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Using Simulation to compare Aircraft Boarding Strategies

Ein simulationsbasierter Vergleich von Boarding Strategien für Passagierflugzeuge

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Abstract: The boarding process has a very important role in the objective of increase the efficiency, profitability, and customer satisfaction of an airline industry. It is one of the significant elements of the turnaround time, a slow boarding process might lead to financial issues to the company and, of course, customer complaints. In this paper are analyzed three boarding strategies presenting a model and an easy to use tool that implements it. The study suggest that differences exists among them, and proposes the most efficient strategy.

1 Introduction

It has been found that many previous works refer to the boarding process as a problem, since it is an activity that cannot start until processes such as fuelling, cleaning or catering are ready. Of course, the main priority during a boarding process is always safety, rather than carrying out a fast boarding. This explains why sometimes the boarding process does not start until fueling is finished, even when it could be done. In addition to this, airline managers have to be aware that the most cost-effective boarding process will have to maintain quality and customer satisfaction.

One of the purposes in reducing the boarding time refers to reduce the number of interferences between passengers inside the airplane. A boarding interference is defined as an instance of a passenger blocking the access of another passenger to his seat. Therefore, the minimization of the total boarding time is related to the minimization of passenger interferences. Also, the total boarding time is related to the number of carry-on luggage that passengers have.

This paper is mainly focused on the boarding process using a bridge. The most popular boarding strategies adopted by the airlines are the following:

- Back-to-front (BtF) boarding policy is the traditional strategy, adopted by most airlines for both narrow and wide-body aircraft. This strategy consists in boarding first class firstly. Then, passengers are called in groups to board the aircraft, following the sequence from back to front.
- Front-to-Back (FtB) boarding policy is other strategy. This strategy consists in boarding first class firstly. Then, passengers are called in groups to board the aircraft, following the sequence from front to back.
- Random boarding strategy does not specify any condition while boarding passengers and the aircraft is boarded in one zone randomly. First class passengers are also boarded firstly. Then, passengers board the airplane in a first-come first-serve basis; or in other words, following a FIFO process (first-in first-out).

In this paper, simulation is used to analyse the aforementioned policies in order to search for the most efficient boarding strategy. The paper is structured as follows: section 2 provides a brief overview of related work. Section 3 describes the model and section 4 includes some numerical experiments. Finally, section 5 summarizes the main results.

2 Related work

The aircraft passenger boarding problem has been previously studied mostly through simulation-based solutions for analysing and improving passenger airplane boarding. Marelli et al. (1998) conducted a simulation-based analysis performed for Boeing. Boeing Corporation created a computer simulation model called Boeing Passenger Enplane/Deplane Simulation (PEDS). The result of its study was that the outside-inside boarding strategy reduced boarding times significantly. Van Landeghem and Beuselinck (2002) carried out a simulation study based on airplane boarding. According to this study, the fastest way to board the passengers on an airplane was to do it individually by their row and seat number. Van den Briel et al. (2005) did not take into account airplane design parameters, and the study showed how strategies based on reducing interferences are better than the traditional back-to-front policy. These authors designed the so-called reverse-pyramid method, with the aim of boarding passengers while utilizing as much as possible the aircraft. The model was mainly developed to minimize passenger boarding interferences, and it was used MINLP, a mixed-integer nonlinearly constrained optimization solver.

Bauer et al. (2007) developed a computer simulation to model the boarding process. These authors considered different boarding strategies and individual variations of passengers. Additionally, they treated the boarding problem as a stochastic process, and specifically, they used queuing theory to reach a better understanding of bottlenecks and their effects.

3 The model

Our model is defined using Specification and Description Language (ITU-T, 2012), a graphical formalism that allows a complete and unambiguous representation of the system behaviour. This formal representation of the model simplify its implementation using different platforms and tools, and also helps us in the future improvement of the model.

The main diagram SYSTEM, represented in **Figure 1**, contains the main processes (SDL PROCESS) that compose the model. In our case 3 processes defines the behaviour of the model:

1. P_PAXArrivals: Defines the arrivals of passengers to the finger in order to start the boarding process. In this process first are considered the passengers for the first class.
2. P_FingerDoor: Represents the waiting zone where the passengers wait until starts his boarding process. Here are defined the different algorithms that rules the way the passengers enters in the plane.
3. P_Plane: In this model, the plane is just a PROCESS that represents the boarding process, in this model is not represented the complete structure of the plane, only the positions that own.

