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Evaluation of boarding time of aircraft considering inexperienced passengers

Yoichi Utsunomiya, Yuko Tomiyama and Takashi Okuda *

Abstract

Air transport companies want to serve all flights on time. However, aircraft departure time is delayed by that there are inexperienced passengers. Inexperienced passengers are customers who do not listen to selfish behavior or announcements. In this study, we evaluated the boarding process of passengers in aircraft by multi-agent simulation in consideration of the inexperienced passengers. We evaluated 6 types of boarding process and several patterns of passengers' behavior. Even if there were inexperienced passengers, the shortest process of average boarding time was in reverse pyramid order. However, this boarding sequence is the most complicated of the six types of boarding processes. The Rear-to-front order is a common process. However, if the proportion of inexperienced passengers is high, boarding time will be long.

Keywords: Aircraft, Boarding order, Inexperienced Passengers, Multi-agent simulation

1 Introduction

In Japan, the Ministry of Land, Infrastructure, Transport and Tourism publish information of air transportation service every 3 months. The information includes comparison of air transportation performance and fare. The information of air transportation performance refers to the rate of on-time operation, the number of delayed flights, and the number of canceled flights. For example, the information is released, such as "the average rate of delayed flights of eleven Japanese airlines was 9.38% in the period of July-September 2015, which was 1.12% decrease from the rate of the same period of the previous year."[1]. Delayed flight is defined as flights which departed more than 15 minutes later than the planned time. The data of each Japanese airline become open to the public and influence on the ranking of airlines and airports[2].

Therefore, air transportation agencies recognize the importance to increase the on-time performance rate and reduce the number of delayed flights. In addition to shortening the time to prepare and check the aircraft, in order to increase the on-time performance rate, it is important not to extend the time for the passengers to board and to be seated. In this study, we call the problem of boarding time extension by the behaviors of passengers "problem of boarding time extension".

* Aichi Prefectural University, Aichi, Japan

There are two factors causing this problem. The first factor is that some passengers have to wait for others to put their baggage into the overhead compartment. The second factor is that some passengers take time to be seated because they have to make another passenger move back to the aisle to reach their seats in the window-side. The first factor is difficult to overcome however the second factor can be decreased. In order to solve the second factor, airlines provide the passengers of the instruction of the most efficient boarding order at the lounge.

There are some ways to decide the boarding order[3], such as an order decided by the order of passengers of arriving at the reception, or another order decided by the position of the reserved seat. However, some of the orders cannot solve the second factor. In addition, some passengers selfishly ignore the announced boarding order and some other passengers do not notice that the order is announced and they end up distracting the order[4][5].

Given the situations described above, in this study, we express the boarding process of the passengers in the aircraft by using the agent-based model[6] with selfish behaviors of passengers taken into consideration. By this simulation, we examine the optimal boarding order to minimize the boarding time.

The outline of this paper is as follows. Related study to this paper is stated in Section 2, the explanations of the problem of boarding time expansion is stated in Section 3, Discussion on the optimal boarding process of the passengers in the aircraft is found in Section 4, the explanation of the boarding process of the passengers in the aircraft by the agent-based model is described in Section 5, the numerical example is showed in Section 6, and the summary of the conclusion of this paper is found in Section 7.

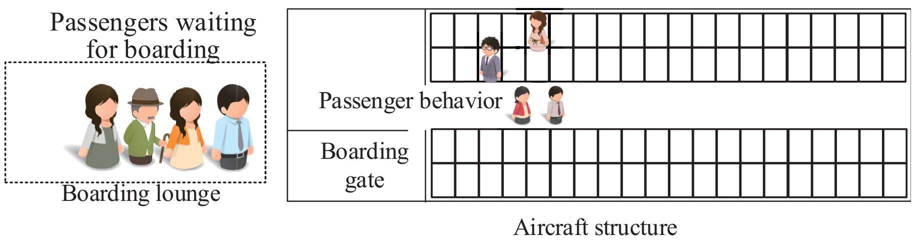

Figure 1: Process of boarding passengers

2 Related studies

The most appropriate boarding order to minimize the boarding time depends on the characteristics of airlines and passengers' behavior. There are some studies in the past in which boarding time was computed by observing the subjects actually board with certain boarding order into a real-size aircraft model and in which boarding time was computed by a discrete-time simulation[7][8]. Boarding time is regarded as the time from the first subject starts to board to all the subjects are seated. It is significant to consider the situation where the passengers do not follow the boarding order when clarifying the optimal boarding order. Using the multi-agent-simulation enables us to discuss precisely the process of the movement[9].

