

Research Article

Intelligent Boarding Modelling and Evaluation: A Simulation-Based Approach

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The boarding efficiency is essential for all airlines due to potential competitive financial pressure. Therefore, the turnaround time needs to be cut down for a shorter boarding time. The paper devised a feasible boarding strategy which combines the management mode decision of passenger boarding with the intelligent deployment of the operation process and will be likely to improve the efficiency of the passenger travel chain. Among which, to decrease the boarding time is an effective method. Firstly, we proposed an improved outside-in strategy, which costs shorter boarding time based on the existing outside-in strategy. However, this method requires passengers to stand in queue in advance. Secondly, we put forward a deterministic queue-ordered boarding method to improve it. Finally, we simulated and applied the strategy to a narrow-body aircraft A320 and a wide-body A380, both representative for their type of airplanes. It turns out that this strategy performs better than the current widely used method and will be able to increase boarding efficiency and thus maximize the profits of airlines.

1. Introduction

Nowadays, the aircrafts try to fly at full capacity as much as possible. Time is precious in the real world for both passengers and airlines. Hence, turnaround time [1], namely, time that an aircraft stays on the ground between flights, needs to be cut down. It is more important in wide-body aircrafts [2]. A reduction in total boarding time can result in significant benefits for the aircraft industry. To reduce the idle time of aircrafts, optimizations can start at any point between arrival and departure [3]. Among all the factors, the boarding time plays an important part in the turnaround time [4]. The aisle of the plane is relatively narrow, and the passengers often carry luggage, which makes it difficult to pass, adding up to the total waiting time. The boarding time is critical because it affects the aircrafts' efficiency and the passenger satisfaction and safety [5].

Bottleneck interference during boarding is the cause of flight delay and increased turnaround time. The main

bottlenecks during check-in include hand luggage and passengers' insufficient preparation for check-in [6]. New solutions are put forward to solve the bottleneck of the process, especially for the wide-body aircrafts [7]. The ideology of the solutions is to eliminate the interferences between the passengers as much as possible, mainly the aisle interference and the seat interference. In order to attain this target, passengers are often divided into groups before they enter the aircraft group by group. In other words, we can increase the efficiency by devising the feasible method of dividing [8].

For aircrafts where the boarding door is in the front, boarding by the class or aircraft section leads to congestion. The inefficiencies in this procedure are obvious to all. However, how do the passengers' boarding delays occur? This is mainly due to boarding interferences—conflicts between passengers during the boarding procedure [9]. Within a passenger aircraft, boarding interferences can occur during boarding. Seat interference happens when a

passenger's seat is in the same row as another passenger's, but is closer to the aisle because there is not much space near the aisle.

Boarding interference, however, is more complex in nature, but can be reduced [10]. If the frequency of interferences increases during the boarding of an aircraft, the boarding time increases.

In order to improve the service operation and management, airlines tend to promote intelligent optimization and decision-making technology for business management based on passenger travel-chain processes. Among them, simulation analysis of business processes and optimization is an important supporting technology and auxiliary method.

2. Literature Review

The boarding problem has been studied for a long time [11]. To decrease the average boarding time effectively, many strategies focus on overcoming the boarding bottleneck. The major strategies used nowadays are as follows.

The basic back-to-front strategy [12, 13] is the traditional way of boarding, in which passengers board from the back to the front [14]. This boarding strategy is used by many companies such as Air Canada. Nyquist and McFadden [15] proposed the another important strategy that is called the outside-in strategy, which has a nickname Wilma. This outside-in system boards all window passengers first, followed by those with middle seats and, finally, those seated in the aisle [16]. This kind of strategy is used by America West Aircrafts [17], Delta, and United.

The reverse pyramid method [17] calls for simultaneously loading an aircraft from the back to the front and outside in. Window and middle passengers near the back of the plane board first; those with aisle seats near the front are called last [18]. By referring to some literature, we find that the outside-in strategy performs relatively better. Zeineddine [19] proposed an optimized aircraft boarding strategy, to minimize the time spent on the ground in order to maximize their profit [20]. Therefore, one of the methods to reduce boarding time is to find and develop a procedure that tries to reduce the amount of seat and aisle interferences [21]. Ferrari and Nagel [20] put forward an effective method to minimize bottlenecks when passengers block the aisle to stow a bag or when they have to get past someone in the middle or aisle seat to get to the window seat. Some researchers did simulations about aircraft boarding [22] and evaluation [23]. In this problem, we consider a reasonable, practical means of aircraft seating arrangement. In order to improve the system's performance and customer satisfaction, the goal is to minimize the total boarding time by proposing an effective boarding scheme [24].

Many scholars have studied boarding optimization strategies. Schmidt [25] gave a discussion on aircraft turnaround. Schultz [26] proposed that boarding is a process influenced by boarding sequence, passenger's personal behavior, and number of hand luggage. Milne and Kelly [27] found that, by assigning passengers to different seats, the process of storing articles takes less time. Besides, some scholars have reduced boarding time by studying the seat

layout of the aircraft [28], while Schmidt [25] devoted himself to the study of the single-aisle and double-aisle aircraft layout. On different boarding strategies, passengers carrying a large amount of luggage should be given priority during boarding [10], and the amount of luggage should be regulated when boarding [29]. On the optimization of boarding strategy, Bachmat et al. [30] used the 1 + 1 multicore growth model with concave boundary conditions to prove that back-to-front boarding is the most effective. As for the team boarding strategy, it is common for teams to board the plane together when traveling by plane [19]. In addition, Bachmat et al. [31] have come up with the most of the current aircraft boarding strategies that are adopted in practice.

As mentioned above, the previous researchers find the outside-in strategy working well. This outside-in system boards all window passengers first, followed by those with middle seats and, finally, those seated in the aisle. When the passengers by the window boarded the plane, they are not ordered. If we improve the outside-in strategy by keeping the passengers in a good order according to their seats before boarding, the boarding time will be cut down due to fewer congestions [10, 32].

Based on the assumption that the aircrafts are single aisled, Schmidt [25] concluded that the number of interferences is the main factor in determining the boarding time.

