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2022

IMMC

Summary Sheet

Summary

As is known to all, time is very precious for airlines, especially the time spent on boarding and disembarking. In order to make airlines more profitable, they should shorten the boarding time of passengers as much as possible. Our team aims to find the fastest boarding method for a variety of different aircraft.

For the first question, we built a model to calculate boarding time, which is applicable to various aircraft. We used this model to find out the relationship between boarding time and line spacing, luggage storage time, seat transfer time, walking time and other influencing factors. By grouping the lines of passengers, we concluded that people in the same group would not interfere with each other when boarding, thus saving time.

Based on the first model, we applied it to three different boarding methods. We built three new models for each of the three boarding methods. For the hard part of the first model, we implement it through the program. Also, given that deplaning is the same as boarding, only in a different direction, we focused primarily on boarding.

Then, we applied the model to the Flying Wing aircraft and the two-entrance, two-aisle aircraft. We divided the seats into sections, each more or less identical to a narrow-body plane.

After that, we continued to consider the capacity restrictions of passenger planes under the impact of the epidemic, and put forward different boarding mode suggestions for different aircraft full capacity rates.

Finally, we analyze the sensitivity of the weight in the model for third question , and find that our model is very sensitive.

Reasonable seating order: How to obtain the highest efficiency?

Team 22208463

March 14th, 2022

CONTENTS

1. Introduction

1.1 Background

While the world is globalizing, people frequently travel from one place to another, and air transportation has gradually become a people's main way travelling. As the saying goes, *Time is money*, the delay in airline boarding and disembarking can do one great harm in certain situations. For example, a simple action in the aisles can affect the queue process for the whole group has to stop for that.

However, these time-consuming operations are mainly determined by human behaviors. In other words, if appropriately instructed, the side effects in these processes can be avoided. Therefore, some airline companies begin to stimulate the factors accounting for the delay and try to resolve the problem by finding the relationship between different luggage, seats and aircraft fuselages.

As a citizen of the globe, we are also concerning about the circumstance more than ever. By using mathematical techniques, we build some models in order to help airline companies tackle the problems and give lots of approaches which is suitable for various planes.

1.2 Restatement of Problem

We need to build a mathematical model to create plane boarding and disembarking methods that will be the most time- effective in real practice. We also have to refinement our models so as to make it available to different occasion.

In order to meet the requirements, we divide the paper into 4 sections to solve the problems.

1. Model A（Boarding and Disembarking Time Model）: In this model, we construct some mathematical models to calculate total aircraft boarding and disembarking times on consideration of various luggage amount and entering order, which will answer the first question.
2. Model Application: In this part, we apply our previous models to specific situations and scenes in the "narrow-body" aircraft to ensure that they are adaptable.
3. Model for other aircrafts: In this part, we altered our strategy to meet the needs of the other two kinds of aircraft by setting various groups. We also tested the performance under different circumstances.

4. Our suggestions based on pandemic: Analyzing the real-time data and developing our algorithm and model, we give out reliable suggestions when the occupancy ratio differs.

2. General Assumptions

1. It takes the same time for one person to put his luggage and pick up his luggage.

In real life, there couldn't an apparent difference in time when one puts and picks up his luggage. And if there is, it is too short to take into consideration.

2. The luggage put into the overhead bins is something relatively light and of middle size.

Most airlines have rules that big packages are not allowed to be taken into the cabin, and it's unnecessary for us to put little ones such as handbags into the overhead bins.

More detailed assumptions will be listed if needed.

3. Model A: Boarding and Disembarking Time Model

3.1 Model Overview

In this model, our prioritized aim is to calculate the total time for boarding and disembarking. As each passenger has to stow their luggage once they approach their seats and get them when they leave. Therefore, a certain amount of time is wasted because of the hinderances caused by blocking the aisle. What's more, the seat interference might also be a contribution to the loss. We stimulate these factors by setting a lot of variables, and seeing the problem from different perspectives, we build 2 models and give out solutions to ensure that it is available to all kinds of planes.

In Part 1, we developed a mathematical model so as to quantify the total time it needs for boarding a plane. Elements like line spacing, luggage storage time and walking time are taken into consideration.

In Part 2, we quantify the total time it needs for boarding a plane by building another model. Elements like line spacing, luggage storage time and walking time are taken into consideration. We also develop an algorithm in pursuit of the shortest time for boarding when passengers are split in groups.

In Part 3, we make our solution more universal for all kinds of airlines when boarding and disembarking the plane and introduce the scope of time with several formulas.

We mainly concentrate on the boarding part, on consideration that embarking the plane is just the same as boarding the plane, only in different directions and without rushing into the plane in random order for the ones who is closest to the exit are always the first to leave.

3.2 Model Assumptions

1. The lateral movement when one gets to his seat is too short to take into account.

Compared to the whole process of the queue signing their seats, the time for one's lateral movement is really negligible to be considered. And the lateral movement also quite little in real life.

2. The distance between two passengers in line is the distance between two rows of seats.

We assume this just for better modeling.

