Problem Chosen	2022	Team Control Number
1	IMMC Summary Sheet	22420155

Optimal Boarding and Disembarking Method based on Time Calculation Model

Abstract

Our team developed a Time-Based calculation model that focuses on three key factors that would affect the total duration of boarding and disembarking. The total time would be calculated by the sum of the walking time for a person to walk from the entrance to their seat, the time taken for all passengers to put their carry-on bags in the overhead bins, and the waiting time for one passenger while other passengers are changing seats.

Our team applied this model to three widely used boarding methods, which included random boarding, section boarding, and seat boarding. In these three boarding methods, our team slightly modified a few parameters in our model. In random boarding, the seats are randomly distributed, while in section and seat boarding, the seat is randomly chosen between sections and columns of seats respectively. In regards to the scenario of passengers not following the prescribed rules, our team conducted an OAT(One at a time) analysis on the sensitivity of the time with the percentage of passengers not following the rules and the extra carry-on luggage number.

Our team experimented with our models on two other aircraft types, the Flying Wing Passenger Aircraft and the Two Entrance, Two Aisle Passenger Aircraft. Same as the narrow-body aircraft, the two aircraft show seat boarding is considered to be the optimal boarding and disembarking method.

Our team modified our model to solve the problem of capacity limits during pandemic situations. In this model, our team only considered random boarding and seat boarding, since during the previous models, random boarding and section boarding shows similar results. Based on calculations, our team found that the total time needed for seat boarding is less than or at most equal to the total time needed for random boarding. As a result, seat boarding is the optimum boarding method in the three boarding methods with three different aircraft.

keywords : Boarding Time Calculation Model; OAT Analysis

LETTER

FROM: Team 22420155 , IMMC
To: Airline Executive
Date: March 14, 2022

Dear Officials:

Thank you for the opportunity you provided us to discuss with you the optimal boarding and disembarking method that our team found using our model. We are writing this letter to inform you of our solutions.

In an aircraft boarding scenario, the aisle is only sufficient enough for one passenger to pass at a time. Therefore, the last passenger would have to wait for all the other passengers to settle down, then put his carry-on luggage in the overhead bin. Based on this logic, our team recognized the total time of boarding and disembarking only includes the waiting time of the last passenger, the time for the last passenger to walk to his seat, and the time needed for all passengers to put their carry-on luggage. Based on this algorithm, our team calculated the boarding time for the three widely used boarding methods, which include random boarding, section boarding, and seat boarding.

In Random boarding, the seats are randomly distributed in the aircraft, which might increase the amount of time needed. In section boarding, the seats are randomly distributed in the three sections of the aircraft starting from the back of the aircraft, Passengers in different sections can be able to put their carry-on bags simultaneously which can decrease a considerable amount of waiting time compared to the random boarding. In-seat boarding, the seats are randomly distributed in columns, while the seat sequence in rows A, B, C, D, E, F are fixed. This boarding method would not only decrease the waiting time but also decrease the time for seat changing, thus it would be the most efficient. Calculations of the practical maximum time, minimum time, and average time also show the same trend, the minimum time needed for seat boarding is 1584 seconds, while random boarding and section boarding needed 3525, 3557 seconds respectively.

Our team further experimented with our model on three passenger aircraft, the narrow-body aircraft, the Flying Wing passenger aircraft, and the Two Entrance, Two Aisle passenger aircraft. While these aircraft platforms have a significant difference, all three aircraft shows that seat boarding is still the optimal boarding method.

In consideration of situations of the pandemic, our team simulated the scenario when there are only 70%, 50%, and 30% of the total seat number of passengers boarding the plane. In this model, our team only considered the total time taken for random boarding and seat boarding, since the previous models already show that the total time taken for random seating and section seating is similar. The result still shows that seat boarding takes less time or at most equal to the total time taken by random boarding in all percentage capacity limitations.

As a conclusion, the optimal boarding method would be seat boarding based on our models and algorithm. Our team hopes that this information can create convenience for your airline’s future decisions. Your airline is welcome to contact our team with further problems.

Sincerely yours

IMMC Team 22420155

Contents

1 Introduction

The advancement of technology has led to significant developments in transportation. One of the main aims of new technology is to increase efficiency and thus save time for people. The development of planes has made it possible for people to travel long distances across the sea in a relatively short time. For every passenger flight, the most time-consuming operation would be boarding and disembarking the aircraft. Due to that travel time is already the minimum with current technologies, people are finding new ways to efficiently reduce the time needed for these two operations.

Aircraft can carry large number of passengers on a single flight. Therefore, a long time would be required for every passenger to settle in their seats. Since the aircraft aisles are only sufficient for one passenger to pass at a time, the movement of the passengers in the front would have a significant effect on the queuing time of the passengers behind. Achieving the shortest times would mean that the times wasted have to be decreased to a minimum. As a result, our team will address this problem and explore a way of boarding the disembarking aircraft in the shortest time, taking into account the time needed to put luggage and the time needed when a seat is unreachable an a passenger would have to let another passenger settle in the seat first.

1.1 Restatement of the Problem

1. Develop an algorithm to evaluate the time taken for each passenger to board the plane, taking into consideration of stowing time of carry-on bags and the extra time is taken in which the passenger does not follow the prescribed boarding and disembarking methods. Construct a model to calculate the total time needed for all passengers to board and disembark the aircraft.