The improved outside-in model allows two columns of passengers (window, middle, or aisle passengers at both sides) board at the same time. In the outside-in strategy, it is good to fill the window seats in the economy class first, then the middle seats, and the aisle seats, so as to eliminate the free-for-all chaos that clogs the cabin [33].

The abovementioned theoretical analysis helps to support airlines in building their intelligent decision-making management system. Due to safety requirements of air travel, it is unrealistic to conduct real rehearsals on airplanes, but simulation technology has been verified as a reliable research tool. The related contents of customer queuing were studied and applied in shopping malls, vehicle scheduling at stations, and other aspects [34, 35]. The boarding process of aircraft passengers needs to consider the internal seat layout of different aircraft types, even the passenger in the terminal building before entering the aircraft, and the psychological requirements of passengers. This is more complicated, with less specialized simulation analysis and related research found.

3. Boarding Model Construction

3.1. Interferences

3.1.1. Seat Interference. We define corresponding passengers as window passengers, middle passengers, and aisle passengers. The time spent on boarding is distributed uniformly, including walking time, time needed for stowing luggage, and time it takes for the seated passengers to give way to others.

A passenger spends extratime on reaching his seat when there are seated passengers in the same row. Assuming there

are six seats per row and a passenger needs to reach the middle seat, as long as the aisle seat is taken, there is seat interference and the interference time is same. If a passenger needs to reach the window seat, the seat interference depends on the seat numbered passengers. The seats what passengers can choose in different conditions are as follows in Figure 1.

3.1.2. Luggage Interference. Another factor that affects boarding time is stowing luggage. The more luggage passengers carry, the greater interference will be caused by stowing luggage and longer the time will be cost. Weibull distribution [26] has been widely used in many different fields. The danger function of Weibull distribution can be increasing, decreasing, or constant. The time needed for stowing luggage follows the Weibull distribution, and the probability density function is

$$f(x; \lambda, k) = \begin{cases} \frac{k}{\lambda} \left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k}, & x \geq 0, \\ 0, & x < 0, \end{cases} \quad (1)$$

where x is a random variable, $\lambda > 0$ is a scale parameter, and $k > 0$ is a shape parameter. Obviously, its cumulative distribution function is an extended exponential distribution function, as in Figure 2.

The cumulative distribution function is

$$F(x, k, \lambda) = \int_0^x \frac{k}{\lambda} \left(\frac{y}{\lambda}\right)^{k-1} e^{-(y/\lambda)^k} dy = 1 - e^{-(x/\lambda)^k}. \quad (2)$$

This cumulative distribution function can measure how long it takes to stow luggage while the flight is full. This indicates that when there are few passengers on the plane, it takes less time to stow luggage. On the contrary, it takes more time as more passengers board the plane, and the growth rate goes up rapidly and then slowly.

3.2. Model Construction

3.2.1. User Preference Modeling. When U is the passenger, S is the seat, r indicates passengers' real preference for seats (S), respectively, and m and n are the number of passengers and seats, then the passenger set can be expressed as $\{U_1, U_2, U_3, \dots, U_{m-1}, U_m\}$, and the set of seats is represented as $\{S_1, S_2, S_3, \dots, S_{n-1}, S_n\}$.

Passengers need to select an integer from 1 to 5 to report their satisfaction with seats. Bigger numbers mean that more passengers like their seats, and 0 indicates that the passenger has not evaluated it. In this paper, the passenger-seat rating matrix is represented by an $m \times n$ matrix (R). In the passenger-seat rating matrix, the more 0 appears, the more sparse the data is. A dataset $D = \{(u, i, r)\}$ indicates that the passenger rates his seat with a score:

$$\begin{bmatrix} \text{User} & S_1 & S_2 & \cdots & S_{n-1} & S_n \\ U_1 & 1 & 0 & \cdots & & 1 \\ U_2 & 0 & 1 & \cdots & 1 & 0 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ U_{m-1} & 0 & 1 & \cdots & 1 & 0 \\ U_m & 0 & 1 & \cdots & 1 & 1 \end{bmatrix}. \quad (3)$$

The seat is scored by many features, such as the number of rows, at the left or right side, and the window, aisle, or middle seat. The seat attribute matrix is as follows:

$$\begin{bmatrix} \text{Attribute} & S_1 & S_2 & \cdots & S_{n-1} & S_n \\ a_1 & 1 & 0 & \cdots & 0 & 1 \\ a_2 & 0 & 1 & \cdots & 1 & 1 \\ \vdots & \vdots & \vdots & \cdots & \vdots & \vdots \\ a_{k-1} & 0 & 1 & \cdots & 1 & 0 \\ a_k & 0 & 0 & \cdots & 1 & 1 \end{bmatrix}. \quad (4)$$

The passengers' preferences are calculated by the passenger-seat rating matrix (R) and the seat attribute matrix (Q). To calculate the passengers' preference, an $m \times k$ matrix is used to represent. The computing method is as follows:

$$P = U * S_i^T. \quad (5)$$

Adopting the data processing method of normalization, $P_{u,a}$ indicates passengers' preferences for different attributes:

$$P_{u,a} = \frac{P_{u,a}}{\sum_{s=1}^k P_{u,s}}. \quad (6)$$

The expectations can be derived based on passengers' preferences:

$$\text{MAE} = \left(\frac{1}{|T|}\right) * \sum_{u,s \in T} |r_{u,s} - \hat{r}_{u,s}|, \quad (7)$$

where $r_{u,s}$ represents the actual score of the passenger (U) on the seat (S), $\hat{r}_{u,s}$ indicates the passenger's predicted score on the seat, and $|T|$ is the size of the test set:

$$\text{RMSE} = \sqrt{\left(\frac{1}{|T|}\right) * \sum_{u,s \in T} |r_{u,s} - \hat{r}_{u,s}|}. \quad (8)$$

The smaller the MAE and RMSE, the better.