3.3 Constants and Variables

Table 1

Symbol Table of the Boarding and disembarking model

Symbol	Definition
	Variables
$P_{\min}$	The minimum time for placing packages into the overhead bins among all the passengers
P_{max}	The maximum time for placing packages into the overhead bins among all the passenger minus $P_{\min}$
ω	The total number of seats in horizontal row
l	The total number of seats in vertical row
l_{max}	The furthest distance from the door among the passengers that caused the obstruction
t_p	The time wasted when one is relatively late than others
t_l	The time wasted when one put its luggage too slow
t_{w}	The time a passenger needs to walk from the entrance to the last row

t_1	The time for one seat exchange in Bubble Sort
T	Total time for boarding
a	The average speed for an ordinary people to walk at the plane aisles
x	The distance between every row
Q	The total amount of people
$S\%$	The percentage of seats already taken
$\mathcal{E}\%$	The percentage of people who didn't show up when firstly preparing for boarding
$R(i, j)$	Coordinates of the person who arrive late
Y	The time one spends when moving between seats or aisles once
n(n≥ 1)	The quantities of groups in one airline when under instruction (the group is a phalanx about 9 to 12 vertical rows)
U	The quantities of groups in one airline without instruction
f	The quantities of groups sorted for preparation to board the plane before entering
$R(i_k, j_k)$	Coordinates of the kth late person
B_{k}	The time the kth person needs for the process from his entry to his seat
y	The number of vacant seats in the previous group
m	The length of a group
b	The number of disruptive passengers
N_p	The average packets' number for one person on such flight
c	The percentage of disruptive people

3.4 Model Mechanism

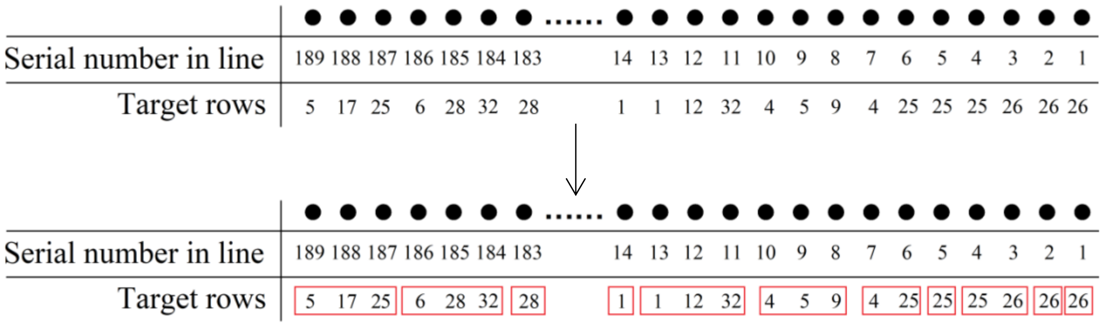
3.4.1 Section Overview

In this part, we will introduce the main idea of our model, which is the basis of our solution in the following paper.

3.4.2 Model Establishing

We assume that everyone who steps into the plane is labelled with his unique serial number in line, target position, package amount and other information (not very essential). By inputting these labels, we can successfully output the time passengers used to board.

Before demonstrating our formulas, we have to establish our critical idea: *Split model*. As the serial number of people increases, we split them into several groups following the rule that people with increasing target seating rows can be defined as a group as the figure shows:



Split grouping figure

Figure 1

The numbers in the same red box are sorted as one group, for each of them satisfies our splitting rule. What's more those who target the same row cannot be put in the same group and the quantity of group members doesn't has a limit as long as it meets our rule.

In addition to that, the reason why we sort them into such group is that when the whole group starts to put their luggage ahead, the time is coincident for them. In other words, their time does not interfere with each other, and only the one who spends the longest time will affect the next group.

3.5 Luggage Consideration

3.5.1 Model Establishing

In our assumption, we think that the luggage people carry to put into the overhead bins are relatively light and of middle size. Besides, the arm strength of each passenger is of little importance in this part, the time for putting them ahead mainly depends on the frequency one picks up the luggage and bent over, which can be easily acquired that:

$$\boldsymbol{T_s = k \times N_p}$$

In which, $\boldsymbol{T_s}$ represents the time for storing the package and $N_P$means the average packets' number for one person on such flight. And we don't need to calculate the value of $\boldsymbol{k}$, because its function is to show that the luggage storage time is proportional to the number of luggage. What's more, in the following models, we considered T_S as an individual variable.

3.6 Part 1: Random grouping Model

3.6.1 Model Overview

In part one, we build the model in terms of the reality where passengers board in a random order without any instruction. We also make it clear the way we define group in this part, for it's at the core of our model.

3.6.2 Model Establishing

Suppose that the person who finish the whole boarding process slowest has the target position $R_{last}(i_{last}, j_{last})$, and the queue is split into U groups without guidance.

For better calculating the total time, we assume that there is an additional man standing at the end of the queue when boarding the plane, which is non-existent in reality. We make such an idealized person in that we can't tell the coordinate of the slowest person in the last group. Therefore, we use it to avoid uncertainty.

