Aircraft Boarding Strategy

-Simulation Study

August 25, 2019

Abstract

Airlines make revenue by running as more times of flight as they can. Minimizing boarding time effectively reduce the turnaround time, so that the airlines are able to schedule more rounds of flight for the short and middle distance trips. Plenty of boarding strategies have been implemented into daily operation by airlines. Unfortunately, none of them is a perfect plan to every airline since different airlines are stick to their own aim and company culture. However, the two strategies that currently popularized are back-to-front and outside-in strategy. In this project, we attempt to find the optimal method of grouping to minimize the passenger's boarding time via simulating the boarding process. Also, at the end of this paper, we will discuss our proposed alternative boarding strategy as well as the future concern that should be further studied.

Contents

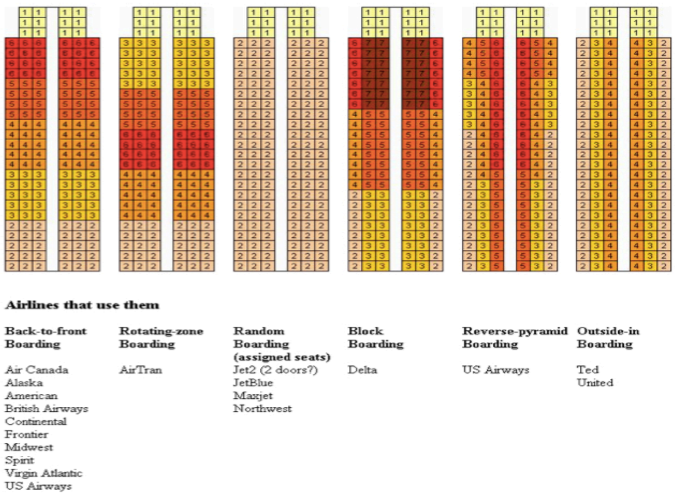
1 Introduction

1.1 Motivation

Flight technology has been well rounded developed since the glider flown by Orville and Wilbur in the fall 1903. Unlike the flight-developing sophistication, the passenger boarding system is still under development. Airline profits its revenue only during the airplanes in operation. Boarding time not only determines the airlines productivity, but also profoundly affects passenger satisfaction. The extended boarding time considerably lessen the passenger's perception of airlines service quality and markedly prolong the airplane turnaround time.

1.2 Boarding Strategies

Different boarding strategies have already been implemented by different airlines in order to minimize the boarding time, for example, back-to-front, outside-in, reverse pyramid, rotating zone and block boarding strategy. In this project, we will focus on the back-to-front and outside-in strategies. For back-to-front strategy, as shown in the left-most in the picture below, first-class passengers are the first group to enter the craft and then the remaining passengers enter in the back-to-front order. For outside-in strategy, the passengers are divided into four groups in order: the first-class, the window seats, middle seats and the aisle seats. For each boarding strategy, the boarding time may vary by different number of groups. Passengers are divided into groups in order to reduce the time obstructed in the aisle; however, if the passengers are over-grouped, passengers will be more easily blocked. We consider an extreme example, if the passengers are divided in 30 groups, one group each row and six passengers, but only two passengers can stow their luggage at the same time, so all the other four passengers have to wait until the first two finish stowing their luggage. In this sense, if the passengers are divided into too many groups, they will also be obstructed and waste time. Thus, in our project, we will find the optimal number of groups that can minimize the boarding time for back-to-front and outside-in strategies. Also, we will try to propose the alternative boarding strategy in attempt to improve the flight boarding technique.



1.3 Interference

Boarding interferences occur when a passenger blocks another passenger to proceed to his or her seat. There will be two kinds to interferences that could occur during the boarding process, aisle interference and seat interference. Aisle interference occurs when a passenger is occupying a row and the passengers behind him have to wait until to row is vacant. For example, if someone is stowing his/her luggage, the passengers behind him/her have to wait until he/she finishes the activity. This considerably increases the boarding time. And another inference occurs when a passenger is seated between the assigned seat. This is what is called seat interference.