When a passenger arrives in a row, his decision to sit or not is determined randomly by his relative preference for that row. When a passenger decides to sit in a row, if there is more than one seat in the row, which seat he chooses to sit in is randomly determined by his relative preference for each seat. But when some seats in that row have been taken, passengers' preference for a particular seat is also adjusted. It is determined by his relative preference and its

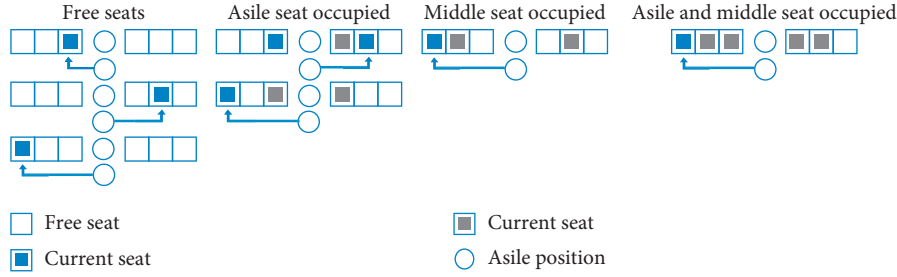


FIGURE 1: The available seats in different conditions.

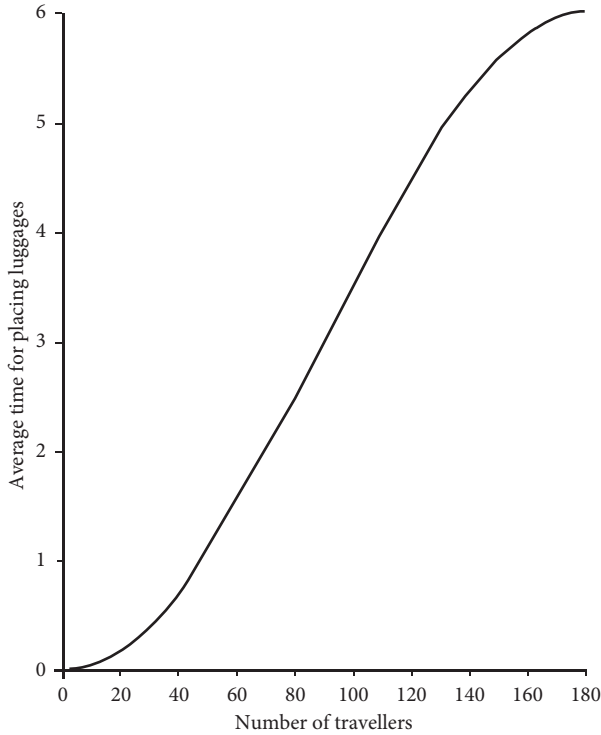


FIGURE 2: Average time of placing luggage to the number of travellers.

corresponding probability. At every circulation, the model recalculates each passenger’s preference for each row and seat. Therefore, the model considers the preference of passengers. According to the Markov chain, there is a stationary distribution, which shows the probability of passengers sitting in a certain row under a certain preference. The stationary distribution is

$$\lim_{n \rightarrow \infty} P^n = \begin{bmatrix} \bar{\pi} \\ \bar{\pi} \\ \vdots \\ \bar{\pi} \end{bmatrix} \quad \lim_{n \rightarrow \infty} P^n = \begin{bmatrix} \bar{\pi} \\ \bar{\pi} \\ \vdots \\ \bar{\pi} \end{bmatrix} \quad (9)$$

3.2.2. Boarding System. In the airline’s production management system, the boarding process business module needs to provide specific operating data, data processing

models, and algorithms. This paper aims to build a model to realize this goal and carry out related analysis.

3.3. An Ideal Deterministic Strategy. Based on above analysis, we can reach a conclusion that the queue-ordered strategy is better than the improved outside-in method if the time spent in placing luggage is taken into account. Passengers are required to stand in a queue group by group before boarding.

We analyzed two specific outside-in boarding ways and concluded that the queue-ordered way is better than the left-by-right way because of a shorter boarding time. Hence, we will study the ready work for a good application and implementation of the queue-ordered way.

The main idea of the method is to label the chairs in the waiting room and device a new boarding pass that indicates both chair numbers in the waiting time and seat in the aircraft [36]. Then, attended by the seating scheme in the queue-ordered way, passengers can take their seats with few seat interference and aisle interference. In short, the central object we research is an improved work in the waiting room compared to in the realistic life and the device of a new boarding pass.

Before proposing a deterministic method, we will introduce some basic, relevant conditions about the aircraft seating problem.

The primary type of aircraft that this paper and all experimentation documented in this paper will focus on is a generic Airbus A320. This aircraft will have of three rows of four first-class seats and 23 rows of six coach class seats.

For the midsize plane, consider the single-aisle condition, and let $N = \{1, 2, 3, \dots, n\}$ represent the set of rows and $M = \{A, B, C, D, E, F\}$ represent the set of seat positions in the aircraft. In addition, let the seats on the left side of the aisle be presented by $L = \{A, B, C\}$ and those on the right side by $R = \{D, E, F\}$; thus, A and F are window seats, and B and E are middle seats, and C and D are aisle seats. Given a row number $i \in N$ and a seat position $j \in M$, all seat locations in the aircraft can be uniquely identified and represented by the pair (ij) just as in a normal aircraft, such as in seat (7C), namely, the 7th row and the left-aisle seat. Table 1 shows the seats distribution in the aircraft.

Based on the above analysis, we can design a new boarding pass and label the chairs in the waiting room.

TABLE 1: The numbers of seats in the aircraft.

Front of a plane						
1A	1B	1C		1D	1E	1F
2A	2B	2C		2D	2E	2F
3A	3B	3C	Aisle	3D	3E	3F
4A	4B	4C		4D	4E	4F
5A	5B	5C		5D	5E	5F
Rear of a plane						

3.3.1. *Label in the Waiting Room.* In the common system, passengers are free to seat in the waiting room, which leads to a chaos while boarding. So, we proposed new chairs with numbers, such as 1, 2, 3, . . . , to present the passengers' positions. The seats on the left side of the aisle are numbered 1, 3, 5, . . . , and the right ones are labeled as 2, 4, 6, For the same-class passengers, those who come earlier can board first, that is, they have the priority to choose the front seats in the waiting room.