Using the time when only is he walking in the aisle to subtract the one when he walks with the queue, we come up with the actual boarding time, which can be stated as:

$$t_{ap} = \frac{[Q + 1 + i_{last} + \omega - (\omega + 1)] \times x}{a}$$

With Q for the total amount of people, x for the distance between every row and a for the average speed walking at the aisles per person, it can then be finished as:

$$t_{ap} = \frac{(Q + i_{last}) \times x}{a}$$

Next, accounting for the time for placing luggage and exchanging seats, the total time can be obtained from that:

$$T = \sum_{i=1}^{U} P_{imax} + \sum_{i=1}^{U} Y_{imax} + \frac{(Q + i_{last}) \times x}{a}$$

In which Y_{imax} means the longest time for exchanging seat when the ith group enter the plane, if there is a seat occupation, and P_{imax} means the maximum time for placing packages into the overhead bins among the group people.

Since the time each group takes, $Y_{i\max}$,depends on the process of the former group, there is an incalculable iteration during the process. The calculation for $\sum_{i=1}^{U} Y_{i\max}$ can only be realized through C++, and the code is attached to the end of the paper.

3.7 Part 2: Ideal grouping Model

3.7.1 Model Overview

In this part, we make a mathematic model to explain the mechanism when boarding a plane which helps reduce the boarding time. Compared with part 1, we assign more passengers in one group in an attempt to save time. Besides this time for sorting, it also has other elements like time for walking, putting luggage and exchanging seats.

3.6.2 Model Establishing

The total time it takes when boarding the plane can be separated into four parts for better calculation.

To begin with, we calculate the minimum time it takes to walk from the entrance to the last row:

$$(P_{min} + t_{\mathrm{w}})\ \omega$$

In which P_{min} symbolize the minimum time for placing packages into the overhead bins among all the passengers, t_{w} symbolize the time it takes walking from the entrance to the end and ω means the seats' number in rampant.

Next, the time which a vertical line of people take to put the luggage, t_l ,can be qualified in this equation:

$$t_l = P_{max} - \frac{l_{max} \times x}{a}$$

It can be obtained that P_{max} is the maximum time for placing packages into the overhead bins among all the passenger minus P_{min}, l_{max} is the furthest distance from the door among the passengers that caused the obstruction and x is for the distance between every row, a for the average speed for an ordinary people to walk at the plane aisles.

In this model, we assume that the airline put the relatively late arrivals in a certain order so as to be efficient. By careful calculation, we know that the number of people is proportional to the ranking time. And applying a famous model Bubble Sort: Compare two adjacent elements in turn, and swap them if the order is wrong (e.g. from big to small, first letter from Z to A), we stimulate the times need considering when giving place as the following equation shows:

$$t_{giving\ place} = \frac{\frac{Q}{f}(\frac{Q}{f} - 1)}{2}$$

In which Q means the total amount of people. We defined group as a phalanx about 9 to 12 vertical rows.

Therefore, with ,t1, the time for one seat exchange, we gain the formula for the time for sorting arrivals in order:

$$t_{sorting} = \frac{\frac{Q}{f}(\frac{Q}{f}-1)}{2}\mathrm{t1}$$

After that, we model the time caused by hinderance of seats and a formula can be provided as below:

$$B_k = \frac{ix}{a} + P_k + (2|j_k| - 1)Y(\frac{|j_k|}{2|j_k| - 1})^{\lambda}$$

In which B_k represents the time kth person needs for the process from his entry to his seat,P_k represents the time the kth person needs from entering the plane to seating down.

As for $\frac{ix}{a}$, it means the time the whole queue takes to get to k's seat, in which i refer to x -coordinate for the person k and x for the distance between every row and a for the average speed for an ordinary people to walk at the plane aisles.

In real life, when one's seat is occupied, some passengers must stand up and move into the aisle so other passengers can reach their seats. By enumeration, we find out that the frequency for the exchange of seats can be explained by this:

$$(2|j_k| - 1)Y(\frac{|j_k|}{2|j_k| - 1})^{\lambda}$$

In this expression, j refer to y -coordinate for the person k and Y for the time one spends when moving between seats or aisles once. We use the variable λ to classify the situations in order to adapt to different situations whether the seat is unreachable or not.

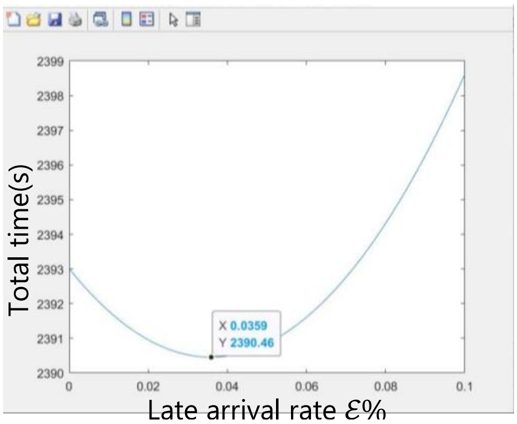
Suppose that the coordinate of the kth person is (i_k, j_k) . If $i_k = i_{k+1}$ and$|j_k| \neq |j_{k+1}|$, it can then be referred that there is more than one person who is late in this group, so λ equals 1 this time.

Under other circumstances, λ equals 0.

