sample(x= c(2.17, 2.3, 2.1),
size = 245, prob = c(0.35, 0.40, 0.25), replace = TRUE),
        priority = sample(x = c(0,1), size = 245,
        prob = c(0.95,0.5), replace = TRUE),
        trouble_some = sample(x = c(0,1,2,3,4),
        size = 245, prob = c(0.70, 0.15, 0.08, 0.05, 0.02),
        replace = TRUE))%>%
  mutate(queue_check = ifelse(priority == 1,
                              0,
                              1)) %>%
  mutate(queue_wrong = 0)%>%
  mutate(gate_time = queue_wrong*trouble_some+5)%>%
  summarise(gate_tot = sum(gate_time)+5)%>%
  pull(gate_tot)



T_shuffle_tot3 <- tibble(row3seats = 1:105,
size = sample(c(rep(2,70),rep(3,35))))%>%
  mutate(Shuffle_time = ifelse(size == 2,
  sample(c(0,0,4,4), prob = c(0.25,0.25,0.25,0.25)),
        ifelse(size == 3,
        sample(c(0,4,0,0,4,0),
        prob = c(16.67,16.67,16.67,16.67,16.67,16.67)),NA)))%>%
  summarise(T_shufflefin =
  sum(Shuffle_time))%>%
  pull(T_shufflefin)

Tsd_tot3 <- tibble(TS = sample(c(0:4),
prob = c(0.55, 0.75, 0.45, 0.35, 0.10),
size = 245, replace = TRUE),
SS = sample(c(rep(1,140),rep(2,105))),
Tsd = 2*(TS+SS)+10)%>%
  summarise(Tsd)%>%
  pull(Tsd)

B3 <- tibble(RS = sample(rep(c(1:35),7)),
order = sample(1:245), RS_O = RS+order,
Bp = ceiling(1/RS_O - 1/113))%>%
  summarise(B = sum(Bp))%>%
  pull(B)

Walking_time_tot3 <- tibble(passenger = 1:245,
entrance = sample(c("A","B"),
size = 245, prob=c(0.5, 0.5), replace = TRUE))%>%
  mutate(Dist_column = sample(c(rep(6,123),
  rep(18,122))))%>%
  mutate(Dist_A_row =
  sample(c(rep(seq(3,42,3),7),
```

```
  rep(seq(60,120,3),7))))%>%
  mutate(Dist_B_row = 120-Dist_A_row)%>%
  mutate(Dist_row =
  ifelse(entrance == "A", Dist_A_row, Dist_B_row))%>%
  mutate(walking_speed =
  sample(x= c(2.17, 2.3, 2.1),
  size = 245, prob = c(0.35, 0.40, 0.25),
  replace = TRUE))%>%
  mutate(walking_time = Dist_row/walking_speed)%>%
  summarise(max_walk = max(walking_time))%>%
  pull(max_walk)
random_simulation3 <- replicate(
  5000,
  {
    expand.grid(time_tot = sample(x = Tsd_tot3, size = B3,
    replace = TRUE))%>%
  summarise(time_tot =
  Walking_time_tot3 +
  sum(time_tot) +T_shuffle_tot3+
  time_gate_random_tot3)%>%
  pull(time_tot)
  }
)

as.data.frame(random_simulation3)%>%
  ggplot(aes(x=random_simulation3))+
  geom_histogram(aes(y=after_stat(count)),
  binwidth = 1,
                     color = "black")+
  labs(title = "Empirical Probability
  Distribution For Random Passenger Placement",
          subtitle = "Total Time For Two-Entrance,
          Two Aisle Aircraft",
          x = "Total Time(Seconds)",
          y = "Frequency")  +
    theme_classic()
```

Figure O - 2E2A




```
seats_simulation3 <- replicate(
  5000,
  {
    expand.grid(time_tot =
    sample(x = Tsd_tot3,
    size = B3, replace = TRUE))%>%
  summarise(time_tot = Walking_time_tot3 +
  sum(time_tot)+
  time_gate_seats_tot3)%>%
  pull(time_tot)
  }
)

as.data.frame(seats_simulation3)%>%
  ggplot(aes(x=seats_simulation3))+
  geom_histogram(aes(y=after_stat(count)),
  binwidth = 1,
                    color = "black")+
  labs(title = "Empirical Probability
  Distribution For Boarding Based on Seats",
       subtitle = "Total Time For Two-Entrance,
       Two Aisle Aircraft",
         x = "Total Time(Seconds)",
         y = "Frequency")  +
    theme_classic()
```

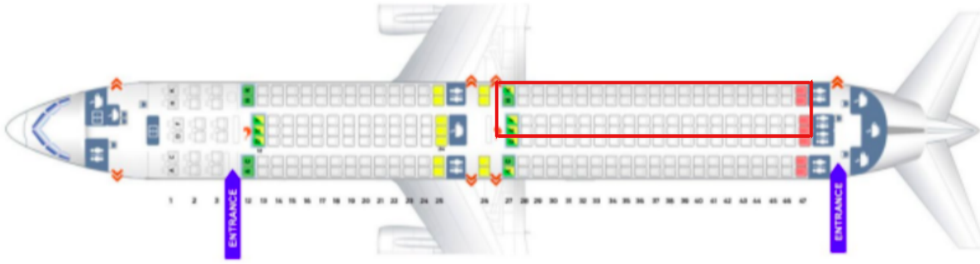


Figure 3. "Two-Entrance, Two Aisle" Passenger Aircraft

Figure P (shown above)- 2E2A

8 Works Cited

[1]"Boeing 737 Aircraft Profile." FlightGlobal, www.flightglobal.com/boeing-737-aircraft-profile/76702.article#Overview. Accessed 10 Apr. 2022.

[2]Google Flights. www.google.com/travel/flights/search?tfs=CBwQAhooagwIAhIIL20vMDFjeF8S CjIwMjItMDQtMjRyDAgDEggvbS8wcmowehooagwIAxIIL20vMHJqMHoSCjIwMjItMDQtMjhy DAgCEggvbS8wMWN4X3ABggELCP___________wFAAUgBmAEBagQQARgB. Accessed 10 Apr. 2022.

[3]Grant, Autumn. "Flying the Friendly Skies with a Disability." Abilities.com, www.abilities.com/community/air-travel.html#: :text=Keep%20in%20mind%2C%20if%20you,the %20last%20passengers%20to%20disembark. Accessed 10 Apr. 2022.