2. a. Use our model to compare the practical maximum, practical minimum, and the average boarding time of the three boarding methods the question gives.

b. Develop a sensitivity analysis of our model, state how the percentage of passengers not following the boarding method and the percentage of passengers carrying luggage influence the total boarding time of each boarding method respectively, thus determining the optimal method.

c. By changing the percentage of passengers that carry more luggage than normal, determines the effect of the total boarding time.

d. Give two additional boarding methods that can decrease the total boarding time compare to the total boarding time when passengers randomly board.

e. State the reason of the disembarking method our team choose

3. Improve our model of calculating the total boarding time so that it can use on the ‘Flying Wing’ and ‘Two Entrance Two Aisle’ aircraft.

4. Prove that our recommended method is still optimal when the passengers’ number is limited to 70%, 50%, and 30%.

1.2 Definition

1. Carry on Bags:
   Carry-on Bags are luggages that are taken by hand by a passenger onto an aircraft. These luggages can fit into the overhead bins of the aircraft above each passenger's seats. The bags can also be put below or beside the seat, however the time taken for the bags to be put below or beside the seat is negligible in our model because passengers can put their luggages after they settle down on their seats.

2. Overhead Bins
   Overhead bins are the storage compartments above every seat, these compartment keep passenger's luggage while they are on the plane. Therefore, luggage would not have to be put below or besides passenger seat.

1.3 Our Works

2 Assumptions and Variables

2.1 Assumptions

For our model, we made the following assumptions:

1. Passengers on the plane have constant walking velocity, which would effectively decrease the uncertainty in our model. The time for a passenger to walk a unit of distance is one second. In this model, we would have to find the relationship between the distance traveled by the passenger and the time needed for the passenger to arrive at their seat, therefore we would need to consider velocity as a controlled variable.

2. In all cases, passengers would not need to call flight attendants, which might cause extra queuing times. Since a flight attendant would have to walk on the corridor, they would have to stand in the corridor to help people in need. However, the corridors can only pass a single person per time, passengers cannot be able to pass. Therefore, we assume that the passengers do not need to call a flight attendant.

3. Every seat has the same side width and length, the separation of seats is the same, which would be represented in our model as single units. Every seat has 1 unit width and 1 unit length. The seat would have to have the same size and separation for the model to have higher accuracy.

4. The sequence in which every passenger boards the plane is the sequence of disembarking of the plane. Each passenger that has carry-on luggage would take their luggage in the sequence of putting luggage in the overhead bin of the boarding method. The optimal boarding method time would therefore be the optimal disembarking method time.

2.2 Variables

Symbol	Meaning
P_n	The number of passengers boarding the plane
V_c	The walk speed of passengers to their seat
P_{B1}	The percentage of passengers that carry one bag
P_{B2}	The percentage of passengers that carry two bags
N_B	Maximum number of bags
D_c	The distance of separation between columns of seats
D_r	The distance of separation between rows of seats
N_r	The row number of the passenger's seat
N_c	The column number of the passenger's seat
T	Total Boarding Time
T_w	The travelling time to the seat
T_B	The time waiting for other passengers to put their luggage
T_l	The time for every passenger to put their luggage
T_{sc}	The time taken for passengers to enable others to get to unreachable seats
T_c	The time taken for each passenger to walk a column
T_s	The time taken for each passenger to walk a row

3 Model Construction

3.1 Boarding Time Calculation Model

For our model, our team would have to estimate the boarding and disembarking time. Due to that using the traveling time of a passenger to walk to their seats from the entrance as the total time is not sufficient since other factors determine the total time, our team calculates the total time for each passenger to board the plane by the following formula:

$$\sum T = T_w + T_l + T_c$$

There are in total 198 seats in our aircraft figure. Our initial thoughts are to add the time for each passenger to reach their seat as the total time needed as the whole boarding time. This model would then calculate the time for the first passenger to reach his seat n times, the time for the second passenger to reach his seat $n-1$ times, and so on. This can be explained by that the time for the second passenger to reach his seat is the time for the second passenger to arrive at his seat plus the queuing times for the first passenger to reach his seat, the third passenger would have to wait for the second passenger which would include the waiting time for the first passenger. However, during boarding, passengers can be able to arrive at their seats simultaneously, because when the first passenger is walking, the second passenger to the thirty-third passenger is also moving, it is only that the passengers are a unit length away from each other.

3.2 Walking time

As a solution, our team found out that based on this logic, the total time taken for the whole boarding would be the time for the last passenger to settle down on his seat. The time for the last passenger to arrive at his seat would be the time for the first passenger to arrive at his seat plus the time difference between the time the second passenger arrives at his seat and the time for the first person to arrive at his seat. Because we assume that the walking velocity if each passenger is the same and the separation between all seats are the same, the time difference of the second and the first passenger would be the same as the time difference between the third and the second passenger would be the same. Therefore the time for the last passenger to arrive at his seat would be the time for the first passenger to arrive at his seat plus $n-1$ times of the time difference, where n is the number of passengers. This model is based on the assumption that the first passenger would seat in the innermost seat of the very back row of the aircraft and so on.

Based on this logic, our team developed a simulation model which can make evidence that our logic is possible. This simulation model would consist of three passengers and the seats are arranged in a single row with three seats arranged beside each other. The initial process of the simulation model is we set the sequence of the passengers in order:

- The first passenger as 1
- The second passenger as 2
- The third passenger as 3

We would then set their seat position. In a three-seat row, there will be in total six combinations:

$$\begin{pmatrix}1 & 2 & 3\end{pmatrix}\begin{pmatrix}1 & 3 & 2\end{pmatrix}\begin{pmatrix}2 & 1 & 3\end{pmatrix}\begin{pmatrix}2 & 3 & 1\end{pmatrix}\begin{pmatrix}3 & 1 & 2\end{pmatrix}\begin{pmatrix}3 & 2 & 1\end{pmatrix}$$

For this simulation, we set the seat position as 2-1-3, which means the first person sits in the second seat, the second person sits in the first seat and the third person sits in the third seat. For each of the three passengers to arrive at their seat, they would have to walk 2 steps, 1 step, and 3 steps relatively. Then we would have to take into consideration the steps they have to wait. Because the first person directly departs, he does not have waiting steps, the second passenger would have to wait for 1 step, the third passenger would have to wait for 2 steps, this made evident that the passenger has to wait $n-1$ step is correct. Moreover, we set the step between arriving at the seat and sitting on the seat as one step. In brief, the three passengers have to walk and wait in total 3 steps, 3 steps, and 6 steps. By using a graph of the motion of each passenger each second, we can analyze that the time of motion of the three passengers can be perfectly avoided.