3.3.2. *Design a New Boarding Pass.* We designed a new boarding pass with the number for the waiting room and the seat in the plane. In terms of above analysis, we can gain the seat number in the aircraft if given the chair number in the waiting room.

According to the improved queue-ordered strategy, we can get the passengers distribution in the aircraft. We can easily get another table which presents the match between chairs in the waiting room and seats in the plane, see Table 2.

In the table, a new boarding pass (01-5A) means a passenger can have a chair labeled 01 in the waiting room and take another seat (5A) in the aircraft. Similarly, a boarding pass (11-5B) shows that a passenger can have a chair labeled 11 in the waiting room and take another seat (5B) in the aircraft. Every boarding pass has a different meaning, which assigns a different chair and seat.

A boarding pass shows a chair in the waiting room and a seat in the aircraft. Compare the two table, they are corresponding with each other, so we can determine what to be printed on the new boarding passes, such as 01-5A, 02-4A, 03-3A, . . . , 06-5F, 07-4F, 08-3F, The first number means the chair number in the waiting room, and the second number shows the seat number in the aircraft.

If there are more seats, we can study it in the same way. If a passenger compartment has N rows, thus we can design some boarding passes such as 01-NA, 02-(N-1)A, and 03-(N-2)A. In other words, a boarding pass represents a chair in the waiting room and a seat in the aircraft. In the meantime, we can find that a chair matches to one seat only.

3.3.3. *Distribute New Boarding Passes.* After designing new boarding passes, we determine a fair and reasonable strategy of distributing the new boarding passes to passengers in the Aircrafts Customer Service Agent. With the principle of "first come first service," we can distribute a boarding pass named 01-5A to the first customer at Customer Service, then another one named 02-4A to the second customer, and distribute other boarding passes in the same way.

TABLE 2: Match between chairs in the waiting room and seats in the plane.

The front of the plane						
05-1A	15-1B	25-1C		30-1D	20-1E	10-1F
04-2A	14-2B	24-2C		29-2D	19-2D	09-2F
03-3A	13-3B	23-3C	Aisle	28-3D	18-3D	08-3F
02-4A	12-4B	22-4C		27-4D	17-4D	07-4F
01-5A	11-5B	21-5C		26-5D	16-5D	06-5F
The back of the plane						

In short, passengers should stand in queue before boarding and take their seats according to the boarding pass he gets. In this way, every passenger has a chosen chair in the waiting room and another chosen seat in the aircraft. Customers are in a good order once they get boarding passes. Furthermore, all can see that they are treated fairly because first-comers are always the first to receive service. That is to say, not only can it minimize boarding time by designing a reasonable order while boarding through a new boarding pass and a group of labeled chairs in the waiting room but it can also maintain customers' satisfaction.

3.4. *A Semistochastic Strategy.* The deterministic method, namely, the queue-ordered strategy, would annoy the passengers and will not benefit the airlines in the end. Furthermore, the complete deterministic technique is hard to apply in the real world because it is difficult to organize the queues and lead them.

In an open seating method, the passengers are free to choose their seats, and it may result in a chaos. We have to come up with a new strategy to overcome the disadvantage of the complete random condition. Hence, we could propose a method that will balance the contradictions between them.

Based on this consideration, an improved semistochastic method can be used in reality to solve the problem. So, we proposed a semistochastic model. At last, we will simulate to test the boarding time of the method.

It is a combination of the deterministic model and stochastic model. In other words, passengers have some right to determine which row to be seated, with the precondition that only in a fixed column, such as columns A, B, and C.

3.4.1. *Design Boarding Pass.* In the deterministic model, the boarding pass is designed to show the chair in the waiting room and the seat in the airplane. A passenger with a unique boarding pass only takes a seat assigned for him, but changing the seat at will is forbidden according to the airline rules.

In the semistochastic model, since the column is fixed and row is stochastic, a boarding pass indicates which column to be seated. For example, everyone in group passengers must select from the left window seats and is free to choose from any row. What a boarding pass tells is the number of columns such as A, B, and C. Once a passenger gets his boarding pass and boards on the airplane, he should comply with the rule.

3.4.2. Boarding Process

Step 1: divide all passengers into six groups, named group A, B, C, D, E, and F. According to the regulation which the airline makes, it is apparent that one in group A can only choose a seat in column A; similarly, other groups can only select corresponding seats.

Step 2: group A have the priority to board, since they all take left window seats, followed by group F, who can only take right window seats. In order to lead a good boarding sequence, use the “call-off” system to inform passengers group by group.

Step 3: as for group A, passengers in the group can take any seat in the left window seat. So, the seating is random to some extent. It avoids a seat interference, but not an aisle interference. If it occurs, people in the back are free to take the front seats or should wait to take the back seats until the congestion is over.

Step 4: with the same method, we can lead groups B, E, C, and D to aboard in order.

From the process of the boarding above, we can see that once the passengers have got on the plane, he will be free to choose the seats in the columns assigned for him according to his will and the current condition of the plane. Once he chooses his seat, he is not allowed to change, which is mentioned in our assumptions partly because of the airline rule. The boarding process is as follows in Figure 3.