This first diagram details the structure of the model.

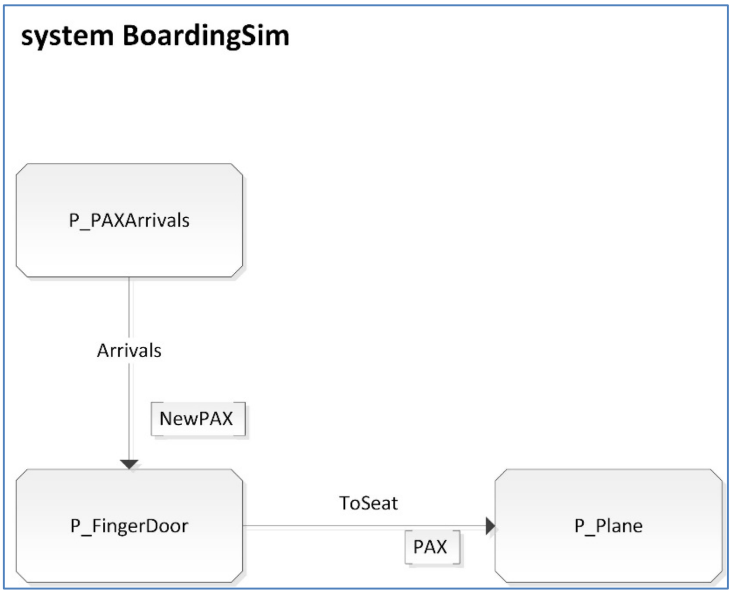

Figure 1: *System diagram, model main elements. Here the three main process that defines the model behaviour are represented.*

Each one of these SDL PROCESS can be detailed, defining the behaviour of the model. **Figure 2**, **Figure 3** and **Figure 4** details the behaviour for *P_FingerDoor* and *P_Plane*. *P_PAXArrivals* is a process that define the arrival process of the different passengers to the model. In our case this process is quite simple, since we suppose that all the passengers are at the beginning of the boarding process in the gate.

P_FingerDoor PROCESS (**Figure 2**) details the movement of the different passenger's thought the gate to the plane. Here is assigned the seat for each passenger on a PROCEDURE named *AssignSeat*. This procedure depends on the policy to test, represented by a number (1 representing Random, 2 representing BtF and 3 representing FtB).

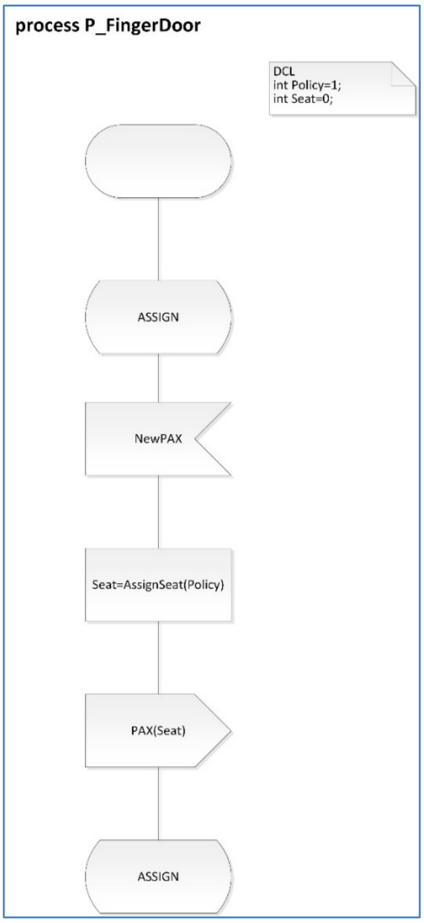

Figure 2: *PROCESS P_FingerDoor, on the PROCEDURE AssignSeat is defined what is the seat to be used by a passenger depending on the Policy we want to test.*