3 The Problem of boarding time extension

In this section, the problem of boarding time extension in aircraft is explained. This problem is that the time from the first passenger boarding until all the passengers are seated is longer than the predetermined time. There are two factors causing this problem as described below.

a) Some passengers keep standing in the aisle to put their baggage into the overhead compartment and other passengers cannot move forward.

b) Exchange of the seat positions is needed in case a passenger who reserved aisle seat is seated before the passenger who reserved window-seat comes.

The case a) cannot be decreased because many passengers need to put their baggage. The case b) should be solved by optimal boarding order. In order to solve this, airlines instruct boarding order to the passengers at boarding lounge. However, this instruction of boarding order still brings up additional two factors into this problem.

c) The boarding order in the instruction is decided by the order of passengers' arrivals.

d) Some passengers do not follow the boarding order instruction.

The case c) is a boarding order decided by the order of arrival of the passengers, however, this order should cause the factor b) during the passengers are boarding. The situation can be solved by deciding the boarding order not by the arriving order of the passengers but the position of the reserved seat. The situation of case d) exists in a certain number of passengers. Therefore, we need to consider an optimal boarding order with consideration of case a) and d). From the four perspectives described above, the boarding process in aircraft is showed in the next section.

4 Process of boarding

The process of boarding can be expressed by dividing five elements: (1) boarding lounge, (2) aircraft body, (3) instruction of boarding order, (4) passengers waiting for boarding, (5) passenger's behavior (Refer to Fig.1).

These five elements are described below.

1. Boarding lounge: Boarding lounge is the place where passengers wait for boarding and instruction of boarding order.

2. Aircraft structure: Aircraft structure is the environment consists of a boarding gate, aisles, and seats.

3. Instruction of boarding order: Airlines provide instruction of boarding order decided by positions of seats.

4. Passengers waiting for boarding: Passengers wait for instruction of boarding order at the boarding lounge, and move forward to boarding gate when instructions of boarding order are announced by airline.

5. Passenger's behavior: Passenger will take eight actions. These actions include to follow the boarding order, to ignore it, to board, to search for their reserved seats, to be seated, to put their baggage, to move back to the aisle to let another passenger to reach the window-seat, and to wait for other passengers putting the baggage.

These eight actions are described below. These eight actions can be categorized as actions which all passengers take before airlines start instruction of boarding order and actions which all passengers take after airlines start instruction of boarding order, and actions which some of the passengers take on condition.

- Actions which all passengers take before airlines start instruction of boarding order
    1. to follow the boarding order
    2. to ignore the boarding order
- Actions which all passengers take after airlines start instruction of boarding order
    3. to board
    4. to search for their reserved seats
    5. to be seated
- Actions which some of the passengers take on condition
    6. to put their baggage
    7. to move back to the aisle to let another passenger to reach the window seat
    8. to wait for another passenger moving the aisle and putting their baggage

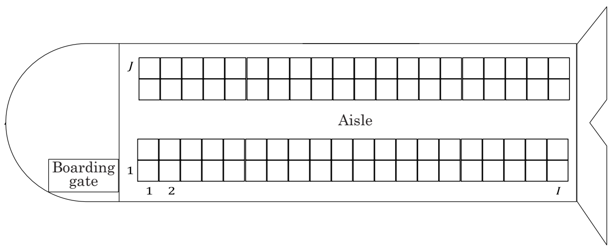

Figure 2: Aircraft model

5 Agent-based model

The process of boarding in aircraft explained in Section 4 can be expressed by using an Agent-based model. The outline of this section is as follows. The model of environment is explained in Section 5.1, the behavior of agents is defined in Section 5.2, and boarding orders are explained in Section 5.3.