The total time can be calculated through this equation with $\overline{B_l}$ representing the average time wasted for one person while being late, and $\mathcal{E}\%$ for the percentage of people who didn't show up when firstly preparing for boarding.

$$t_{late} = \overline{B_l} \times \omega \times l \times s\% \times \mathcal{E}\%$$

We search for accurate data carefully and apply them to our algorithm, trying to find out the best value for $\mathcal{E}\%$ as the figure shows.



Late arrival rate and total time figure

Figure 2

It's apparent that $\mathcal{E}\%$ has its lowest time when it equals 3.59%, which we considered the best rate for late arrival rate.

Lastly, we sum up all the fragments to get T, the total time it takes for boarding:

$$T = \sum_{i=1}^{\omega}(P_{imin}+t_w + P_{imax} - \frac{l_{imax}x}{a}) + \frac{\frac{Q}{f}(\frac{Q}{f}-1)}{2}t+\overline{B_l} \times \omega l s\% \times \mathcal{E}\%$$

3.8 Part 3: Under guidance grouping Model

3.8.1 Model overview

Based on the preceded model in Part 1 and 2, we build the third model in order to qualify the minimum and maximum time when boarding the plane.

3.8.2 Model establishing

In part 2, we divide the seats into several groups to consider the minimum time when boarding the plane in the first place, and each group consists of 9 to 12 vertical lines.

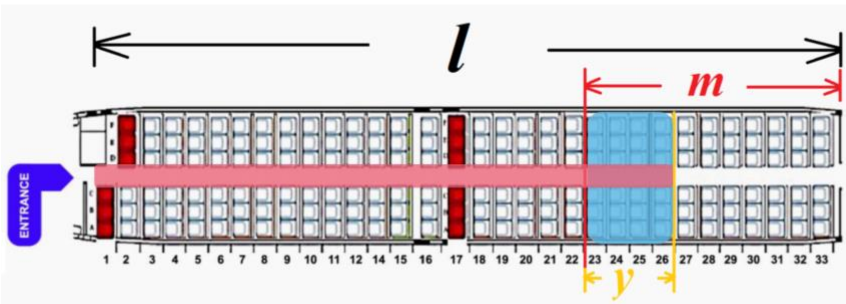
From the previous model, it can be inferred that $\frac{Qx}{a}$ is the time for the whole queue to approach their seats. And as for the rest, we assume that the following group start going once there is only one row left not being full of passengers in the previous row. In addition to this, the last group isn't suitable for the assumption, for it doesn't has a following group. So we can indicate that when using the most time-saving method, the time for luggage storage can be described as:

$$\bar{P}[n(\omega-1)+1]$$

With n on behalf of the number of groups, we add them up. Therefore, we can gain the mathematical relation as followed:

$$t_{min}=\bar{P}[n(\omega-1)+1]+\frac{Qx}{a}$$

Secondly, we try to depict the maximum time when boarding the plane. A preparation must be made before we produce the final formula. We assumed that the second group starts walking when there are y lines of vacant seats are left in the previous group.



Guidance method figure

Figure 3

Since only one person can stand in the horizontal space, we assume that the distance between two passengers in line is the distance between two rows of seats, which can be depicted as:

$$y_1\omega=l-m+y_1$$

After finishing the formula:

$$y_1=\frac{l-m}{\omega-1}$$

Similar for the second and n[th] groups:

$$y_2 = \frac{l-2m}{\omega-1}, y_n = \frac{l-nm}{\omega-1}$$

To simplify the calculation, we will use the average $\bar{y}$ to figure out the final answer.

$$\bar{y} = \frac{2l-(n+1)m}{2\omega-2}$$

In which, m represents the length of a group and ω for the total number of seats in horizontal row.

Now that we are considering the most time-consuming process, we think it the scene where the closest seat to the aisle is first occupied and second close. Using the arithmetic progression, we can know that longest time for half vertical line can be describe as:

$$t_{half} = \frac{\omega^2-4}{4} \times Y$$

In which Y refers to the time one spends when moving between seats or aisles once.

To sum up the longest time for boarding can be described as:

$$t_{max} = t_{walk} + t_l + t_{giving\ seat}$$

$$\therefore t_{max} = \left[\frac{n(m-\bar{y})x}{v} + \frac{\bar{y}x}{v}\right] + [P_{max} \times (m-\bar{y})n\omega + \bar{y}P_{max}\omega] + \left[n \times (m-\bar{y})Y \times \frac{\omega^2-4}{4} + \bar{y} \times Y\frac{\omega^2-4}{4}\right]$$

It should be noted that the last group isn't calculate the same as previous ones like the paragraphs before has explained. Therefore, they are listed individually.

$$\therefore t_{max} = (mn - \bar{y}n + \bar{y})\left(\frac{x}{v} + P_{max} \cdot \omega + \frac{\omega^2-4}{4} \cdot Y\right)$$

We have now shown the shortest time and longest time for boarding, then the total time for boarding must be in the closed range of

$$[t_{min}, t_{max}]$$

We mainly concentrate on the boarding part, on consideration that embarking the plane is just the same as boarding the plane, only in different directions and without rushing into the plane in random order for the ones who is closest to the exit are always the first to leave.