In the compartment, let us take the window passengers as example to illustrate the process of seating. As we know, they can only choose the window seats, but have the right to choose any one of these seats. The first passenger of the queue has the priority to choose a window seat at his will. Then, the second passenger of the queue chooses a window seat according to his will and the current condition of the compartment, such as the congestion condition. The other passengers of the queue choose their seats in the same way. When the last one of the queue finds his seat, the second queue starts its progress. This will give the passengers more freedom of choosing seats.

$$\left(\lambda + \sum_{j=1}^n v_j \right) \varphi(i_1, i_2, \dots, i_n) = \lambda \varphi(i_1 - 1, i_2, \dots, i_n) + v_n \varphi(i_1, i_2, \dots, i_n + 1) + \sum v_j \varphi(i_1, i_2, \dots, i_{n+1} - 1, \dots). \quad (11)$$

Therefore, the number of passenger in every processor needs to be greater than 0, and φ must meet the following conditions:

$$\begin{aligned} \lambda \varphi(0, 0, \dots, 0) &= v_1 \varphi(1, 0, \dots, 0) \\ (\lambda + v_1) \varphi(0, 0, \dots, 0) &= v_2 \varphi(i_1, 0, \dots, 0) + \lambda \varphi(i_1 - 1, 0, \dots, 0) \\ (\lambda + v_n) \varphi(0, 0, \dots, i_{n-1}) &= v_{n-1} \varphi(0, 0, \dots, i_{n-1} - 1) + v_n \varphi(0, 0, \dots, i_n + 1). \end{aligned} \quad (12)$$

The sum of all probabilities is 1, and it means

3.4.3. *Queue Model of Boarding System.* Boarding process is a random process; we try to make queuing analysis to simulate the boarding process. When one passenger arrives at some row, he will choose to enter in the low or go on walking to other row; we take every row as a process, and there is a queue of passengers in every processor. If it is full in the processor, the passengers need to keep moving to another processor. If there is traffic in the system, it means there are passengers blocked in the queue. It is a waiting line system problem. The queue model of the boarding system is as follows in Figure 4.

Symbols:

R : number of rows of seats in the plane

C : number of columns of seats in the plane

L : time for luggage, regarded as a variable in the simulation

V : passengers' walking speed

T : time for seated passengers to stand up to wait for other passengers, regarded as a variable in the simulation

λ : speed of passengers entering the plane, set as constant

The lower limit of boarding time is

$$T = \frac{CR}{v} + L + (L - 2R) \left(\frac{C}{2} - 1 \right), \quad (10)$$

where $\varphi(u_1, u_2, \dots, u_{m-1})$ represents the probability that the aisle seat is taken and v_i is the walking speed. The bottleneck occurs when there is the biggest traffic in the system. The number of passengers is different on each node, which forms an n -dimensional space.

First, in order to make sure the passengers not be lost in the system, we need to calculate the input and output of every processor:

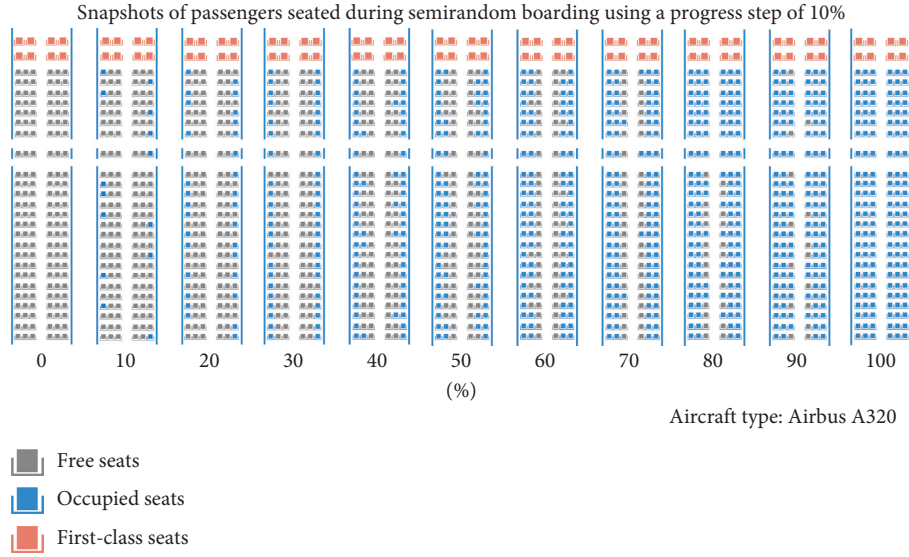


FIGURE 3: Boarding process.

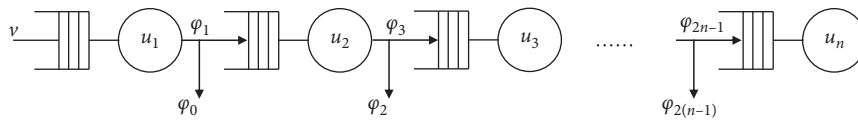


FIGURE 4: Queue model of the boarding system.

$$\sum_{k_1 \geq 0} \cdots \sum_{k_n \geq 0} \varphi(k_1, k_2, \dots, k_n) = 1. \quad (13)$$

In the subsection, we get the solution:

$$\varphi(i_1, i_2, \dots, i_n) = \prod_{j=1}^n (1 - \varphi_j) \varphi_j^{i_j}. \quad (14)$$

In the equation,

$$\varphi_j = \frac{\lambda}{v_j}. \quad (15)$$

4. Simulation to the Model

Different from the experimental test [37], case study [28], and simulation design approach are always used [38–40], we try to simulate the boarding process with different boarding strategies on a specific aircraft to find out which strategy works the best.

The computer simulation program used for this paper is based upon the Airbus A320, which has three rows with four first-class seats and 23 rows with six coach class seats. The total number of the seats is 138. The seating configuration for an Airbus A320 can be found in this paper.

4.1. Simulation of Boarding Process. We wrote a Matlab program to simulate the boarding process with different boarding strategies. Each boarding method was simulated

100 times in order to get a group of accurate results. In the simulation, it is assumed that the walking speed is 1.4 m/s, the intervals of passenger boarding is 5 s, the probability of passing congestion is 5%, and the time required to store luggage is proportional to the seat numbered passengers.

The passenger boarding procedure is a major factor in determining how efficient and how profitable an airline is. So, the calculation of the average boarding time is critical in evaluating the boarding technique. Figure 5 shows boarding time in different boarding strategies.

4.2. Results Analysis. We make comparisons of the three techniques from the aspects of the process of boarding, design of boarding pass, and seat interference.