We show the snapshot of multi agent simulator(refer to Fig.3).

5.1 The model of the environment

In this study, we assumed an aircraft of narrow body (refer to Fig.2). There is one boarding gate, and the number of rows is twenty ($I = 20$), and the number of seats in one row is four ($J = 4$). We regard the agents as the passengers.

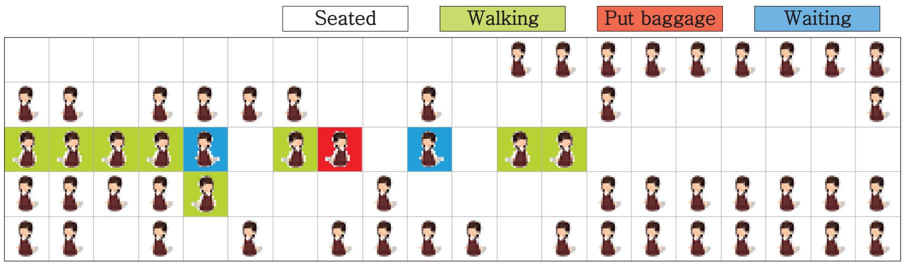

Figure 3: Snapshot of Multi agent simulator

5.2 Agent Behavior

Section 5.2 contains explanation on behavior of agent. All agents come from the boarding gate and sit in the reserved seat. The next agent will board as soon as the first agent boards. The reserved seat is decided before a passenger arrives at the boarding lounge. The airline staffs provide passengers of the instruction of boarding order explained in Section 5.3 when they announce passengers to start boarding. When the agent listens to the instruction, it takes either of two actions.

- To follow the boarding order: Agent starts boarding by following the instruction of boarding order.
- To ignore the boarding order: Agent starts boarding at the wrong timing from the instruction.

The actions the ignoring agent takes in each boarding order are explained in Section 5.3. An agent takes actions described below when boarding. At first, there are three kinds of actions which all agents take.

- To board: Agent boards from the boarding gate into the cabin.
- To search: Agent searches for own reserved seat from the aisle.
- To be seated: Agents is seated own reserved seat.

Next, we explain actions which only some of the agents take. When agent takes three actions above, some of them take actions below if some conditions applies.

- To put the baggage: Agents having their baggage put them into the overhead compartment from the aisle and take some time until their being seated.
- To move: In the case where an agent who should be seated aisle-seat is seated before the agent who should be seated window-seat, the agent of aisle seat need to move back to the aisle to let the agent of window-seat pass through.
- To wait: In the case where the former agent is taking actions above or waiting, the next agent needs to wait. When the former agent finishes taking the action, the next agent can move forward the aisle.

We defined moving for exchange the position needs longer time than putting the baggage.

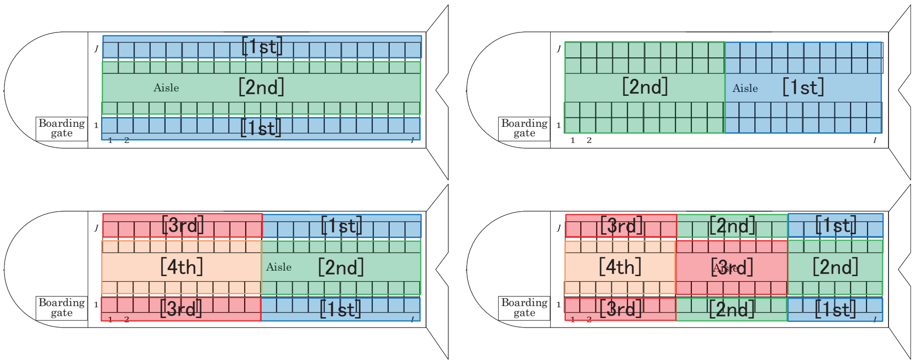

Figure 4: (a) Boarding order: Window-seat prioritized order, (b) Boarding order: Rear-seat prioritized order, (c) Boarding order: Window-rear-seat prioritized order, (d) Boarding order: Reverse-pyramid order

5.3 The boarding orders

Airline staffs announce the agent to start boarding at the boarding lounge. Then, the agents start to board by either of the following six boarding orders.