4. Model Application

4.1 Section Overview

In this section, we test our model to see its performance when facing specific situations to the standard of “narrow-body” aircraft. By comparing various boarding method, analyzing the influence of luggage amount, disruptive passengers and providing disembarking method, our model have proved to be very practical.

4.2 Part 1: Comparison between methods

4.4.1 Model Establishing

In part 1, we draw a comparison between the methods provided in Model A: Random grouping, ideal grouping, corresponding to boarding by sections, and Under guidance grouping, corresponding to boarding by seats. By using the real-life data, we gain the table as followed:

method time s%	average（70%）	5%	95%	30%	50%
Random(s)	1590.56	146.15	2054.17	616.35	1162.96
Ideal(s)	443.34	253.34	605.54	287.14	349.41
UG min(s)	357.34	25.52	484.96	153.14	255.24
max(s)	1314.61	75.41	1824.10	156.41	956.08

Comparison figure

Figure 4

In which $S\%$ means the percentage of seats already taken, and the unit for time is second. It’s apparent that the under-guidance method takes the shortest time in every situation and boarding randomly takes the longest time when $S\%$ is over 30%, which is accorded to common knowledge. The performance of boarding by sections has no distinctive features compared with the rest.

We also develop an algorithm in search of the optimal value for some of our variables:

P_{imax}	20
Y	0.5
ε	0.359
$\bar{p}$	10
$\bar{B}_i$	10

Optimal value figure

Figure 5

In which P_{max} represents maximum time for placing packages into the overhead bins in group i, Y for the time one spends when moving between seats or aisles once, $\mathcal{E}\%$ for the percentage of people who didn’t show up when firstly preparing for boarding, $\bar{p}$ for the average time for putting luggage,$\bar{B}_i$ for the average time for one person to approach his seat from the entrance.

So in terms of the "narrow body" aircraft, under-guidance model is the best choice.

4.3 Part 2: Disruptive occasions

4.3.1 Model Overview

In view of Model A, we make our model more suitable to real life by taking disruptive passengers who break the rules into account and provide a general formula for that.

4.3.2 Model Establishing

In part 2, we assumed that there is no passenger who mean to disobey the rules on the plane or deliberately aim at causing troubles. But there are some who break the rules on purpose. To say in other words, their actions are reasonable and acceptable, however, not following the guidance.

A typical example is when a mother is travelling with her only child, she wants to look after him so she stands behind him in line. However, the positions of their seats have made it clear that they ought not to stay close in line. (Perhaps their seats are next to each other when the rule is allowing passengers board in the order of horizontal line, or perhaps they are not sorted in the same group when passengers board in certain groups…)

Therefore, if the mother insists to stand behind her child, which most will do, she has undoubtedly broken the rules, though not intentionally. The influence of this can be noticed in this group, which the kid supposes to be in, that all of the passengers has one position backward. It can then be inferred that more time has been taken when one cut in line, and the time for which is P_{imax}.

In conclusion, the additional time it spends depends on the number of disruptive passengers b and P_{imax}:

$$T = bP_{imax}$$

4.4 Part 3: Effect of luggage and disruptive passengers

4.4.1 Model Overview

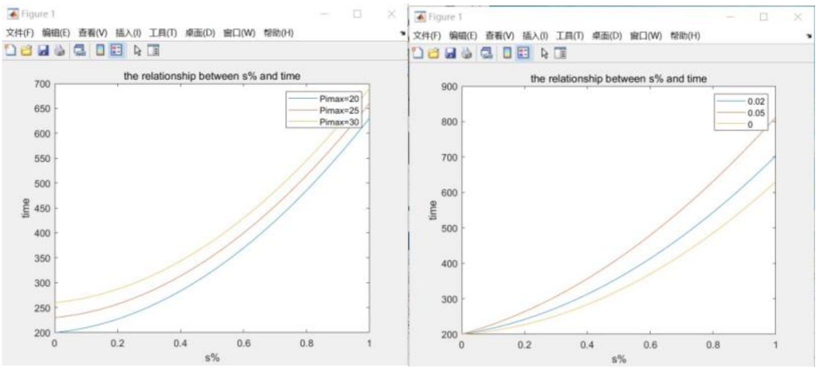
In this part, we aim at finding the best solution the percentage of passengers not following the prescribed boarding method and on the average number of carry-on bags per flight and results of various situations.

4.4.2 Model Establishing

Verbal statements are no guarantee, so we use Python to help analyze our models, using the random section in which to set a number of random orders to the passengers. At the same time, the position of them hasn't changed a bit.

For the figure on the left, we change the amount of luggage to search for the relationship between $S\%$,the percentage of seats already taken, and the total time. The blue curve represents the origin time without any changes. By comparison with the yellow one and the red one, we can tell that with the increase of luggage and $S\%$, the total time for putting luggage

P_{imax} will increase. In addition to that, we can tell from the figure that the bigger $S\%$, the faster P_{imax} grows.



