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Article

A Simulation Study of Aircraft Boarding Strategies

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Abstract: To ensure the safety of passengers concerning virus propagation, such as COVID-19, and keep the turnaround time at low levels, airlines should seek efficient aircraft boarding strategies in terms of both physical distancing and boarding times. This study seeks to analyze the impact of different boarding strategies in the context of the International Air Transport Association's recommendations during the pandemic to reduce interference and physical contact between passengers in airplanes. Boarding strategies such as *back-to-front*, *outside-in*, *reverse pyramid*, *blocks*, *Steffen*, and *modified optimal* have been tested in this context. This study extends the previous literature using discrete event simulation to evaluate the impact of the occupation of the middle seat by family members only. This study also analyses the impact of having passengers carrying hand luggage and priority passengers on the performance of these strategies concerning boarding times. In general, the simulation results revealed a 15% improvement in boarding times when the *reverse pyramid* strategy is used compared to a random strategy, which essentially results from a reduction in the boarding interferences between passengers. The results also show that *Steffen's* strategy is the best performing, while the *blocks* strategy results in the worst performance. This study has practical implications for airline companies concerning both operation efficiency and passenger safety.

Keywords: COVID-19 pandemic; boarding strategies; discrete-event simulation

MSC: 68-04

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1. Introduction

The recent pandemic caused by the COVID-19 virus (SARS-CoV-2) has been a source of concern for airlines regarding safe flight environments. The main reason is that infected people may experience no symptoms. Nevertheless, they may have high viral loads and spread the disease [1]. Furthermore, the effects of pandemics may have an important economic impact on airline companies [2]. In this context, airlines struggle to increase passenger safety in air transport, and amongst other measures to reduce the risk of contagion, passenger boarding has been subjected to physical distancing [3]. A minimum distance of 1 to 2 m between passengers was recommended by the International Air Transport Association (IATA) [4]. IATA also recommended ensuring a limited number of passengers passing each other, sequential boarding, and keeping empty seats.

To ensure not only the safety of the passengers but also to reduce the boarding time, the interference between passengers should be minimized to smooth the passenger flow during the boarding process. This means that airlines must adopt efficient boarding strategies to reduce the turnaround time and increase profit. This is because the boarding process significantly contributes to delays in the turnaround time, an important source of uncertainty [5].

In this study, we develop a simulation tool using Arena® 14.0 software to analyze the impact of different boarding strategies on an Airbus A320. In particular, this study addresses the IATA recommendations for ensuring an unoccupied middle seat to reduce the risk of contagion. This study extends the research of Schultz and Soolaki [6] and Cotfas et al. [7] using discrete event simulation to consider the occupation of this middle seat only by family members. This allows for an increase in aircraft capacity, thus reducing the economic loss of unoccupied seats. This will also allow families to board and travel together, increasing passengers' satisfaction and sense of safety, which is particularly relevant for families traveling with children. This study also considers the impact of having passengers carrying hand luggage and priority passengers in the performance of different boarding strategies. Boarding strategies such as *back-to-front*, *outside-in*, *reverse pyramid*, *blocks*, *Steffen*, and *modified optimal* have been tested in this context.

The remainder of this study is organized as follows. Section 2 reviews the existing literature concerning aircraft boarding strategies in the context of a pandemic. Section 3 describes the methods used to carry out this study, including the simulation model and assumptions. Section 4 presents and discusses the simulation results, and finally, in Section 5, this study's main conclusions and directions for future research work are put forward.

2. Literature Review

The recent pandemic scenario has had a huge impact on mobility with serious implications for economic and social activities. In order to reduce the spread of the virus and prevent deaths and the burden on local health systems, most nations have promoted specific measures, such as physical distancing, travel restrictions, and the temporary suspension of commercial and social activities [8]. The airline industry has been no exception and was impacted on a worldwide scale by the pandemic. To keep air travel operational and restore passengers' confidence, airlines had to implement measures to prevent contagion and virus propagation [9]. The IATA medical advisory group has recommended measures such as keeping empty seats [4] and blocking middle seats have been implemented, for example, by Alaska Airlines, Wizz Air, and EasyJet [10].

For many airline companies, the issue of physical distancing has led to a reduction of approximately one-third in the maximum seating capacity of the aircraft. This was due to the implementation of the 'empty middle seat' policy, which required the seat in the middle, between the window and the aisle, as shown in Figure 1, to be kept empty. A study undertaken by Barnett and Fleming [11] indicates that if the middle seat is kept unoccupied, the risk of COVID-19 contagion is reduced by half. Nevertheless, physical distancing between passengers in the aisle of the aircraft may lead to delays in the boarding process.