4.2.1. The Current Outside-In Strategy. The outside-in is a widely used technique now and has obtained good effects in practice. Passengers getting on the plane have queued in the sequence before they sit on the plane. It accentuates the concept of group and “call-off” passengers group by group; thus, a call off system is needed in the technique. The boarding pass shows which seat to take in the airplane. Passengers in the same group have boarding passes with the same column number but different row numbers.

In the method, aisle interference may happen when passengers in the same group search their seats. Nevertheless, seat interferences will not occur because different groups have different priorities.

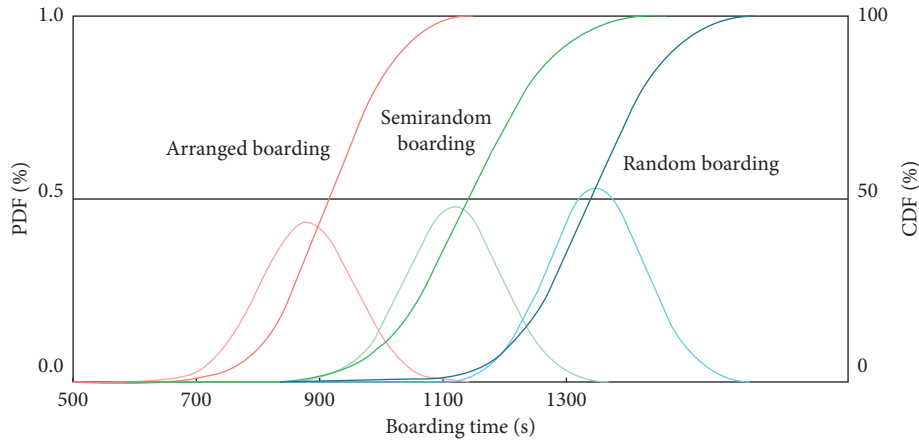


FIGURE 5: Probability function and distribution of boarding time in different strategies.

4.2.2. The Ideal Deterministic Model. In this model, though every passenger has a unique seat number, which indicates his seat on the airplane, and passengers board the plane group by group as mentioned above, the difference is that they queue in a good order before boarding in every group compared with the column-fixed strategy. A boarding pass indicates the chair number in the waiting room and which seat to sit on the plane. Actually, the establishment of the model depends mainly on the design of a new boarding pass and labels on the chairs in the waiting room.

Hence, both the aisle interferences and seat interferences have been eliminated in the model because of a reasonable and effective work arranged in the waiting room. This technique will decrease the chaos effectively.

4.2.3. The Enabling Semistochastic Model. Passengers are free to choose any row in the assigned column, namely, they have the right to determine where to sit. If there is congestion ahead, passengers can choose a handy seat or wait until the congestion is over and select a back seat. The boarding pass only tells which column to sit in, and a passenger can choose at his will under the restriction. This technique gives the passengers more freedom to choose his seat, which increases the satisfaction of them.

Because there is certain randomness when choosing the seat, the aisle interferences will happen though the interference may be less than the queue-ordered strategy. No seat interference will occur in this strategy. Moreover, one of the homologies of the three strategies is that passengers board on the plane group by group, and people in the same group are required to sit in the assigned columns.

The results obtained from the simulation were graphed and then compared. After executing the program above, we find a figure that reveals the tendency of the boarding time with the increase of the average time passengers placing their luggage. Figure 6 shows comparison of boarding time in different strategies. From the comparison of the figures, it can be concluded that taking user preferences into account will bring higher efficiency.

First, the strategy of dividing passengers into six groups, namely, the queue-ordered technique performs better than

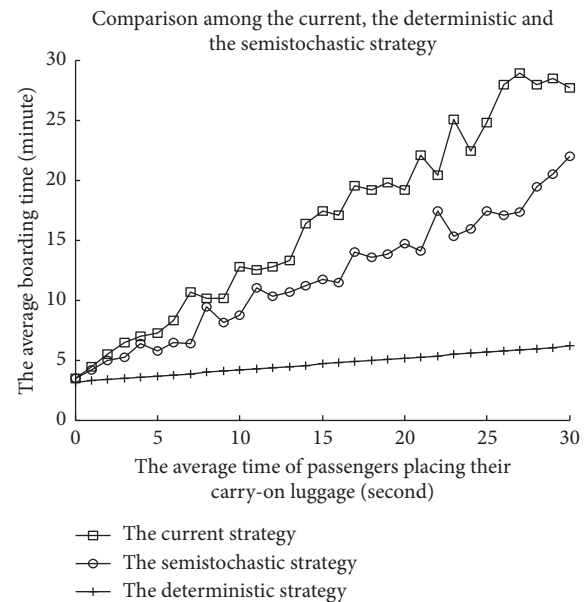


FIGURE 6: Comparison of boarding time in different strategies.

the outside-in technique. And, the advantage manifests as the average time passengers placing their luggage increases, which fits well with the conclusions of our theories deduced.

Second, from the tendency of the curves, we find that the average boarding time has a linear increase as the increase of the average placing time for all techniques. The reason is that, with the increase of the average placing time, the congestion caused by the passengers ahead will become severe, which will prolong the average boarding time.

Third, the semistochastic technique in this paper performs between the queue-ordered technique and the outside-in technique. Although its performance is worse than the ideal conditions, it can be used in the real world due to its simplicity and feasibility.

Finally, when the average time approaches zero, the effect of the three techniques performs equally to each other. That is mainly because all passengers do not have to place their luggage under such circumstances, and they can sit down as soon as they find their seats. In other words, the

move of the passenger flow in the aisle is successive, and the speed of the flow is completely dependent on the passengers' average moving speed, which is a constant. Hence, the boarding time of the two techniques is identical.

4.3. Model Validation. As Christmas is coming, many people go back to their hometown by air for its fast speed. We contacted an airline and obtained some information. According to the statistical data, the average, minimum, and maximum time for a passenger to place his carry-on luggage is 35, 20, and 61 seconds, respectively, and the average time of passengers traveling from one row to the next row is about 2 seconds. The time of a passenger placing his carry-on luggage is longer than ever before because it is during the spring festival and all the passengers have luggage. Besides, most of the passengers take too much luggage with them; thus, the time of a passenger placing the luggage and traveling from one row to the next row increase sharply. Usually, the average boarding time is between 20 and 35 seconds, but now the average boarding time is about 40 to 60 seconds. The increase of the boarding time has caused flight delay, and passengers complain about the flight delay.