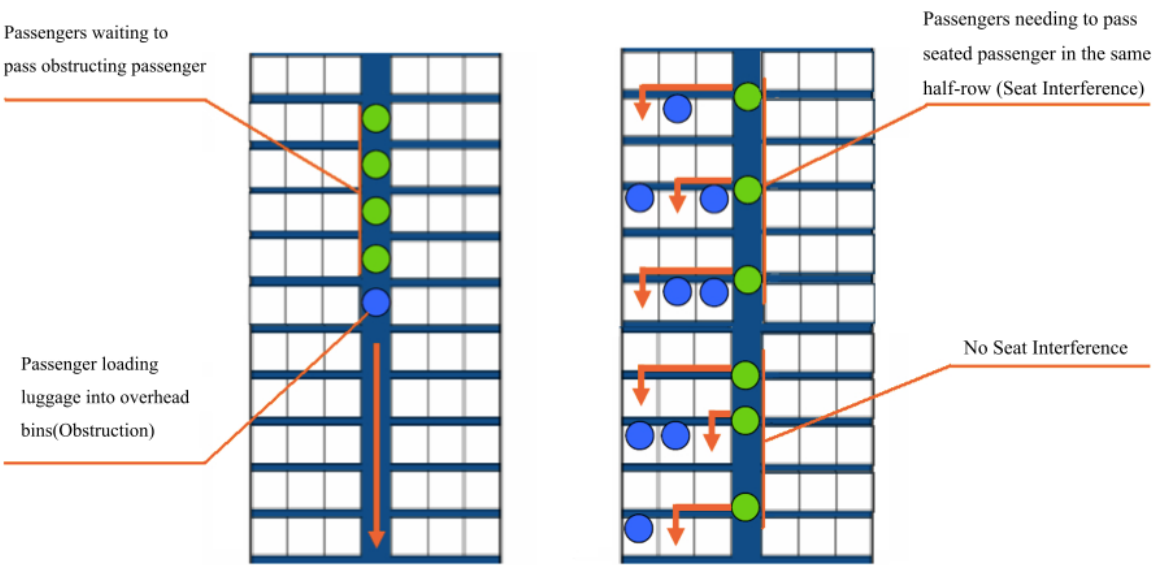
For aisle interference, as the picture below on the left, the blue passenger is stow his/her luggage, stopping in the middle of the aisle and blocking all the green obstructed passengers behind him.

For seat interference, as shown in the picture on the right, there are mainly three cases may be taken into consideration.

Case1: assume a passenger is seated in seat aisle seat in row 6 (6C). When the passenger with window(6A) or middle seat(6B) in row 6 boards the aircraft, passenger 6C must stand up, get out of his/her seat to allow passenger 6A or6B access and then sit back again to their seats.

Case2: assume a passenger is seated in seat middle in row 7(7B). When the passenger with seat window seat in row 7(7A) boards the aircraft, passenger 7B must stand up, get out of his/her seat to allow passenger 7A access and then he can sit back to his seat again.

Case3: If passengers 8B and 8C are already seated, but 8A arrives later. Then both of 8B and 8 C have to stand up, get out of their seats to let 8A access and then sit back again.



2 Assumption and Boarding Model

2.1 Assumptions

- People have the same walking speed.
- People have the same occupied length in the aisle.
- During the boarding process, people would only wait for others putting baggage in to cabin or seat for others.

2.2 The Boarding Model

To analyze for a single person's boarding process, we could figure out that the person is whether walking to his seat or waiting for others who block the aisle. To simulate the entire boarding process, we need to deal with all the people's walking time and waiting time.

However, people's speeds are constant and the same, therefore, we can split all people's total time boarding into two part: walking time and waiting time. Under ideal model – people don't wait, the total boarding time is the walking time of the last person from start to he sit down. Under this assumption, we can simulate the process by just computing all the people's unique waiting time and the last person's total walking time.