Effecting factors figure

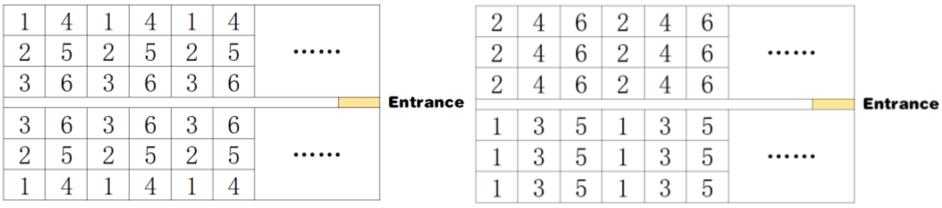
Figure 6

For the figure on the right, the percentage of disruptive passengers is altered randomly by Python. Therefore, we can be informed that the more the disruptive are, the more time it consumes. In addition to that P_{imax} grows faster when there are more people seated.

Since our model changes while the number of disruptive passengers and luggage amount alter, our method need the cooperation from passengers.

4.5 Part 4: Additional models

We think of two additional models in part 4. The first one follows the rule that passengers walk to the seats according to the size of numbers. (Left figure) For example, all the ones hold number 1 are those enter in priority, then 2,3,4…



Additional models figure

Figure 7

The other model is the right one, which passengers enter in the order from number1 to 6. The difference between the two of them is that when following the first model there isn't much hinderance when putting the luggage as the second one, for less people are in the same line.

By making a comparison among all the models, we find out that both of them are not capable as the previous three.

4.6 Part 5: Optimal choice for disembarking

4.6.1 Model Overview

In part 5, we view the problem from two perspectives in order to make an optimal choice when disembarking.

4.6.2 Model Establishing

The first model can be applied to a situation where the airline instructs the passengers in a vertical line. Therefore, the total time T will be the sum of picking up luggage and the walking through the aisles:

$$T = \sum_{i=1}^{\omega} P_{imax} + \frac{lx}{a} \times \omega$$

In which, P_{imax} refers to the longest getting luggage time in group i, and $\frac{lx}{a} \times \omega$ for the time the whole queue walks to disembark, which has been explained in our previous models.

The second scene is where passengers disembark in a certain group. Its mechanism is similar to our *Under Guidance model* in Model A, which can be stated as:

$$t_{min} = \bar{P}[n(\omega - 1) + 1] + \frac{Qx}{a}$$

In which, n represents the time one spends when moving between seats or aisles once, and Q for the total amount of people, and ω for the total number of seats in horizontal row.

5. Model for other aircrafts

5.1 Model overview

Based on the type of “narrow-body” aircraft and the “flying-wing” and “two-entrance” aircrafts, we design some unique ways for entering

5.4 Model Establishing

As the figures show, we divide the aircraft into several parts according to the position of their seats. Suppose that all the seat has its optimal entrance and aisle, which we mainly assess from the distance.

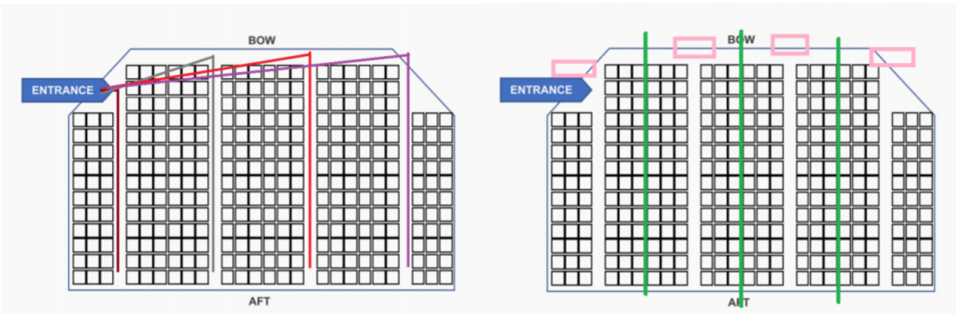
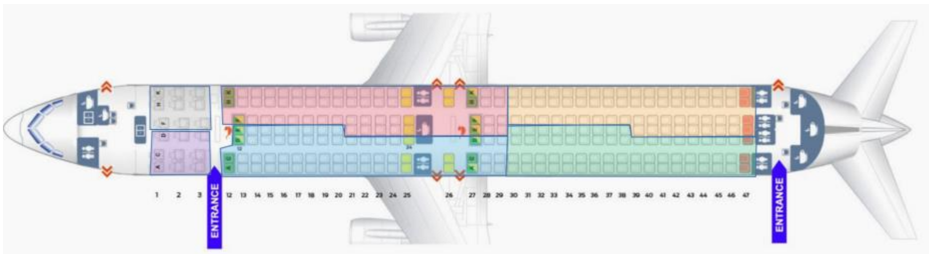


Figure 2. “Flying Wing” Passenger Aircraft **Figure 2.** “Flying Wing” Passenger Aircraft

Grouping strategy figure

Figure 8&9



After splitting the aircraft, it is as if all parts have a new entrance, and the pink boxes in figure 8 means the “invisible entrance”, we can then use our previous models to solve the problem.