We reset the parameter according to the data we collected and simulate the boarding process with outside-in and our proposed strategies. We run the program 100 times, and the average boarding time is 45.2166 minutes if we use the outside-in boarding method. When we use the semistochastic boarding method, the average boarding time is 34.3703 minutes. The results show that our program can simulate the real boarding process to a certain extent as well as our semirandom boarding method. Our boarding strategy is superior to the boarding method from the outside to the inside.

Based on the analysis above, we can conclude that the semistochastic technique we designed has a practical meaning. It could decrease the average boarding time to some extent and is not too complicated to apply in practice.

5. Boarding Approaches

5.1. Narrow-Body Aircraft Boarding. We can find the seating configuration for a generic A320, which is a typical small aircraft used in most airlines in Figure 7. This kind of airplane has three rows of four first-class seats in Zone A and 23 rows of six coach class seats in Zone B, that is to say, 12 first-class seats and 126 coach and business class seats. It is noted that the computer simulation program used for this paper is based upon the A320.

When passengers queue in order before boarding, the first-class passengers stand in the front because they have a priority to board, followed by coach and business passengers. To these people, we can apply the model established above to address the airplane seating problem. The airlines are free to choose which strategy to adopt from the three following methods: the outside-in technique, the deterministic model (the queue-ordered strategy), and the semistochastic model (the column-fixed strategy). As we research, the boarding time in the queue-ordered strategy is

shorter than the outside-in technique. However, it is difficult to implement in real life. We suggest the column-fixed strategy, which cannot only ensure a shorter boarding time but can be implemented in reality.

In short, business-class passengers board first, and then, the economy-class passengers, in the column-fixed strategy. That is to say, for the same class passengers, they have right to choose any row in the fixed column to seat.

When the passengers depart from small airplanes, it is an inverse process to the boarding. So, we can approach to the problem in a similar way. The basic idea is to let passengers depart in a good order and on the principle of "first come last go," for example, leading passengers to depart column by column. They can also decide for themselves when to leave in the given time.

5.2. Middle-Body Aircraft Boarding. The B747-400 is a midsize airplane with a capacity of 272 seats. There are two decks in the plane, and there are a few passengers in the upper deck who can board fast through another gate connected to the upper deck. In this sense, the most time spent is determined by the boarding time on the lower deck.

In Figure 8, it can be seen that there are two entrances for boarding in the lower deck. The front one is for the first-class passengers and business passengers, and the back one is for the economy passengers. The seats in row 20 to row 25 (Zones A and B) are for the first-class passengers, seats in row 27 to row 33 (Zones C and D) are business seats, and seats in row 35 to row 54 (Zones E, F, G, and H) are economy seats.

It is noted that there are two aisles, not a single-aisle, and the seats are symmetric regardless of first-class, business, or economy compartments. The difference is that there are two seats at the two sides in the first two compartments, but three seats in the economy compartment.

Now, we can determine how all the passengers' board. In the first entrance, two factors will be primarily taken into account. One is the priority. The first-class passengers have the right to board first, followed by the business passengers. The other is the consideration about congestions. Passengers in Zone B should board earlier than people in Zone A. Similarly, passengers in Zone D should board earlier than people in Zone C. Hence, the boarding order from the front to the back is passengers in Zones B, A, D, and C.

While the first class and business class passengers are boarding, the economy class passengers are busy boarding through the second entrance. Since there are generally more passengers, it will take more time to board. With the same analysis method, we can easily recognize that the passengers in Zones F and H can board earlier than others. In the front-half order, passengers in Zones F and H will appear alternately for fairness, and it will reduce boarding time especially when most passengers have much luggage to place. The procedure of boarding is depicted as follows:

Step 1: divide all passengers into two groups. First-class and business-class passengers will gather near the main entrance, while economy-class passengers will appear near the back door.

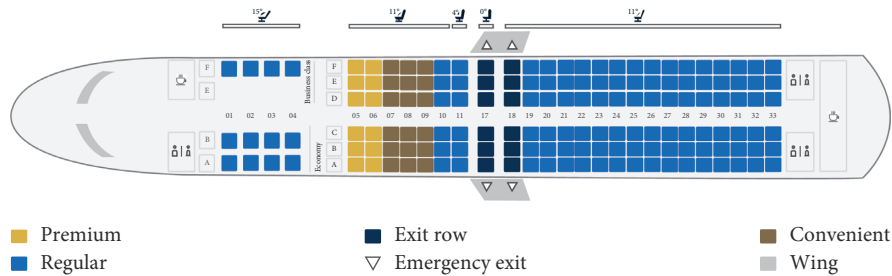


FIGURE 7: Seating configuration for an Airbus A320.

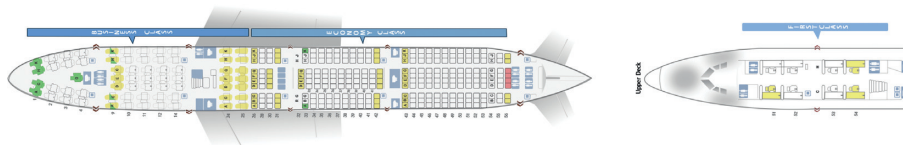


FIGURE 8: Seating configuration for B747-400.

Step 2: let the first-class and business passengers queue in a good order besides the front entrance before boarding. The order in the sequence are passengers in Zones B, A, D, and C. In some specific zones, they comply with the principle “first come first service.”

Step 3: at the same time, economy passengers are queuing as well. The front-half passengers are ones who will take seats in Zones F and H. The passengers in these two zones will appear alternately for fairness. Similarly, the back-half passengers are ones who will take seats in Zones E and G, and they take seats alternately too.