As several people might wait at the same time, hence, we need to look for a method to reduce the repeating time recorded. Vector seems to be good for our simulation. We use a vector long enough to record our total boarding time, the nth position represents the nth second after start. When people stop, we change the value of that second from 0 to be 1 in our time recording vector. And after our entire simulation process, the non-zero vector length is our total unique waiting time.

To be more specific about the waiting time, we assume people have a probability of 0.8 to bring baggage and putting baggage costs everyone 30 seconds. Furthermore, if the passenger are at window and the passenger in the middle and the passenger at aisle have already seated, it would cost people in the aisle 5 seconds; if the passenger at aisle hasn't seated, it would cost people in the aisle 4 seconds; if the passenger in the middle hasn't seated, it would cost people in the aisle 3 seconds. And if the passenger is seating in the middle, he will block others for 3 seconds if the passenger at aisle has seated. Otherwise, seating wouldn't affect the boarding time.

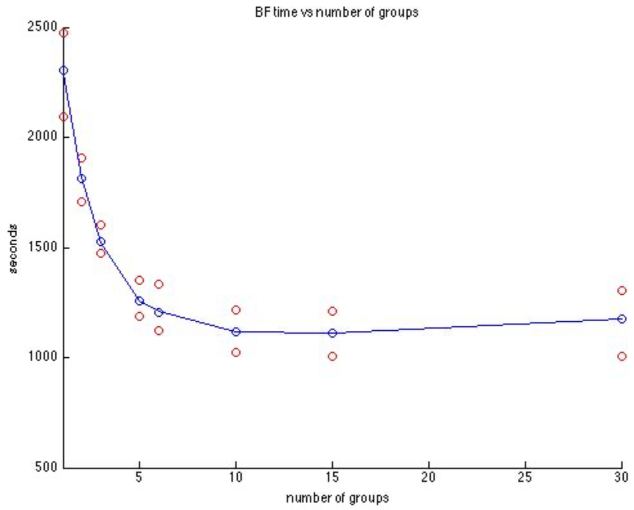
By adding the total waiting time and the total walking time, we could get the total time for boarding, this is the base of our simulation. Afterwards, we consider Back to Front and Outside In methods, also with concern of first class boarding. They can all be simulated by our simulation base with a little further edition.

3 Result and analysis

We simulate the boarding process using Back-To-Front Strategy and Outside-In Strategy, and for each method we find the relationships between the boarding time and the two main influencing factor --- number group assigned and number of passengers. Here are the results we get:

3.1 Back-To-Front

3.1.1 Time vs. number of groups (under 100 simulations)




```
>> BackToFront
N=1 n=180 average=2303.69=38min23.69sec Tmax=2471 Tmin=2094
N=2 n=180 average=1814.59=30min14.59sec Tmax=1904 Tmin=1709
N=3 n=180 average=1526.78=25min26.78sec Tmax=1601 Tmin=1473
N=5 n=180 average=1259.55=20min59.55sec Tmax=1348 Tmin=1187
N=6 n=180 average=1206.23=20min6.23sec Tmax=1335 Tmin=1124
N=10 n=180 average=1117.2=18min37.2sec Tmax=1214 Tmin=1026
N=15 n=180 average=1108.51=18min28.51sec Tmax=1210 Tmin=1007
N=30 n=180 average=1172.65=19min32.65sec Tmax=1302 Tmin=1004

p =

   1.0e+03 *

   -0.0000    0.0006   -0.0153    0.1679   -0.8863    3.0346
```

First, we focus on the case when there are 180 passengers since it is a typical number of passengers for a small size plane. We divide the passengers into 1,2,3,5,6,10,15 and 30 groups respectively (the reason we choose these numbers is that we want the number of rows of each group is an integer), and then do the simulations. As we can see from the graph and the result outputs, when n =180, if we divide people into 10 or 15 groups (besides first class), the boarding time is minimized as around 18 min 30 sec. Actually, we also test for numbers between 10 to 15 and 20 groups as well, and find the optimal number of groups to minimize the boarding time is actually around 12, but there just have a few second differences. Since less is better (due to customer's satisfaction index), we just say the optimal number of groups is 10 (besides first class).