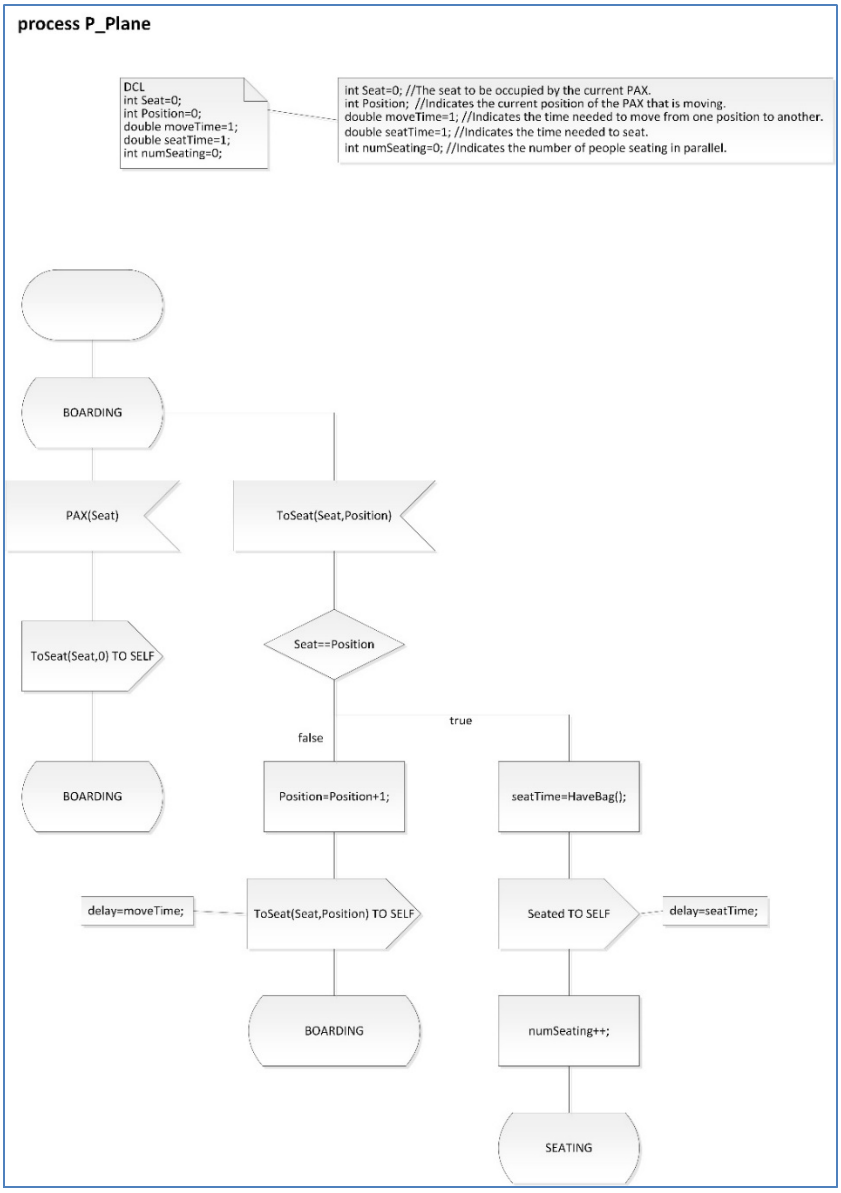

Figure 3: *P_Plane BOARDING state*

The model takes care of the movement of the passengers inside the plane and the possible queues due to the limited space inside the cabin. *P_Plane* represents the movement of the passengers inside the plane to reach its final seat. Each passenger has a final position and needs a time to reach this position. Also, this movement can be delayed due to the interference with other passengers. The time needed to seat, obtained from the PROCEDURE *HaveBag* takes care if other passengers exists in the row. In that case the delay needed to seat increases. Also this PROCEDURE analyses if is needed more time to store carry-on luggage.

Figure 4: *P_Plane SEATING state*

P_Plane owns two states, BOARDING and SEATING. On BOARDING state the passengers are in movement, to reach its final position, on SEATING state the passengers are waiting until all the passengers that are in the position are seated.

4 Numerical Experiments

In this article, three boarding strategies are tested (Random, Back-to-Front, and Front-To-Back).

We have only considered airplanes with one single aisle in the center, and three seats in each size of this aisle. These three specific types of airplanes correspond to mid-sized airplanes. We have not considered small nor large airplanes because, since they have a different configuration of seats, we would have had to change the model layout.

As a medium-small commercial airplane, we have considered an Airbus A320 (see **Figure 5**), which allows a total of 152 passengers (8 in first class and 144 in economy class); secondly, a Boeing B757-200 (see **Figure 6**) with capacity of 178 passengers (16 in first class and 162 in economy class) has been used as a medium airplane; finally, as a medium-large aircraft we have considered a Tupolev Tu-214 (see **Figure 7**) that allows a maximum of 212 passengers (32 in first class and 180 in economy class).