- First-come First-served order (fcfs): Under this order, the agent start to board by the order of arrival at the boarding gate. No agent distracts the assumed boarding order in this case.

- Window-seat prioritized order (w-a): Under this order, agents who reserved window-seat can board with first. After all agents who reserved the window-seat are seated, agents who reserved aisle-seat are allowed to board (refer to Fig.4(a)).

- Rear-seat prioritized order (r-f): Under this order, agents who reserved seat at rear side are allowed to board first. Subsequently, after all agents who reserved the rear-seat are seated, agents who reserved front-side-seat start to board (refer to Fig.4(b)). Some of the agents who reserved front-side-seat ignore the instruction of the boarding order and start boarding before all the rear-seat agents are seated.

- Window-rear-seat prioritized order (w-a+alpha): under this order, agents who reserved rear-seat at window side board first. Subsequently, after all agents who reserved the rear-window-seat are seated, agents who reserved the rear aisle seat board next, and after that, the agents who reserved the front-window-seat are called and the front-aisle-seat finally follow (refer to Fig.4(c)). In this case, some of the agent ignore the instruction of the supposed boarding order and try to board before they are called by airline staffs.

- Reverse-pyramid order (rp): under this order, the agents who reserved 2/5 part from the back of the aircraft of window side board the first. Subsequently, after all agents who reserved the 2/5 rear-window-seat board, agents who reserved the 2/5 part of rear-aisle-seat and 3/10 of central part of window-seat are allowed to board. After that, agents who reserved the 3/10 of central part of aisle-seat and the 3/10 of front part of window-seat board. And finally, agents who reserved the 3/10 of front part of aisle-seat board (refer to Fig.4(d)). Agents who ignore the Reverse-pyramid order start boarding in the wrong period even they have not yet been called.

- Unreserved seat (unreserved): Related studies indicate there is a tendency for many agents to choose seat of the front part. Under this boarding order, no agents are considered to violating the boarding order as well as the case in first-come first-served order. First-come first-served order is often used by Low Cost Carrier (LCC). However, Rear-seat prioritized order is most frequently used by LCC, while window-seat prioritized order and window-rear-seat prioritized order are used by some airlines. Reverse-pyramid order is not used by most of airlines and is only for experimentally use. Some American airlines introduce unreserved seat and it is known that many passengers tend to choose seats of the front part.

6 Numerical Example

We perform simulation based on the model of the environment, the behavior of agents, and boarding orders which were showed in Section 5. We use Multi-agent simulator artisoc[10] to perform this simulation. We perform this simulation 30 times to compute the boarding time for each boarding order. We calculate average time from the results of 30 trials. When we compute boarding time, we regard time to proceed a certain distance on this model as "1 step".

In the simulation, there is a boarding gate and an aisle. The number of rows is $I = 20$, and the number of seat in each of the row is $J = 4$. So, the total number of the seats is 80. At the initial state, all seats are not used. All seats are to be used in this simulation. In addition, we assume all the agents are already set at the boarding lounge and no agents are absolutely late for the boarding time. After agents start boarding, they proceed with a certain regular interval. All agents move quickly after listening to the instruction of the boarding order, so we do not consider the possibility of the extension of the boarding time due to the complexity of the boarding order. We define the rate of agents who put their baggage as 50% on average because they have little baggage when they use a narrow body aircraft. We define the waiting time for another agent who put the baggage as from 1 to 5 steps and the waiting time for another agent who moves back to the aisle as 5 steps. The waiting time for another agent who put the baggage is decided by the random variable.