In order to evaluate each option later, we calculate the maximum boarding time and minimum boarding time among 100 simulations for each case as well. They are shown as the red circles on the plot.

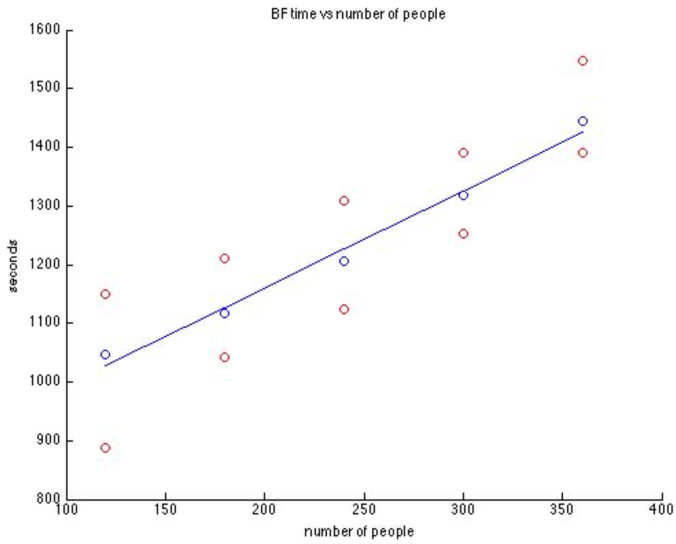
Since our simulations can just test for numbers of groups with integer row numbers for each group (N = 1,2,3,5,6,10,15), we try to find a formula to estimate the boarding time for any number of groups. We then do the non-linear regression for our original plot and find our experimental model formula for 180 passengers as:

$$T = \varepsilon N^5 + 0.6N^4 - 15.3N^3 + 167.9N^2 - 886.3N + 3034.6$$

where N is the number of groups, ε is a very small positive number and T is the total boarding time.

3.1.2 Time vs. number of people (under 100 simulations)

After we got the result above, we want to know if we set the number of groups as N =10, how the boarding time changes with the change of the number of total passengers.

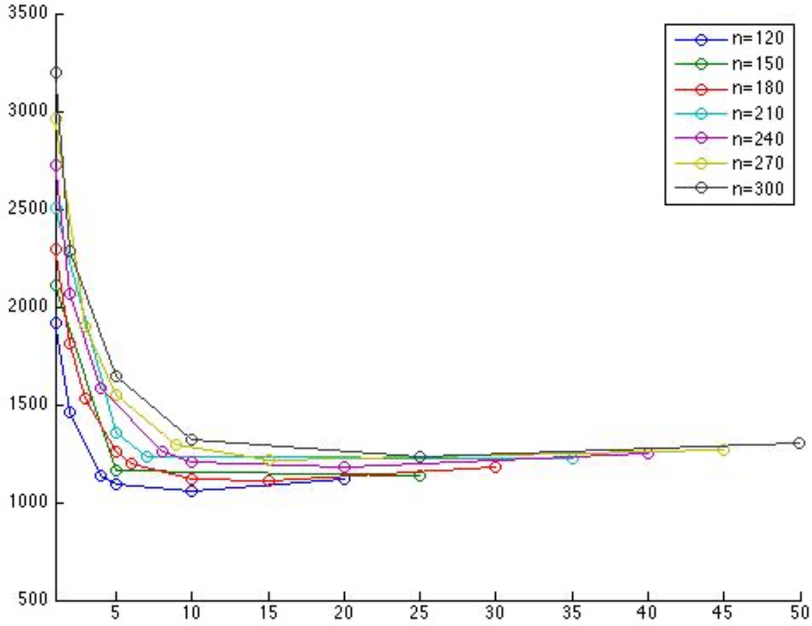



```
>> BackToFront2
N=10 n=120 average=1045.97=17min25.97sec Tmax=1150 Tmin=888
N=10 n=180 average=1117.3=18min37.3sec Tmax=1210 Tmin=1043
N=10 n=240 average=1205.68=20min5.68sec Tmax=1308 Tmin=1125
N=10 n=300 average=1318.96=21min58.96sec Tmax=1390 Tmin=1252
N=10 n=360 average=1443.37=24min3.37sec Tmax=1547 Tmin=1390

p =

    1.6608   827.6720
```