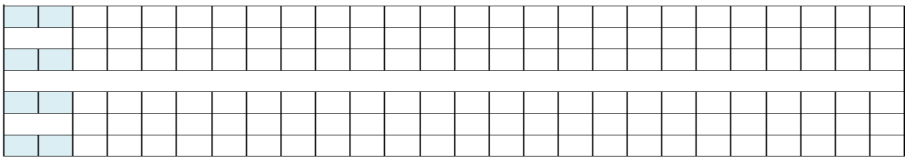

Figure 5: *Medium-small airplanes (Airbus A320). Configuration 8/144, first class: 2 rows * 4 seats and economy class: 24 rows * 6 seats.*

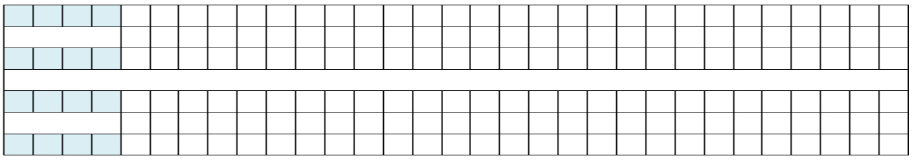

Figure 6: *Medium airplanes (Boeing B757-200). Configuration: 16/162, first class: 4 rows * 4 seats, economy class: 27 rows * 6 seats.*

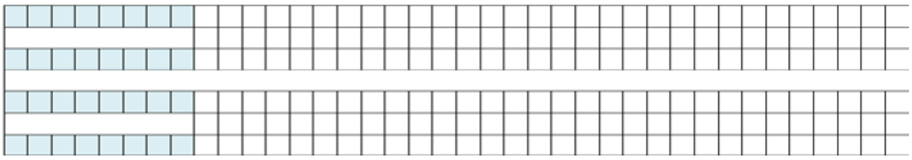

Figure 7: *Medium-large airplanes (Tupolev Tu-214). Configuration: 32/180, first class: 8 rows * 4 seats, economy class: 30 rows * 6 seats.*

Also according to the occupancy level, our model has considered two different specific scenarios to study within each aircraft classification:

Medium-small airplanes (Airbus A320: 152 passengers):

- medium occupancy level: 76 passengers (4/72)
- high occupancy level: 152 passengers (8/144)

Medium airplanes (178 passengers: Boeing B757-200):

- medium occupancy level: 89 passengers (8/81)
- high occupancy level: 178 passengers (16/162)

Medium-large airplanes (212 passengers: Tupolev Tu-214):

- medium occupancy level: 106 passengers (16/90)
- high occupancy level: 212 passengers (32/180)

The model assumes some other parameters as a constants:

- Walking time per row = 1 time unit (0.5 seconds)
- Seating time interference = 10 time unit (5 seconds)
- Baggage stowage time = 12 time unit (6 seconds)

In each scenario 30 iterations have been computed to test its robustness. Because of the quantity of information extracted from each scenario, a sample has been chosen. An Analysis of Variance (ANOVA) for the scenario Medium–Large aircrafts with Medium Occupancy level has been done. The results from this ANOVA tests (p-value = 0.000 and non-overlapping confidence intervals) allow us to conclude that there exist significant differences in average boarding times among the different boarding policies considered.

Table 1 summarizes the results associated to the 18 different scenarios considered. Figure 8 and Figure 9 shows the box-plots for the medium-large airplanes (Tupolev Tu-214) for medium and high occupancy.

Table 1: *Summary Results. On the model BtF and FtB random appears mainly because the passengers in each row can be situated following different ordination patterns, that means not always the first person that arrive to the row is who must be seated on the window seat.*

	Medium-Small Aircraft			
	Random	BtF	FtB	nIterations
Medium Occupancy Level	495.8	565.1	747.1	30
High Occupancy Level	1008.5	1330.9	1522.7	30
	Medium Aircraft			
	Random	BtF	FtB	
Medium Occupancy Level	574.1	654.4	855.7	30
High Occupancy Level	1140.8	1517.9	1746.2	30
	Medium-Large Aircraft			
	Random	BtF	FtB	
Medium Occupancy Level	663.1	754.5	957.6	30
High Occupancy Level	1314.3	1707.8	1934.1	30