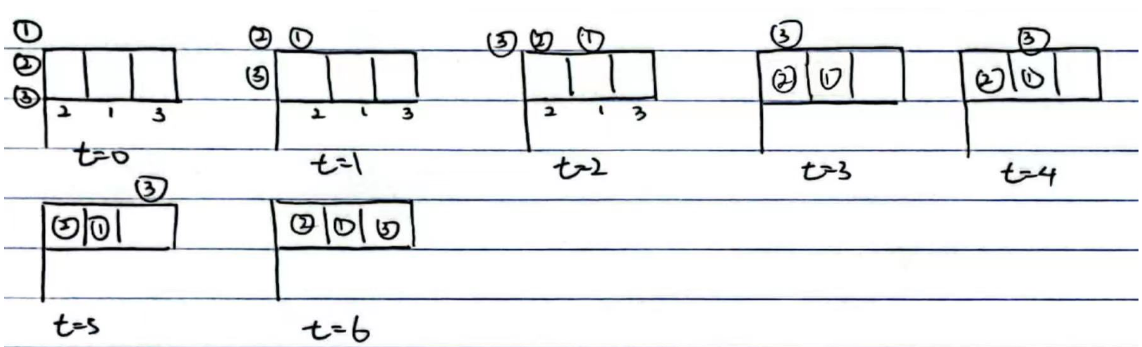

Figure 1: 2-1-3 Setting

From the graph, the numbers will circle are the passengers, and the boarding process is accorded to it. The number below the seats shows which passenger' s seat is it. Our team found that the three passengers in the 2-1-3 arrangement can finish boarding in 6 seconds. Based on the previous formula, we checked our model. Because there are three passengers in this simulation, n is equal to 3, which is 2 units of waiting time. The last passenger needs 3 steps to arrive at their seat plus 1 steps to settle down on his seat, which makes 6 steps in total. This result is the same as the result of the simulation. Our team listed all the possible outcomes for simulations with three passengers and we found out that this calculation suits every process with three passengers. However, there are 2 anomalies in 4 passenger boarding, it is when the seat position is 1-2-3-4 or 4-3-2-1. Similarly, 5 passenger boarding, 6 passenger boarding, and n passenger boarding would all have anomalies. However, in most of the boarding, the walking times can be calculated using this formula.

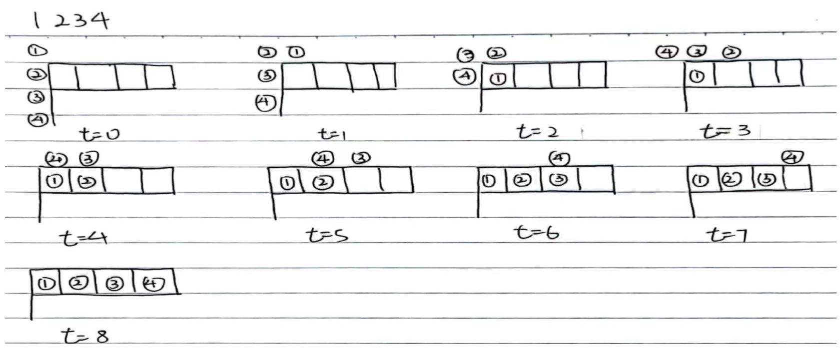

Figure 2: 1-2-3-4 Setting

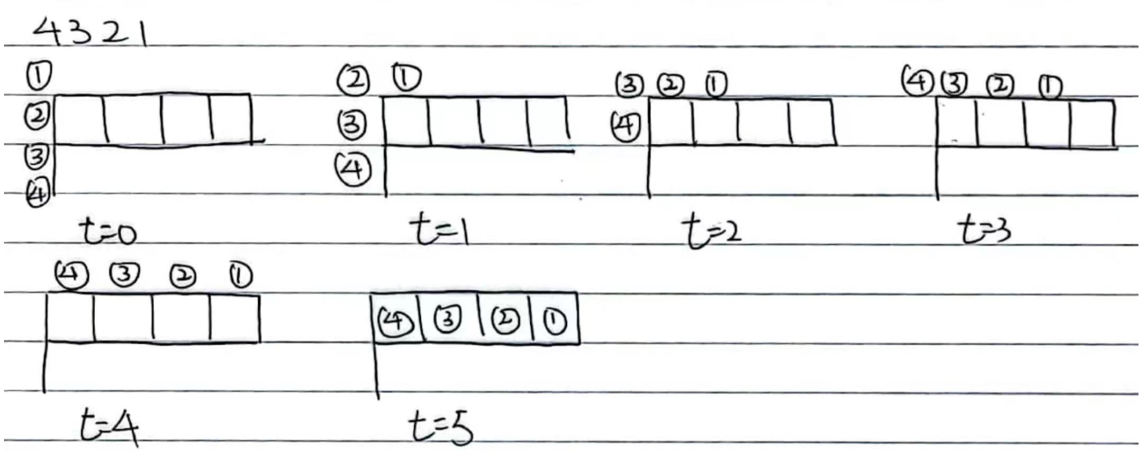

Figure 3: 4-3-2-1 Setting

3.3 Waiting Time

Our team further considered the scenario when a passenger is already seated on the out seat, while a passenger sits in the inward seat, the first passenger would have to get out and let the other passenger in and then settle down in his seat. Our team considers this scenario as a seat change. In each scenario of the seat change scenario, our team calculates the total time spent on waiting and entering the seat by taking the average of the time spent on each section and multiplying it by the total amount of columns.