As expected, there's a positive linear relationship between the boarding time and number of people. We now get that when there are n = 120 passengers and N = 10 groups, we should get the minimum boarding time (around 17min 26sec) under Back-To-Front model.

3.1.3 Time vs. number of groups vs. number of people

In order to confirm our result from above, we combine the influencing factors together and plot the boarding time for different number of passengers with different numbers of groups.



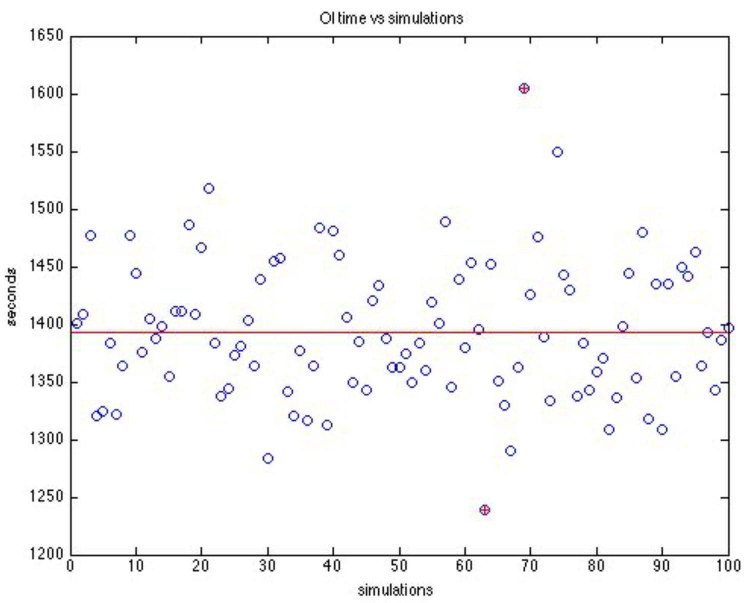

```
>> BankToFront3
N=1 n=120 average=1919.11=31min59.11sec
N=2 n=120 average=1457.4=24min17.4sec
N=4 n=120 average=1134.93=18min54.93sec
N=5 n=120 average=1090.4=18min10.4sec
N=10 n=120 average=1060.23=17min40.23sec
N=20 n=120 average=1117.13=18min37.13sec

N=1 n=150 average=2106.17=35min6.17sec
N=5 n=150 average=1166.59=19min26.59sec
N=25 n=150 average=1135.9=18min55.9sec

N=1 n=180 average=2293.97=38min13.97sec
N=2 n=180 average=1811.21=30min11.21sec
N=3 n=180 average=1529.32=25min29.32sec
N=5 n=180 average=1261.43=21min1.43sec
N=6 n=180 average=1201.16=20min1.16sec
N=10 n=180 average=1119.83=18min39.83sec
N=15 n=180 average=1113.07=18min33.07sec
N=30 n=180 average=1184.02=19min44.02sec

N=1 n=210 average=2501.53=41min41.53sec
N=5 n=210 average=1355.56=22min35.56sec
N=7 n=210 average=1231.14=20min31.14sec
N=35 n=210 average=1223.21=20min23.21sec

N=1 n=240 average=2724.66=45min24.66sec
N=2 n=240 average=2067.41=34min27.41sec
N=4 n=240 average=1585.4=26min25.4sec
N=8 n=240 average=1256.53=20min56.53sec
N=10 n=240 average=1203.86=20min3.86sec
N=20 n=240 average=1180.78=19min40.78sec
N=40 n=240 average=1247.84=20min47.84sec

N=1 n=270 average=2960.98=49min20.98sec
N=3 n=270 average=1896.93=31min36.93sec
N=5 n=270 average=1546.96=25min46.96sec
N=9 n=270 average=1289.61=21min29.61sec
N=15 n=270 average=1213.06=20min13.06sec
N=45 n=270 average=1270.11=21min10.11sec

N=1 n=300 average=3193.05=53min13.05sec
N=2 n=300 average=2284.2=38min4.2sec
N=5 n=300 average=1647.64=27min27.64sec
N=10 n=300 average=1316.85=21min56.85sec
N=25 n=300 average=1231.28=20min31.28sec
N=50 n=300 average=1302.35=21min42.35sec
```