As for figure 9, there are two entrances and two aisles in this aircraft. Since we want to distribute the aisles and doors as evenly as possible, we cut it into such sections based on the idea of equivalence, which means that people in this column will be seated in half a row. That is to say, half will be seated from the left, and the other from the right. It may be better to drawn in zigzag, but the effect is actually the same as the one shown in the picture.

The following figure demonstrate the performance of our models on various situations.

Detailed analyses will be shown in the next part.

title	figure8	figure8	figure9	figure9
s%	figure8	figure8	grey/purple part	red/blue/green/yellow
number of seats	75.00	84.00	9.00	54.00
number of people	52.00	58.00	9.00	37.00
row number	14.00	14.00	3.00	18.00
column number	6.00	6.00	3.00	5.00
Number of random grouping	30.00	33.00	5.00	19.00
time for seat changes	62.00	64.00	6.00	12.00
random	668.60	734.71	110.73	426.22
	734.71		426.22	
IS	200.20	208.98	67.56	164.03
	208.98		164.03	
UG min	159.53	165.25	38.57	125.24
	165.25		125.24	
max	515.02	574.44	93.61	360.77
	574.44		360.77	

Grouping result figure

Figure 10

6. Suggestions according to pandemic situations

6.1 Suggestions

Since we are all experiencing the period of pandemic, we assess our model to make it available to the current situation.

After careful analysis, we get the conclusion that:

When the full occupancy rate of the aircraft *S*% is 70%, we recommend boarding by seat or boarding by section for “Flying Wing” Passenger Aircraft and “Two-Entrance, Two Aisle” Passenger Aircraft.

When *S*% is 50%, we recommend boarding by section for “Flying Wing” and boarding by seat for “Two-Entrance, Two Aisle”.

When *S*% is 30%, we recommend Random boarding for “Two-Entrance, Two Aisle” and boarding by section for “Flying Wing”.

7. Strengths and Weaknesses

7.1 Strengths

1. Universality

After doing some preconditioning in advance, our model can be applied to every kind of plane, for we use the split method which enables each divided part to be equivalent to a one-door-one-section situation. From our perspective, this method is really creative and valid.

2. Validity

By applying the random passenger boarding order to our model(which is generated with Python's random module),we obtain some satisfied boarding time. Some of them match the ordinary data and others are relatively time-efficient, whose results show of our model and the efficient of our designed guidance.

3. Transparency

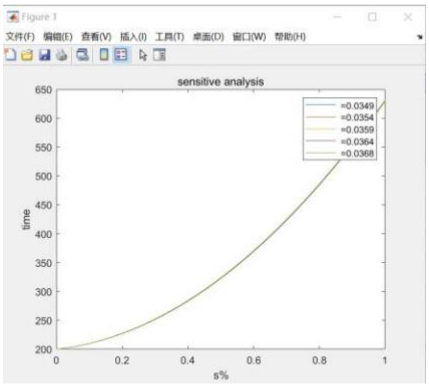
We set a lot of variables in the model so that the airline company only need to input the data when applying our models. After this simple action, they will receive every detail about the boarding time and the suggestions among three methods.Therefore,there is no unreasonable calculation during our model application and the working process is entirely transparent.

7.2 Weaknesses

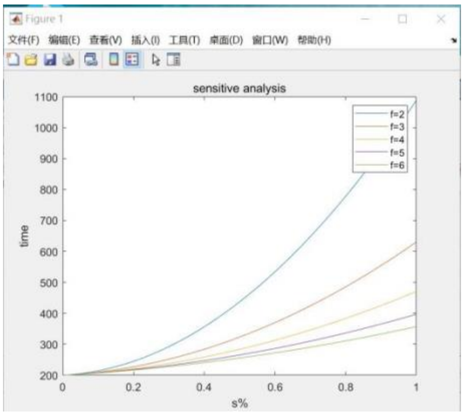
1. Result-illegibility

Since a part of our calculation is accomplished by algorithm instead of function and the program has its limitation, we fail to draw the final figure about "Boarding Time and Aircraft Occupancy Rate" of the three boarding methods, though we hope to in the first place. Therefore, the most time-saving plan in every occupancy rate will be the final suggestion to the airline company. As the foregoing reason shows, the figure is not successfully drawn, but the our suggestions are still very scientific and reasonable.

8. Sensitive Analysis



(not that sensitive) We can see that the proportion of people ordered in the second time(ε%) has little to do with the time. Therefore, as an airline company, when choosing the right proportion of people to order them in the second time, all you should do is to calculate a right range for ε% instead of a precise figure.



(sensitive)

We can see from the picture that time is very sensitive to the number of windows that allow a sequence of people to place in order. The airline should carefully think about how many windows they should set. Through finding the right balance between the efficiency brought by more windows and the more money caused by it, the company is able to get the highest profit.

A Letter to the airline executive

Dear airline executive:

We feel most honored to be invited to device an effective assessment tool for the boarding and disembarking process of airline. To our knowledge, the time spends for boarding and disembarking is very valuable for all the passengers and to an extent affect the satisfaction of the flight and your service, which is essential to the company as well. However, successful grouping before boarding can eliminate the unnecessary loss caused by disarray.