$$\left\{[2\sum_{r=1}^{N_r-2} T_s \times r \times (N_r! - \frac{N_r!}{N_r} - 2 \times r + 2)] + N_r! \times (N_r - 1) + N_r! \times \sum_{r=1}^{N_r} r]\right\} \times N_r!^{-1} \times N_c$$

The average is given by first adding the sum of the time entering the seat individually and the extra time spent on going out and reentering the seat. This brings complexity and many possibilities for the total time taken if the sequence of the entering is different, but the possibility of each of the order of entering is the same, thus allowing us to take the average of the total time of those total possible possibilities. The person sitting in the innermost seat has to go in first to allow other people in the other seats to get in without getting out. Therefore, every person that is B or C would have to come out if they are ahead of A, so when sorting out all the possible possibilities in the 3 seat scenario, is 6 possibilities.

$$(ABC)\,(ACB)\,(BAC)\,(BCA)\,(CAB)\,(CBA)$$

In the perfect scenario ABC is 3+2+1 time unit. In other possibilities like BAC when B is the first, B has to get out to let A in, thus the time unit is

$$2 \times 2\,(in - out) + 3\,(A) + 2\,(B) + 1\,(C)$$

Similarly, for C, we can see that the time added in the last part of the calculation and every equation, there is a 3+2+1. This is because no matter what seat exchange happens before A, the final time added is always in the order of A, B, C, since A would not need to go out. Therefore, in any case, the following equation would always have to be considered.

$$N_r! \times \sum_{r=1}^{N_r} r$$

Then, with listing all the time in 3 seat scenario and 4 seat scenario, we found that except for the time taken of the aisle seat person, all other people before take to calculate.

$$[2\sum_{r=1}^{N_r-2} T_c \times r \times (N_r! - \frac{N_r!}{N_r} - 2 \times r + 2)]$$

This pattern happens because, to have a person go out, the person is out of order from the perfect pattern. This makes at least one of the people go out and back for the inner person to get in. In every scenario that is equally likely to happen, the number of times the first person goes out and back is

$$N_r! \times (N_r - 1)$$

which in other words is calculating the time extra than the 4+3+2+1, for example, B has to go out and back every time unless he is in the last place of the order. C has to do the same but with 2 fewer exceptions, and so on with the increase of 2n+2.

$$N_f \times n!$$

because the person has to go out and in for half of the total possibilities because it only has to be added extra whenever it is ahead of A or ahead of C or ahead of B. this accounts for half of the possibilities. Thus adding all the possibilities and dividing it by the total number of possibilities which is n!, we can get an average time unit for the total time spent on waiting and entering the seat in a section of the column (A-C) and for the total time spent waiting, multiply the average number of time per column by the total number of columns.

3.4 Luggage time

The time for passengers to settle down on their seats would also include the time for the passengers themselves and others to put their bags. Although, there might be the uncertainty of the total amount of bags passengers taken, which is a normal scenario each passenger can take one or no bags., our team found out that the total time would always be

$$[(P_{B1} \times N_B + P_{B2} \times N_B) \times T_B]$$

In our model, our team made a simulation with three groups of ten to find the time needed for passengers to put one carry-on bag onto the overhead bin. Due to that, every bag may not have the same weight, our team used the average times. The solution showed that the average time for a passenger to lift one carry-on bag onto the overhead bin would be approximately 5 seconds, therefore the time for carry-on bags in this formula would be 5 seconds. Our team found that the time for others to put the carry-on bags can be neglected in the luggage time because this time is already included in the waiting time.

However, there might be a scenario in which passengers don't follow the prescribed rules for the boarding and disembarking method, they might take more than one carry-on bag. For the calculation for our model, we set the passengers to take two pieces of luggage.

4 Narrow-Body Aircraft model

4.1 Three widely used Boarding Method

The application of our model to narrow-body aircraft also shows possible results. This model made evaluations of the practical maximum and practical minimum time using three widely used boarding and disembarking methods.

4.1.1 Random Boarding

Random boarding is when the seats of the passenger are randomly distributed in the aircraft and the seating order would also be random, which would include the extra time for a seat change. In our model, the time for the last passenger to settle down on his seat determines the total time, since the seat number is the only variable in this model, the seat number of the last passenger would be the key factor. Therefore, the scenario in which the last passenger's seat is at the 95% seat of the total seat from the entrance would have the longest boarding time and vice versa. The 95% seat number and the 5% seat number are rounded up and down respectively to avoid a non-integer seat number. Regarding the probability of seat numbers first line to thirty-third line not in order, our team calculate the average waiting time for a seat change in half a row which is three seats is 9.3s. Lastly, the total luggage times would be calculated by total luggage number times five seconds which is the average time.