Seen from the graph, we find the lowest point occurs when n = 120 and N = 10 as 17min 40 sec., which means the boarding time is minimized when the total passengers is 120 and divide them into 10 groups, verifying our previous result.

3.2 Outside-In:

For the Outside-In Strategy, since it only divides passenger into 3 groups besides first class, we first finds the average boarding time for 180 passengers and then, as done above, find how the boarding time relates to the change of number of total passengers.

3.2.1 Time vs. simulations

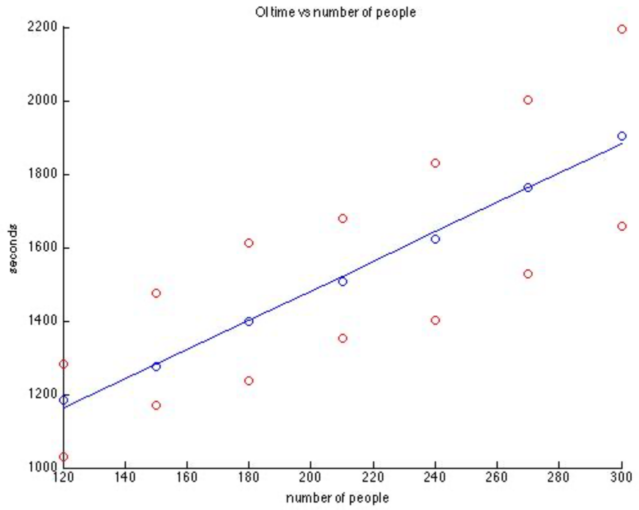



```
>> OutsideIn
N=3 n=180 average=1393.28=23min13.28sec Tmax=1605 Tmin=1239
```

Here, we just plot the data point got from each simulation with the estimated time as y axis. The red ones there are Tmax and Tmin among these 100 simulations and the average time is about 23 min 13 sec..

3.2.2 Time vs. number of people

Then we change the number of passengers and see how the boarding time changes.




```
>> OutsideIn2
N=3 n=120 average=1182.83=19min42.83sec Tmax=1281 Tmin=1031
N=3 n=150 average=1275.23=21min15.23sec Tmax=1474 Tmin=1170
N=3 n=180 average=1397.14=23min17.14sec Tmax=1612 Tmin=1238
N=3 n=210 average=1507.96=25min7.96sec Tmax=1678 Tmin=1352
N=3 n=240 average=1622.39=27min2.39sec Tmax=1830 Tmin=1403
N=3 n=270 average=1764.82=29min24.82sec Tmax=2000 Tmin=1529
N=3 n=300 average=1904.09=31min44.09sec Tmax=2196 Tmin=1658

p =

    4.0098   680.0132
```

As expected, and the same with BTF strategy, there's a positive linear relationship between the number of passengers and the boarding time. The minimum boarding time occurs when n = 120, N =3 as 19 min 42 sec.