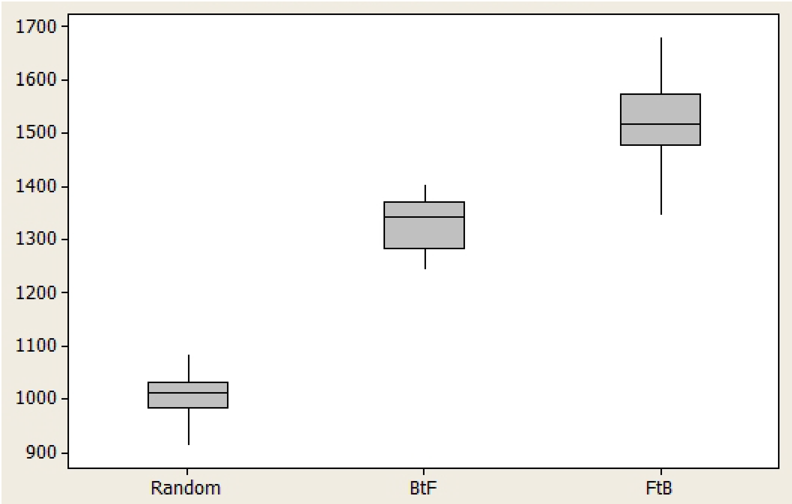

Figure 8: *Box-plot for high occupancy level (100%). Medium-large airplanes (Tupolev Tu-214).*

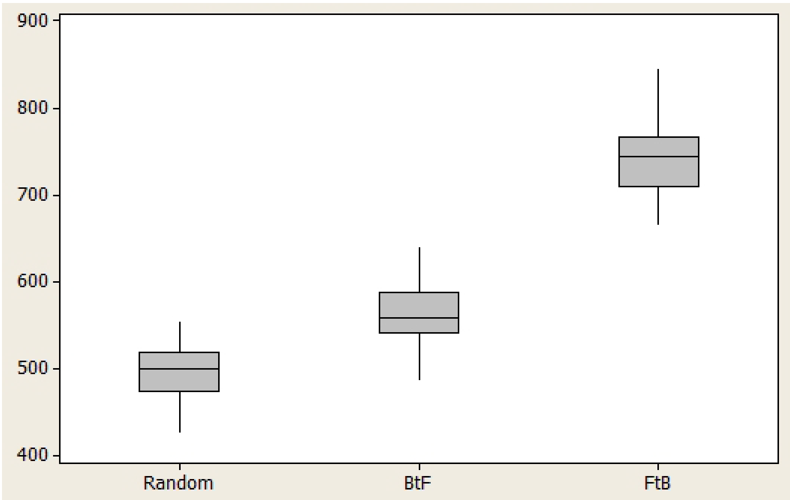

Figure 9: *Box-plot for medium occupancy level (100%). Medium-large airplanes (Tupolev Tu-214).*

5 Concluding remarks

In this study we analyse only the case of boarding passengers through the bridge, without considering the case where aircrafts park at a remote stand. This implies that the passengers are emplaned using one single door. Also, in the considerations used in this study, we analyse only planes with one aisle in the center, and three seats in each side off the aisle, with the category of mid-size planes.

Our results seem to confirm that the traditional back-to-front approach is not the most efficient one. In contrast, the random boarding strategy seems to perform the best in all scenarios. Some studies suggested that airline managers should apply a certain boarding method according to the airplane size, or the occupancy of the flight and aircraft size. However, basing on our simulations, the random method must be seriously considered to be used by airlines. Also, as observed proved in our simulation study, as well as in some studies analysed in the literature review, the passenger occupancy level becomes a very important factor. The results of the simulation show how the time difference between boarding methods increases as the occupancy level raises.

Other contribution of this paper is the simplicity of the model and its usability through the Excel that implements the model.

For future work it would be desirable to real-life data representing uncertainty in the system by using some probability distributions, e.g. statistical distributions (i.e. Weibull, or LogNormal. Gamma, Normal) to test possible behaviours. A more accurate model could consider airplanes with for seats per row and one single aisle, as well as large airplanes with two different aisle. Thereby, passengers were enplaned using one single door. The airplane used for the simulation took under consideration those with one single aisle in the center and three seats in each size of this aisle. These types of aircrafts are classified in the category of mid-sized airplanes. Therefore, in this paper, we have presented a simulation-based approach for solving the boarding process problem.

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