4.1.2 Section Boarding

Similar to the random boarding method, the seat number is still the independent variable of our model. However, in section boarding, passengers would have to be randomly distributed in the three sectors of the narrow-body aircraft. Although the boarding method is arranged in sectors,the arrangement of sectors are still from the back to the front of the aircraft. Different from the first boarding method, the seat of the last person would not be 95% and 5% in the whole aircraft, but the percentile from the first row to the last row in the last boarding section. Moreover, the luggage time would only be the luggage number in the last section times 5s, because while the passengers in the first section is putting their bags, the passengers in the second section is already boarding.

4.1.3 Seat Boarding

Boarding by seat would be considered to be the most efficient boarding method in these three boarding methods because the sequence of the seat is all arranged from A to C and F to D, therefore the waiting time would always be equal to 3+2+1 seconds and there would be no possibility of changing seats because the walking time of all passengers are the same as the previous models. The percentile for this boarding method would be 95% and 5% seats in whole plane.

4.2 Practical Maximum and Practical Minimum Time

As a result of this model, the total time for these three models is calculated.

	Minimum Time	Maximum Time	Average Time
Random	3525	3535	3530
Section	3557	3525	3541
Seat	1584	1616	1600

The average time of the three boarding method is calculated by the average of the maximum and the minimum time.In response to this method, our team made an analysis using OAT(One at a time)analysis on the scenarios at which the passenger do not follow the boarding method in regards to the aspect of the percentage of passengers and the number of bags.

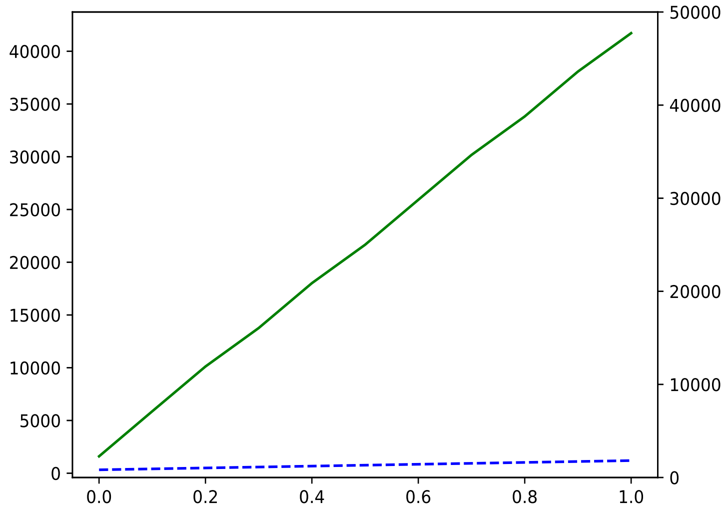

Figure 4: Sensitivity Analysis

First, a different percentage of people not following the rules would have a different effect on the total time taken. Passengers that follow the rule would only have to wait 6 seconds while passengers that don’t follow the rules would have to wait for 9.3 seconds on average. Our team used different percentages respectively and found a linear relationship of the total time in respect to the percentage of passengers not following the rule. Similarly, the number of luggage would also affect the total time. Passengers are prohibited from taking extra hand-carry luggage, there is a maximum limit for luggage amount. The number of luggage carried per person would significantly affect the queuing times; therefore, to let out time be reasonable, passengers are limited to take hand-carry luggage under 10 kilograms.[1][2][3][4] Passengers that do not follow the rule would take one or two bags. It would take 5s to put one carry-on luggage, 10s to put two bags. Different percentages are used to calculate the total time used.From the table, we can analyze that the time change by number of luggage is much smaller than the effect by the percentage of passengers not followed the boarding method.

4.3 Two additional possible Boarding Method

One possible boarding method would be to arrange the passenger boarding order according to the number of carry-on luggage passengers take. Passengers with more luggage can be able to board the aircraft first. One of the main advantages of this boarding method is that it can significantly decrease the time for passengers with no carry-on luggage to wait for passengers with two luggage. Passengers with the most luggage will be arranged in the A seat of the last row, the passenger with the second most luggage will be arranged in the seat in the last row beside it, and so on. Therefore, passengers with no carry-on luggage can be able to settle down on their seats quickly even though there might be a lot of passengers that need to put their luggage in the overhead bins. However, since each passenger is only allowed to bring a maximum of 2 bags with a total of less than 10kg, therefore there would be the scenario where all of the passengers take two carry-on bags each. As a result, this model would also have to include random choices. When more than one passenger is taking the same number of carry-on luggage, the arrangement sequence would be selected randomly. This model would have drawbacks because our previous models show that the time taken would have a significant increase when the percentage of passengers that takes more than a specific number of luggage exceeds a limit. As a result, the time taken would have high inaccuracy.

Our team considered a second boarding method based on the distance. The passenger that has to walk the longest distance can be able to board the plane first and while the first passenger is boarding, all the other passengers are boarding in the order of this sequence. Therefore, the person the walks the longest distance can have the longest times to walk, which would not increase the waiting time of the passengers in the back. One of the advantages of this model is that it is convenient, however, it would also have to include random choices.

4.4 Optimal Boarding and Disembarking Method

The solutions shows that boarding based on the sequence of seat would be the most time-saving, the maximum time needed is about 1584 seconds. This boarding method is the most effective because waiting time is not needed, passengers in the window seat would settle down first. The disembarking time is the same because the optimal boarding time is the optimal disembarking time.

5 Suitable Aircrafts

5.1 Flying Wing Passenger Aircraft

The main difference between the flying wing passenger aircraft with the narrow body aircraft is that the aircraft has wider platforms, there are more seats in a row and the number of aisles increases. By changing a few setting, our model can suit well with is aircraft. For the seats, our team decided to divide the seats into four sections. The three columns beside an aisle is considered as a group. The four groups are similar to the platform of a narrow body aircraft, with 9 seats less on boths sides. The results of the narrow body aircraft has six rows with thirty three columns each,the minimum time needed to board and disembark is 1584 seconds. This aircraft has approximately 24 rows with 11 columns each, this can give us an approximation of the total time needed, which is about 2112 seconds. While there is a significant increase in the number of seats in this aircraft, the total time taken is much less than the minimum time needed for passengers to board the narrow body aircraft by random and section boarding. Our team thus infers that the seat boarding is the optimal boarding method for the Flying Wing Passenger Aircraft.