3.3 Comparison

So far, we have done the simulations of Back-To-Front (BF) and Outside-In (OI) Method and now we need to compare their result:

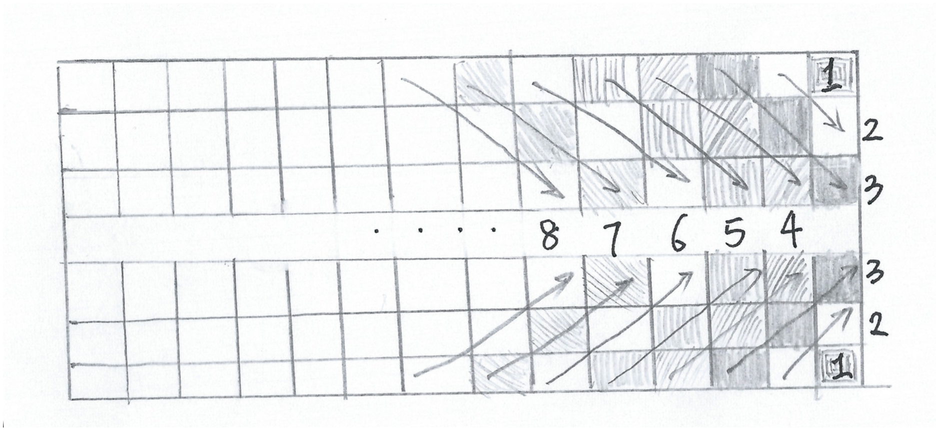
- OI:
- n = 180, N =3, T_{OI} = 23 min 13 sec
- BF:
- n = 180, N =3, T_{BF} = 25 min 26 sec
- n = 180, N = 10, T = 18 min 27 sec

As shown, under the same n,N, T_{OI} = 23min13sec., which is a little bit faster than T_{BF} = 25 min 26sec., but basically there's no significant difference . But the OI strategy is significant slow when compare to the best result under BF strategy: n = 180, N = 10, T = 18 min 27 sec. But since OI has the limitation that can just have 3 groups, we can not increase its group numbers and see how it goes. So this triggers us to find a new method to break this limitations.

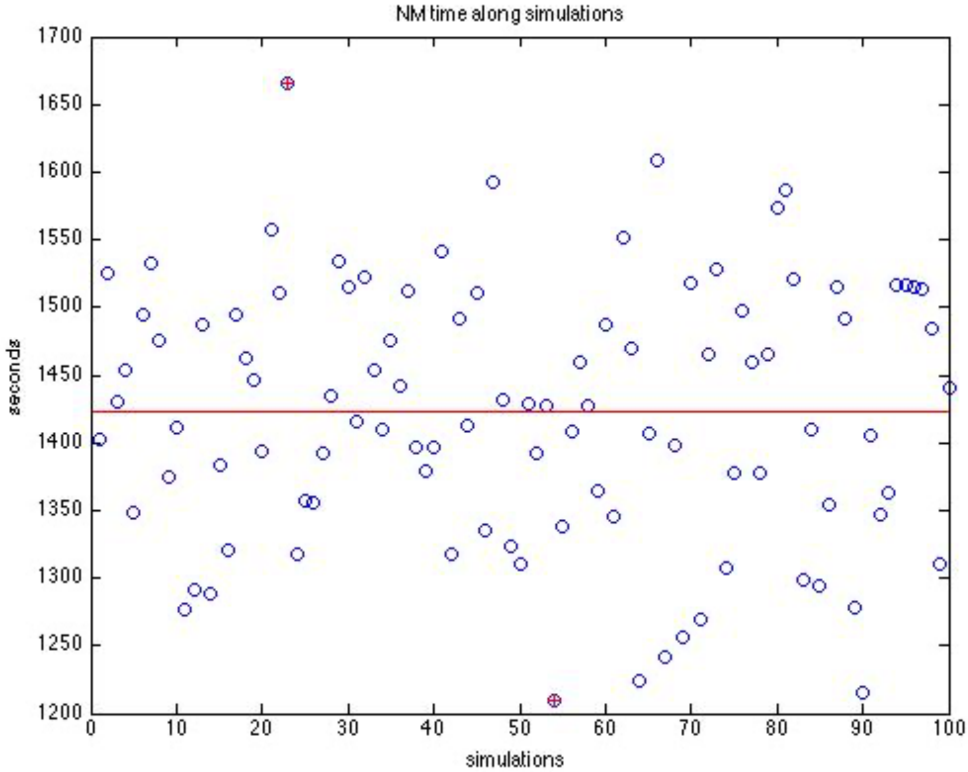
4 Alternative Strategy

4.1 *First Attempt*

Basically, our primary thought is to increase the number of groups based on the Outside-In Method and our goal is gong to eliminates the seat interference and also reduce the bagging interference. The arrangement of groups is as below:



We think this strategy must be the best one cuz it eliminate the interferences as many as possible.