Step 4: after a reasonable arrangement to all the passengers, the problem turns to be a process to every section, namely, passengers in every zone. We can consider it to be a problem in a small airplane.

To select from the outside-in strategy, the queue-ordered strategy, and the column-fixed strategy what we have researched above, the column-fixed strategy is our choice since it gives passengers’ some freedom to choose.

When the passengers get off from midsize planes, it is a reverse process of boarding. We can use a similar method to arrange it. Passengers of different zones leave in a good order. For example, passengers in Zones F and H leave in the same way as those in Zones E and G. In the interior of every section, passengers can queue column by column to get off. Furthermore, the first-class passengers can get off earlier than business passengers. Generally, late comers can depart early.

5.3. Wide-Body Aircraft Boarding. Figure 9 shows the seating configuration on the upper and lower deck in A380, a large plane with a capacity of 800. In the lower deck, it is obvious that there are more seats, mainly economy seats. In the lower deck, there are three entrances in the plane, the front one is for the first-class passengers, the middle and back entrances are for the economy seats.

To reduce the interferences between passengers, we consider there are two passages to the upper and lower deck, respectively. Then, we can consider each deck as a midsize plane and use the same method to address the problem.

It is noted that, in large airplanes, time spent on placing luggage can be ignored. As we know, it is a dominant factor for boarding delay to unload luggage. All passengers are required to unload luggage under the deck, and time spent on the work is removed from our consideration. The procedure for boarding large planes is as follows:

Step 1: design two different passages leading to the plane, one is to the lower deck, the other is to the upper deck.

Step 2: in the lower deck, according to the method mentioned above, divide lower passengers into 3 groups besides the front, middle, and back entrance.

Step 3: the first-class passengers can board earlier than others. For example, passengers in Zones LA and LB will get on the plane earlier than passengers in Zones LC and LD.

Step 4: passengers in Zones LD, LF, and LH can get on earlier than passengers in Zones LC, LE, and LG.

Step 5: queue in order. Passengers who can board earlier stand in the front of the sequence.

Step 6: in the upper deck, arrange passengers in a similar method.

Since getting off from large planes is opposed to boarding, we follow the principle of priority between different classes and “late comers get off earlier” for same class passengers.

As can be seen from the figures above, with the increase of the average time of passengers placing their carry-on luggage, the average boarding time increases no matter corresponsive which strategy is adopted. So, the average time of passengers placing their carry-on luggage will determine in a great extent the total length of the boarding time. If the

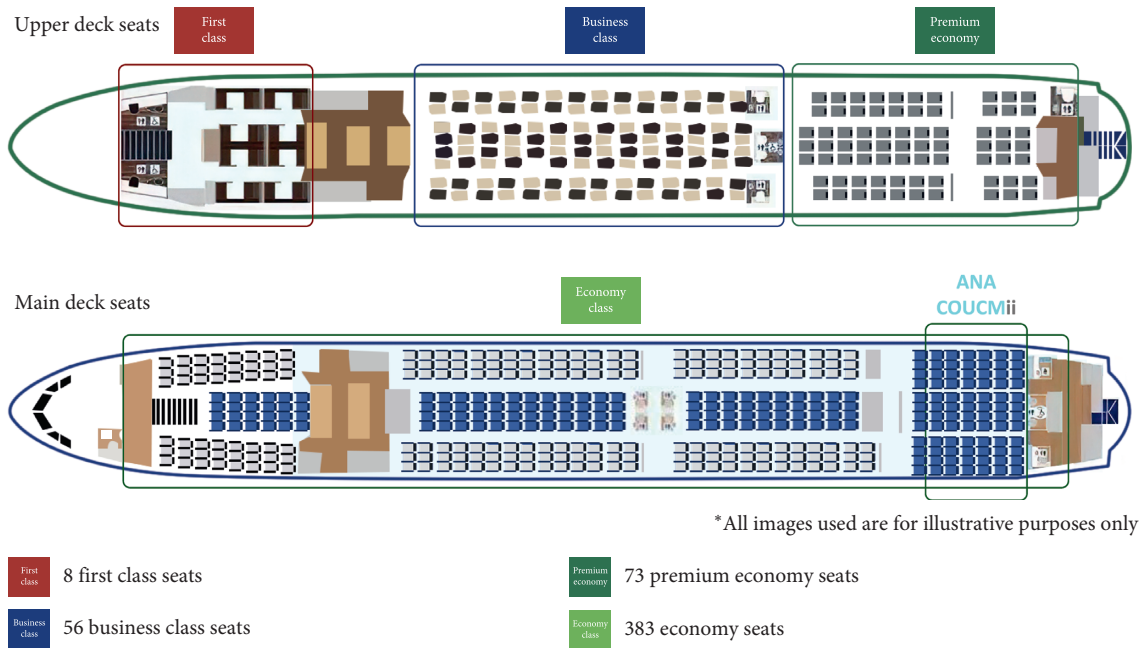


FIGURE 9: Seating configuration for an Airbus A380.

airlines restrict the passengers' carry-on luggage, the boarding delays that plague airlines can be alleviated.

6. Conclusions

In this paper, we aim to design new boarding procedures and implementation methods to minimize boarding time and increase passenger satisfaction. We proposed two strategies to solve the boarding problem and a new method for estimating boarding time. We also simulate the boarding process with different strategies on A320, B747-400, and A380 based on real data provided by the airlines to verify the research model and the simulation process.

The boarding strategy optimization provides a good insight into a better boarding process based on user preferences. In the simulation process, the deterministic model works better than the outside-in method as it reduces two types of interferences and significantly improves boarding efficiency. Unlike most boarding methods [41], these solutions do not require much human action. The ideas and conceptual designs put forward in this paper will be possible inspirations for boarding time improvement, but further research is still needed to test their effectiveness in the real operating environment.

For the follow-up research, it is necessary to make sure that the boarding model and strategy proposed in this research can fulfill the data standards and data interface requirements of the airline's operation management system, so as to effectively support the improvement of airline operation management efficiency and passenger service quality level.

Data Availability

The data used to support the finding of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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