5.2 Two-Entrance, Two Aisle Passenger Aircraft

The main advantages for this aircraft seat distribution is that there are two entrances, which means that there can be more passengers boarding the aircraft at the same time. Our team divided the passengers into six groups, two of which walk the aisle neared to the entrance, two of which walk the aisle furthur from the entrance and two waiting groups. Each of the two group board the aircraft from the two entrances respectively. For the two column on both sides of the aircraft, the order of boarding would still be the in A-B-C. Each of the two groups that walks the aisle would settle down either in the two seats at the side or the column of seats that is beside the aisle. The waiting group would then settle down in the middle seat in the middle column of the aircraft. The advantage of this boarding method is that the waiting group can find the place where there are less luggage, they can be able to settle down on their seat with less time. However, this model is still based on the seat boarding method.

6 Capacity Limitation

6.1 Narrow Body Aircraft Random Boarding

6.1.1 70% Capacity

In our model, we have already calculated the minimum time needed to board the narrow-body aircraft with random boarding and section boarding, and the total time needed is similar. Therefore, to simplify this model, our team decided to use only the random boarding method to calculate the time. When the passenger number is decreased to 70%, equivalent to 138 passengers. Due to the pandemic, the optium seat arrangment would be to have the largest separation. In this scenerio, passengers can be able to sit a seat away from each other, which the aisle is also considered as a seat away. The arrangement would have 6 passengers left. These passengers would have to be arranged in the seats between other passengers. Consequently, we would have to considered the boarding sequence. In the scenario of three seats two passengers, there would be two possibilities:

- Passenger with A seat goes in first and Passenger with C seat goes in second. This sequence would take 4 seconds.
- Passenger with C seat goes in first and Passenger with A seat goes in second. This sequence would take 6 seconds.

Since we cannot quite determine which passenger settles down first, we would take the average time which is 5 seconds. The total time would then be

$$5 \times 60 + 9.3 \times 6 = 355.8s$$

6.1.2 50% Capacity

In this capacity limit, there are only 99 passengers. The seat can be randomly arranged from the window seats on the two sides, this enables the seats to be the furthest away from each other. The other proportion of passenger would be arranged a seat separation from one side of the window seat. Therefore, there will be a side where three seats have two passenger with one seat separation and one side with only a column of passengers settling in the window seat.

6.1.3 30% Capacity

In this scenario, there are 59 passengers if we round down. The two column of window seats is sufficient enough for the passengers, therefore they can be able to have largest separation.

6.2 Narrow Body Aircraft Seat Boarding

While the 50% and 30% capacity stays the same, the 70% capacity in seat boarding is different from random boarding. In random boarding, there might be two possible seat arrangements. However, in the seat boarding, there would only be A-B-C sequence, so the waiting time would be 4 seconds.

6.3 Flying Wing Passenger Aircraft

6.3.1 Capacity Limit

The Flying Wing Passenger Aircraft is approximately 4 times that of the narrow body aircraft. Therefore the time for 70%,50% and 30% for the Flying Wing Passenger Aircraft would be 4 times the time for the narrow body aircraft.

Fly wing	random	by seat
70%	1334	1184
50%	924	924
30%	708	708

6.4 Two Entrance, Two Aisle Aircraft

6.5 Capacity Limit

There are two entrance in a Two Entrance, Two Aisle Aircraft. From the front entrance, there are 13 rows and from the back entrance there are

19 rows. Using our previous formula, our team would only need to consider the time needed for boarding from the back entrance because there are more rows. The largest separation would be achieved when passenger settle down on both sides of the window seat and one seat separation in the middle. However, the seats are insufficient, other 18 passengers would have to be randomly arranged. This would create two possibilities.

- If three passengers settle down in a row, either 4 seconds or 6 seconds will be needed
- If two passengers settle down in a row, 3 seconds would be needed

Based on calculation similar to the previous models, the time needed for two entrance, two aisle aircraft would be the following:

Two entrance Two aisle	random	by seat
70%	78	69
50%	53	53
30%	32	32

6.6 Results

The total time needed for boarding and disembarking by seat boarding still shows the highest efficieny, the time taken is equal to or less than random boarding. As a result, seat boarding is the optimum boarding and disembarking method for all three aircrafts.

7 Advantages and Disadvantages Analysis

7.1 Advantages

1. The main advantage of our model has high suitability. The three aircraft types can suit well with our models. While they may be a different number of rows, columns, and aisles, the algorithm are all the same.
2. Our model would not have to minus the time for simultaneous actions, because the total time is calculated by the time used by the last passenger, so our team's calculation are more convenient.

7.2 Disadvantages

1. The walking velocity, the time to put luggage, and the time for passengers to settle down on their seats are the same, which would have some inaccuracy in boarding situations.
2. When there is a seat change, there would be a lot of passengers standing on the aisle at the same time. In boarding situations, it cannot be achieved.

References

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[3] ”Carry-on Bags”. Www.Koreanair.Com, 2022, https://www.koreanair.com/cn/zh-cn/airport/baggage/carry-on. Accessed 10 Mar 2022.

[4] ”Delta Homepage”. Zh.Delta.Com, 2022, https://zh.delta.com/cn/zh. Accessed 10 Mar 2022.