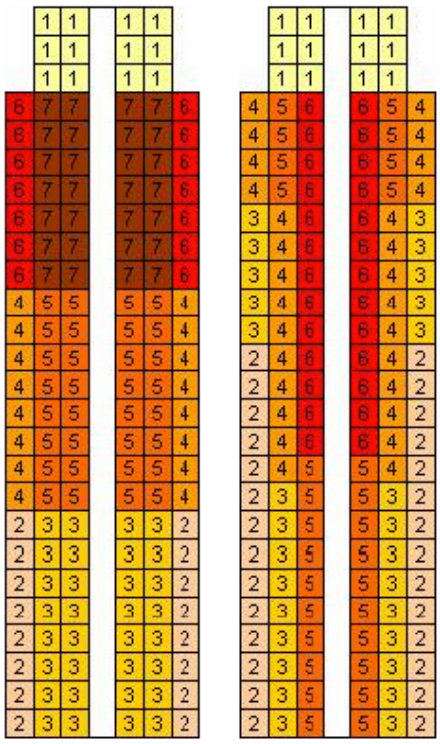



```
>> NewMethod
N=30 n=180 average=1422.7=23min42.7sec Tmax=1665 Tmin=1210
```

However, we found the come out is almost the same with the OI strategy with n =180.The average time is around 23min. Then we find out actually they all eliminates the seating interference but the bagging interference is random and they should have almost the same performance, which cause their result coming out really similar. We can only admit that our new method fails!

4.2 Other thoughts

We then think more about the combination of BF and OI, but find out it's actually the same with The block boarding or more 'scientific' one—reverse pyramid boarding. We didn't simulate these two methods, but we believe they must have really good result, not like our strategy.



Block Boarding

Delta

Reverse-pyramid Boarding

US Airways

4.3 Further works

4.3.1 Given the number of total passengers (which is fixed by the size of the plane), an airline company need to consider three aspects to decide strategies and how to assign groups:

(i) Satisfaction index: with so many groups, custom are tired to follow instruction and line up in order before boarding; relate with the reviews and ratings of the airline from customer; have further influence on the future career of the airline company.

(ii) Average Boarding Time: the most important elements need to be considered; relate directly with the profit of the airline company.

(iii) Maximum boarding time and minimum boarding time (Tmax and Tmin):It corresponds to the efficiency of the strategy itself and test whether this strategy is steady or not.

In our model, we didn't consider passenger's feeling. We just solve the problem mathematically, and that's why we got the minimize group around 10 to 15, but we rarely see this assign strategy in reality. The airlines need to consider whether customers are willing to be instructed and line up as told. It's really annoying if we are told to be at group 9 or 10, and I need to wait for my groups to board.

4.3.2 We made a lot of assumptions and we idealize the reality, so we got pretty good result, the best is 17 min and most of the result around 20min, faster than any experience we had. We think that's because we ignore the complexities such as: change seat, special need, early/late arrival, old/children, all of which will extend the boarding time.

4.3.3 Other complexities need to be consider to improve our model:

--- When we have a bigger plane, it always means the travel distance is longer and so people will carry more and bigger bags. Also when the plane is bigger, the number of total passengers increases, and there are surely more bags on board.

--- walking velocity of passengers is inversely proportional to the number of bags one has

...

With all these complexities considered and added into our model, the simulation result will become more close to the reality. Due to our limitation of abilities, we hope we can improve our model in the near future.

5 Reference

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