We show the difference in the average boarding time by changing the rate of agents who violate the boarding order range from 0% to 50% as shown in Fig.5. The comparison of average boarding time of each boarding order from Fig.5 we figured out the average boarding time is minimized in Reverse-pyramid order under the condition of no agents violate the boarding order, followed by, window-rear-seat prioritized order, window-seat prioritized order, rear-seat prioritized order, First-come First-served order. The Unreserved seat was longest among these orders. As the rate of agents who violate the boarding order changed, we did not find the significant difference in order of the average boarding time in most of the cases. But the average times were converged when the rate of violators increased in Reverse-pyramid order Window-rear-seat prioritized order, and window-seat prioritized order. Under the rear-seat prioritized order, the average time becomes longer than the cases in First-come First-served order and Unreserved seat when the rate of violators was more than 20%.

When the rate of violators increases, the difference in time between Reverse-pyramid order and Window-rear-seat prioritized order become small. This suggests Window-rear-seat prioritized order should be shortened the boarding time as well.

We focus on the results of Rear-seat prioritized order and Window-seat prioritized order.

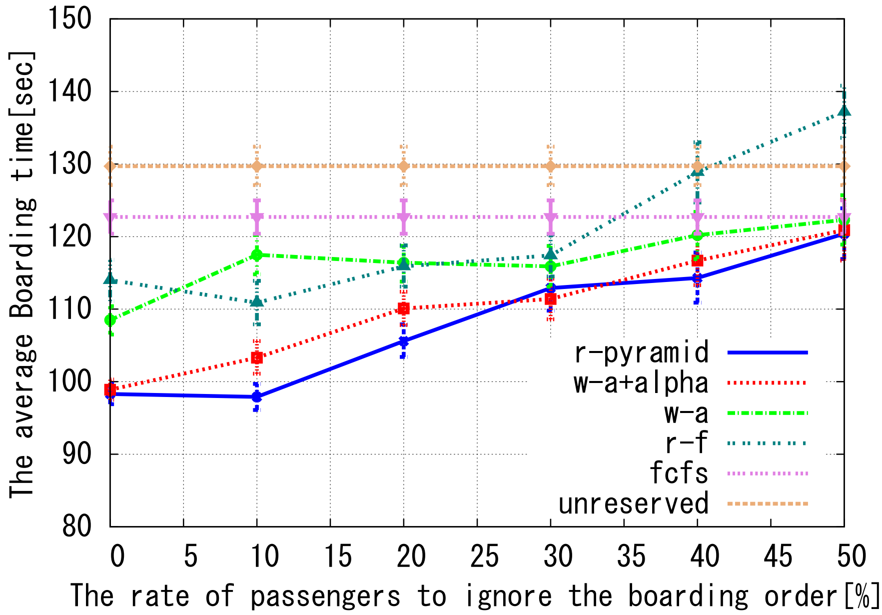

Figure 5: Average boarding time each of boarding order, when there is rate of agents who ignore the boarding order

The average time of Rear-seat prioritized order became increasingly long when the rate of violators is more than 20%. On the other hand, the average boarding time of Window-seat prioritized order became only slightly long when the rate of violators was more than 10%. From this, it is suggested it is important to let agents of rear-seat board first. We found it becomes even more important when the rate of violators increases.

We focus on the results of Rear-seat prioritized order and Unreserved seat. When the rate of violators increases, Rear-seat prioritized order becomes similar to the Front-seat prioritized order. We performed simulation regarding that agents tend to choose to be seated front part of the aircraft when it is in the unreserved seat situation. As a result, the average time of Rear-seat prioritized order becomes longer than unreserved seat when the rate of violators increases.

Now, we define the rate of violators as r. Tab.1. shows the number and the rate of agents who move to the aisle, when the rate of violators changes.