Appendices

Appendix A: Python Code

```
import numpy as np
import random
import math
import bisect


def random_all_passenger_seat_position(passenger_num, seat_num
    , rows_num):
    position_x = random.sample(range(1,passenger_num+1),
        passenger_num)
    position_y = (random.sample(range(1,seat_num+1),seat_num))
        * rows_num
    seat_position = np.dstack((position_x,position_y))
    print(seat_position)
# 随机生成的所有乘客的座位坐标

def random_last_passenger_seat_position(rows_num, seat_num):
    position_x = random.randint(1,rows_num)
    position_y = random.randint(1,seat_num)
    position = np.dstack((position_x,position_y))
    print(position)
# 随机生成最后一名乘客的座位坐标

def by_section_last_passenger_seat_position(rows_num, seat_num
    , section_num):
    position_x = random.randint(1,rows_num / section_num)
    position_y = random.randint(1,seat_num)
    position = np.dstack((position_x, position_y))
    print(position)
```

```python
# 按照section随机生成最后一名乘客的座位坐标

def by_section_last_passenger_seat_position_maxima(rows_num,
   seat_num):
    position_x = math.ceil(rows_num / section_num * 0.95)
    position_y = math.ceil(seat_num * 0.95)
    position = np.dstack((position_x, position_y))
    print(position)
# 按照section生成最大时间的最后一名乘客的座位坐标

def by_section_last_passenger_seat_position_minima(rows_num,
   seat_num):
    position_x = math.floor(rows_num  * 0.05)
    position_y = math.ceil(seat_num * 0.05)
    position = np.dstack((position_x, position_y))
    print(position)
# 按照section生成最小时间的最后一名乘客的座位坐标

def by_section_last_passenger_seat_position_average(maxima,
   minima):
    average = (maxima + minima) / 2
# 按照section的maxima和minima求出它的平均

def by_seat_last_passenger_seat_position(rows_num, seat_num):
    position_x = random.randint(1,rows_num)
    position_y = seat_num
    position = np.dstack((position_x, position_y))
    print(position)
# 按照seat随机生成最后一名乘客的座位坐标,

def by_seat_last_passenger_seat_position_maxima(rows_num,
   seat_num):
    position_x = math.ceil(rows_num * 0.95)
    position_y = math.ceil(seat_num * 0.95)
    position = np.dstack((position_x, position_y))
    print(position)
# 按照seat生成最大时间的最后一名乘客的座位坐标
```

```
def by_seat_last_passenger_seat_position_minima(rows_num,
    seat_num):
     position_x = math.floor(rows_num * 0.05)
     position_y = math.ceil(seat_num * 0.05)
     position = np.dstack((position_x, position_y))
     print(position)
# 按照seat生成最小时间的最后一名乘客的座位坐标

def by_seat_last_passenger_seat_position_average(maxima,
    minima):
     average = (maxima + minima) / 2
# 按照seat的maxima和minima求出它的平均

def fun_multiple(n):
    if n<=1:
        return 1
    else:
        return n*fun_multiple(n-1)
# n的阶乘

def fun_sum(n):
    if n <=1:
        return 1
    else:
        return n + fun_sum(n-1)
# n的求和

def walking_time(walking_distance_x):
    walking_time = passenger_num - 1 + walking_distance_x
    print(walking_time)
# 所有乘客走到他们位置的时间

def waiting_time(seat_num_in_a_row, seat_distance, rows_num,
    furthest_distance):
    for i in range(1,2):
        waiting_time_1 = 2* (1 * seat_distance * (fun_multiple
            (seat_num_in_a_row)-fun_multiple(seat_num_in_a_row)
            /seat_num_in_a_row - 2 * 1 + 2))
```

```
    waiting_time_2 =  (furthest_distance-1) * fun_multiple(
       seat_num_in_a_row) + fun_multiple(seat_num_in_a_row) *
       fun_sum(seat_num_in_a_row)
    waiting_time_3 =  fun_multiple(seat_num_in_a_row) /
       rows_num

    print((waiting_time_1+waiting_time_2)/waiting_time_3)
#  所有乘客平均入座时间

def luggage_time(luggage_num, put_luggage_speed):
    luggage_num = random.randint(1,198) # 当超载的情况下, max
       设为396, 即每个乘客
    print(luggage_num)
# 所有乘客放行李的时间

def order(values):
    l = []
    for i in values:
        position = bisect.bisect_left(l, i)
        bisect.insort_left(l, i)
    print(''.format(i, position), l)



# 2a parameters

passenger_num = 198
# 总乘客数量
rows_num = 33
# 总列数
seat_num = 3
# 每一行有多少个椅子
seat_distance = 1
# 每一个椅子的距离
section_num = 3
# 乘客分成几批登机
luggage = 296
# 最大行李数量
```

```python
put_luggage_time = 5
# 放一个行李的时间

#2a codes
for i in range(10):
    random_last_passenger_seat_position(rows_num,seat_num)
    maxima = max(random_last_passenger_seat_position(rows_num,
        seat_num))
    minima = min(random_last_passenger_seat_position(rows_num,
        seat_num))
by_section_last_passenger_seat_position_average(section_maxima
    , section_minima)



section_minima =
    by_section_last_passenger_seat_position_minima(rows_num,
    seat_num)
section_maxima =
    by_section_last_passenger_seat_position_maxima(rows_num,
    seat_num)
by_section_last_passenger_seat_position_average(section_maxima
    , section_minima)
section_luggage_time = int(rows_num / section_num) * luggage *
     put_luggage_time / 6
print(section_luggage_time)
section_waiting_time = waiting_time(seat_num,seat_distance,
    rows_num,seat_num)


section_time_maxima = 9.3 * 66 + section_luggage_time +