We employed mathematical modelling and finally get the optimal solution for different kinds of flight. Since we are experiencing the pandemic, the occupancy rates are varied to make it more practical.

Here are some of our advice we find during the process which we think it valuable for you.

- **Give clear order to the passengers and avoid bringing numbers of packages**, for fear that disruptive passengers will cut in line and ignore the grouping regulation, which leads to more timing cost. The limitation for the number of luggage is for the reason that the frequency one puts up his luggage has a direct impact on total time.
- **For the aircrafts like "Narrow-body",** the method that suggest entering/disembarking in the form of groups which consists of 9 to 12 columns is recommended in all kinds of situations because it has a long aisle, while boarding by seat is favorable when occupancy rates is 50% to 70%.
- **For the aircrafts like "flying wings":** In response to this many-aisles one-door aircraft, we proposed the idea as grouping at the same time in order to minimize the time. Boarding by section when over 50% occupancy and random boarding when 30%are the additional tips, for which there isn't much difference when few passengers are boarding.
- **For the aircrafts like " Two-Entrance, Two Aisle":** Similar to the previous aircraft, we consider it better to board by seat when half of the seats are occupied for it has two entrances and long aisles, that make it possible for the queue to walk faster. For the rest 30% situation, we strongly suggest random as a better choice.

We hope that our models can do our modest bit in the future development of your airline, and we wish there won't be any loss caused by boarding and disembarking time as they already have.

Yours sincerely
Team IMMC22208463
March 14^{th} ,2022

Appendix

1. Algorithm for calculating the sum of Y_{imax} in the random model

```
/*explanation:
 if you input rows number,column number,passenger number,
 as well as the specific information of each passenger,
 including row number,column number and the time needed
 to put their luggage.
 you would get the time by which people need to exchange.
 */
#include<bits/stdc++.h>
using namespace std;
struct computer{
 int i,j;//目标座位的排数和列数
};
int main(){
 int w,l,n,tim=0;//w排数，l列数(包含走道)，n总乘客数 ,tim为交换次数
 bool pos[100][100];//判断函数=1->有人：=0->无人 ,例：i为1-33，j为1-6
 computer cus[300];
 cin>>w>>l>>n;
 int lmid=(l+1)/2;
 for(int k=1;k<=n;k++)
  cin>>cus[k].i>>cus[k].j;
 int h=1,h_pose=0;
 cus[n+1].i=0;
 while(h<=n){
  if(cus[h].i>cus[h+1].i||cus[h].i==cus[h+1].i){
   int chanmax=0;//每组交换的最大次数
   for(int x=h_pose+1;x<=h;x++){
    int timeach=0;
    if(cus[x].j<lmid)
     for(int y=cus[x].j;y<lmid;y++)
      if(pos[cus[x].i][y]==1)
       timeach++;
    if(cus[x].j>lmid)
     for(int y=lmid;y<cus[x].j;y++)
```

```
    if(pos[cus[x].i][y]==1)
     timeach++;
   if(timeach!=0)
   timeach=2*timeach+1;
   if(timeach>chanmax)
   chanmax=timeach;
   h_pose=h;
   pos[cus[x].i][cus[x].j]=1;
  }
  tim+=chanmax;
 }
 h++;
}
cout<<tim;
return 0;
```

2. Aircraft types

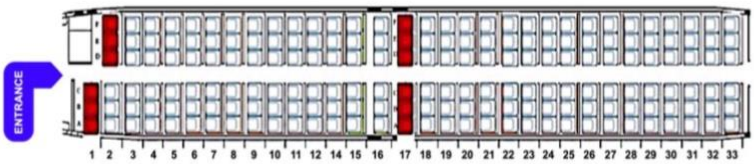


Figure 1. "Narrow-Body" Passenger Aircraft

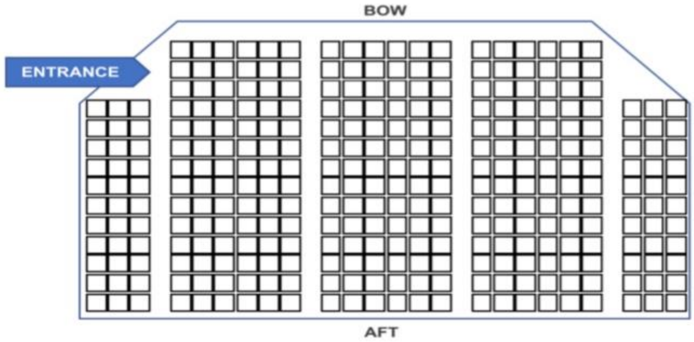


Figure 2. "Flying Wing" Passenger Aircraft

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

References

[1]https://gimg2.baidu.com/image_search/src=http%3A%2F%2Fimg.mp.itc.cn%2Fupload%2F20170109%2F901de7d18b4843bdb8f6480402b87efe_th.jpeg&refer=http%3A%2F%2Fimg.mp.itc.cn&app=2002&size=f9999,10000&q=a80&n=0&g=0n&fmt=jpeg?sec=1649505183&t=08d21d7dfbc525a071c5d879f11eb2e3