From Tab.1, when the rate of violators is 0%, the number of agents who move to the aisle is 0.00 in Reverse-pyramid order and Window-rear-seat prioritized order and Window-seat prioritized order. The number of agents who move to the aisle in Rear-seat prioritized, First-come First-served order and Unreserved seat is not 0. The number of agents who move to the aisle in First-come First-served order is largest. The number of agents who move to the aisle in Rear-seat priority order and Unreserved seat are about the same.

We focus on the average number of agents who move to the aisle in First-come First-served order and Unreserved seat when the condition of the rate of violators is 0%. The number of agents who move to the aisle in First-come First-served order is larger than Unreserved seat. However, from the result of average boarding time at Fig.5, the time of First-come First-served order is shorter than that of Unreserved seat. Therefore, we confirmed it had much effect to let agents of front seat board earlier.

When the rate of violators increases, the average number of agents who move to the

Table 1: The number of agents who move to aisle and the rate of the number of agents who move to aisle

Boarding order	Number of agent(average)					
	0.0%	10.0%	20.0%	30.0%	40.0%	50.0%
r-pyramid	0.00	0.27	1.87	5.60	9.80	14.73
w-a+alpha	0.00	0.23	1.57	4.87	8.60	13.03
w-a	0.00	2.90	6.33	10.57	14.47	22.10
r-f	19.63	19.23	19.30	21.93	27.37	28.67
fcfs	20.93	20.93	20.93	20.93	20.93	20.93
Unreserved	19.73	19.73	19.73	19.73	19.73	19.73

Boarding order	Rate[%]					
	0.0%	10.0%	20.0%	30.0%	40.0%	50.0%
r-pyramid	0.00	0.33	2.33	7.00	12.25	18.42
w-a+alpha	0.00	0.29	1.96	6.08	10.75	16.29
w-a	0.00	3.63	7.92	13.21	18.08	27.63
r-f	24.54	24.04	24.13	27.42	34.21	35.83
fcfs	26.17	26.17	26.17	26.17	26.17	26.17
Unreserved	24.67	24.67	24.67	24.67	24.67	24.67

aisle in Reverse-pyramid order and Window-rear-seat prioritized order, window-seat prioritized order increased. We focus on the average number of agents who move to the aisle in Reverse-pyramid order and Window-rear-seat prioritized order. We found the average number of agents who move to the aisle in Reverse-pyramid increased when the rate of violators is more than 30%. This suggests it is not effective to divide into three such as front part and center part, rear part.

We also compare to add the result of Window-seat prioritized order. When the rate of violators slightly increases, the average number of agents who move to the aisle becomes largest in Reverse-pyramid order and Window-rear-seat order. From this result, we confirmed it is effective to divide into four sections such as front-seat and rear-seat condition to the window side and the aisle side. At last, we consider Rear-seat prioritized order. The average number of agents who move to the aisle do not increase in comparison with the average number of agents who move to the aisle when the rate of violators is 0%. However, the average number of agents who move to the aisle increases when the rate of violators is more than 40%. Therefore, we confirmed it is effective to divide into more than two seat areas. It has a larger effect in that agents who reserved the rear-seat board first than the effect of the increase of the average number of agents who move to the aisle.

7 Conclusion

In this study, we did the simulation was carried out in consideration of the passenger's shallow experiences violating the designated boarding order using the agent-based model. When all passengers boarded properly, I confirmed that the optimum boarding order is reverse-pyramid. However, we found it is effective to board in Window-rear-seat prioritized order because its average boarding time is similar to that of Reverse-pyramid order when the rate of violators increased. In addition, it is suggested that seating the rear-seat first is important by the comparison between Rear-seat prioritized order and window-seat prioritized order.

For future issues, we should introduce an agent's attribute relation of passengers to perform simulation such as wife and husband or friends where they board together in the process of boarding. In addition, each agent should be decided the speed by whether he has baggage or not. In the simulation in this study, all agents are assumed to be ready at the boarding lounge, some agents might be late and end up to causing extension of boarding time or due to the complexity of the instruction of boarding order in actual situations.

We extend agent-based simulation model from narrow-body to wide-body and apply it for long distance flight.

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