    passenger_num - 1 + 11
section_time_minima = 9.3 * 66 + section_luggage_time +
    passenger_num - 1 + 1
section_time_average = (section_time_minima +
    section_time_maxima) / 2
print(section_time_minima)
print(section_time_maxima)
```

```python
print(section_time_average)

seat_luggage_time = passenger_num * put_luggage_time
seat_maxima = by_seat_last_passenger_seat_position_maxima(
    rows_num, seat_num)
seat_minima = by_seat_last_passenger_seat_position_minima(
    rows_num, seat_num)
by_seat_last_passenger_seat_position_average(seat_maxima,
    seat_minima)
seat_time_maxima = 6 * 66 + seat_luggage_time + passenger_num
    - 1 + 33
seat_time_minima = 6 * 66 + seat_luggage_time + passenger_num
    - 1 + 1
seat_time_average = (seat_time_minima + seat_time_maxima) / 2
print(seat_time_minima)
print(seat_time_maxima)
print(seat_time_average)

random_luggage_time = section_luggage_time
random_time_maxima = 9.3 * 66 + random_luggage_time +
    passenger_num - 1 + 33
random_time_minima = 9.3 * 66 + random_luggage_time +
    passenger_num - 1 + 1
random_time_average = (random_time_minima + random_time_maxima
    ) / 2
print(random_time_maxima)
print(random_time_minima)
print(random_time_average)

# 2b parameters
not_follow_percentage = 1
# 不遵守登机策略的乘客占比
probability_of_one_bag = 1
# 带了一个行李的乘客的百分比
not_follow_rows_num = math.ceil(rows_num * 2 *
    not_follow_percentage)
# 2b codes
walking_time(17)
```

```
seat_waiting_time_change = math.ceil((1 -
   not_follow_percentage) * rows_num) * 6 + math.ceil(
   not_follow_rows_num * 66) * 9.3
seat_time_percentage_of_passengers = seat_luggage_time + 214 +
    seat_waiting_time_change
print(seat_time_percentage_of_passengers)

seat_waiting_time = rows_num * 2 * 9.3
seat_luggage_time_change = probability_of_one_bag *
   passenger_num * put_luggage_time
seat_time_lugggage_change = seat_luggage_time_change + 214 +
   seat_waiting_time
print(seat_time_lugggage_change)

# 2c parameters
probability_of_one_bag = 0
probability_of_two_bags = 1

# 2c codes
add_luggage_time = put_luggage_time * (probability_of_one_bag
   * passenger_num * 1 + probability_of_two_bags *
   passenger_num * 2)
print(add_luggage_time)

# problem 4 parameters
passengers_limit_percentage = 0.7
# 登机人数限制

#problem 4 codes
for i in range(10):
    random_last_passenger_seat_position(rows_num *
       passengers_limit_percentage,seat_num)
    maxima = max(random_last_passenger_seat_position(rows_num,
       seat_num))
    minima = min(random_last_passenger_seat_position(rows_num,
       seat_num))

by_section_last_passenger_seat_position_average(rows_num *
```

```
    passengers_limit_percentage, seat_num)
section_minima =
    by_section_last_passenger_seat_position_minima(rows_num *
    passengers_limit_percentage, seat_num)
section_maxima =
    by_section_last_passenger_seat_position_maxima(rows_num *
    passengers_limit_percentage, seat_num)
by_section_last_passenger_seat_position_average(section_maxima
    , section_minima)
section_luggage_time = int(rows_num / section_num) * luggage *
     put_luggage_time / 6
print(section_luggage_time)
section_waiting_time = waiting_time(seat_num,seat_distance,
    rows_num,seat_num)

section_time_maxima = 9.3 * 66 + section_luggage_time *
    passengers_limit_percentage + passenger_num *
    passengers_limit_percentage - 1 + 11
section_time_minima = 9.3 * 66 + section_luggage_time *
    passengers_limit_percentage + passenger_num *
    passengers_limit_percentage - 1 + 1
section_time_average = (section_time_minima +
    section_time_maxima) / 2
print(section_time_minima)
print(section_time_maxima)
print(section_time_average)

seat_luggage_time = passenger_num *
    passengers_limit_percentage * put_luggage_time
seat_maxima = by_seat_last_passenger_seat_position_maxima(
    rows_num, seat_num)
seat_minima = by_seat_last_passenger_seat_position_minima(
    rows_num, seat_num)
by_seat_last_passenger_seat_position_average(seat_maxima,
    seat_minima)
seat_time_maxima = 6 * 66 + seat_luggage_time *
    passengers_limit_percentage + passenger_num *
    passengers_limit_percentage - 1 + 33
```

```
seat_time_minima = 6 * 66 + seat_luggage_time *
   passengers_limit_percentage + passenger_num *
   passengers_limit_percentage - 1 + 1
seat_time_average = (seat_time_minima + seat_time_maxima) / 2
print(seat_time_minima)
print(seat_time_maxima)
print(seat_time_average)

random_luggage_time = section_luggage_time
random_time_maxima = 9.3 * 66 + random_luggage_time *
   passengers_limit_percentage + passenger_num *
   passengers_limit_percentage - 1 + 33
random_time_minima = 9.3 * 66 + random_luggage_time *
   passengers_limit_percentage + passenger_num *
   passengers_limit_percentage- 1 + 1
random_time_average = (random_time_minima + random_time_maxima
   ) / 2
print(random_time_maxima)
print(random_time_minima)
print(random_time_average)
```