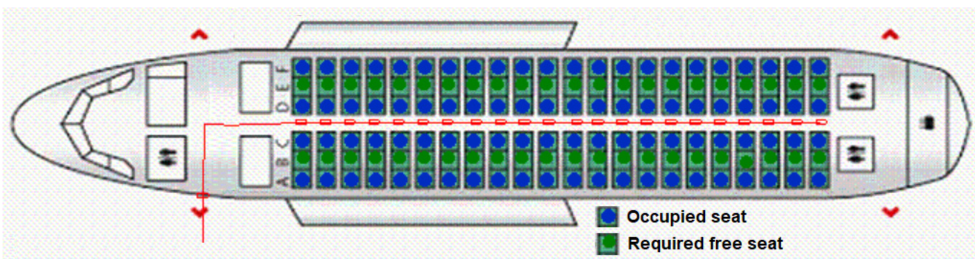

Figure 1. Configuration of an aircraft in a pandemic context.

Passenger interference in the boarding process occurs when one passenger blocks another passenger attempting to access their seat [12]. We assume there is a correspondence between the number of passenger interferences and the boarding time. Thus, by reducing passenger interferences, individual passengers' seating times will be shortened, and the overall boarding time will be reduced.

Passenger interference can be of two types: aisle interference and seat interference. Aisle interference occurs when a passenger is blocked in the aisle by another passenger, which usually occurs when hand luggage is stowed in the designated compartment. Seat interference occurs when a passenger wants to sit down but needs to ask a passenger already seated to get up. According to Delcea et al. [13] and Cotfas et al. [7], passengers may encounter four types of seat interference during the boarding process, as shown in Figure 2. However, in the context of the 'empty middle seat policy', the only possible type of interference is that of type 3; i.e., the passenger with a window seat will have to ask the passenger in the aisle seat to get up.

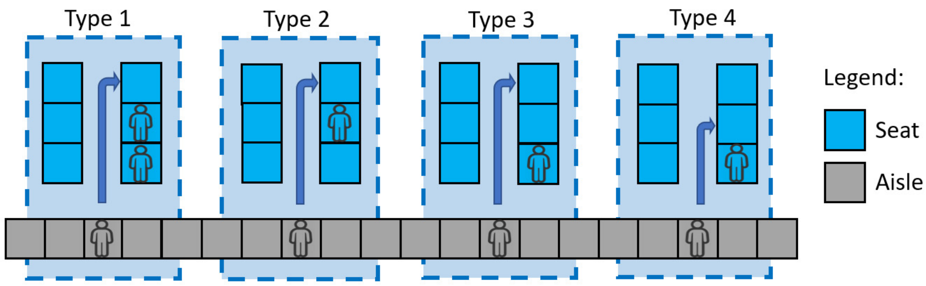

Figure 2. Types of seat interference (adapted from [7]).

Several boarding strategies have been used by airlines. These aim to sequence passengers during the boarding process to minimize the impact of the interferences. The main boarding strategies are as follows (see, e.g., [7]):

- Random: All passengers belong to a single boarding group, with passengers entering the aircraft randomly, allowing passengers traveling with friends or family members to board together. This approach is often used as a benchmark for other boarding strategies [14].
- Back-to-Front: In this strategy, the first passengers to board are those seated in the last rows of the plane. Boarding continues until the front rows are reached [14]. The back-to-front boarding strategy is usually simplified (to increase practicality) by aggregating rows of seats in blocks.
- Outside-In: In this strategy, the first passengers to board are those who have window seats. They are followed by passengers in the middle seats and, finally, those in the aisle seats. This strategy eliminates seat interference [15].
- Reverse Pyramid: This strategy is a combination of the back-to-front and outside-in strategies. Boarding takes place by allowing the simultaneous entry of passengers from back to front, as well as from the outside inwards. The first passengers to board are those in window seats and those who have middle seats at the rear of the aircraft. Passengers seated in the aisle in the front section of the plane are the last to board. This strategy eliminates seat interference [15].
- Blocks: In this strategy, airplane rows are divided into zones, each of these containing several rows. This strategy first boards passengers in the last rows (zone 1). The passengers who are in the front rows (zone 2) then follow. Subsequently, the order is repeated for the farthest zone (the last unoccupied rows), the front rows, and so on [15].
- Steffen: This strategy implies the call of the passengers one by one to board the airplane. This is carried out from back to front and from the windows to the aisles. Adjacent passengers in each row are seated two rows away from each other in corresponding seats (for example, 12F, 10F, 8F, 6F, 4F, and 2F). Passengers first occupy the even and odd rows on each side of the aircraft cabin, following the order of window seats, then middle seats, and, finally, aisle seats [14].

- Modified Optimal: This method consists of boarding passengers in alternating rows. Passengers are divided into four boarding groups. The first of these consists of all the passengers in even rows but only on one side of the plane. The second group includes all the passengers seated on the other side of the plane. The third and fourth groups are the passengers seated in odd rows on either side of the plane [15].

Several studies have been conducted to test boarding strategies on an aircraft. Different approaches have been used to address the problem, including simulation (e.g., [15–19]), analytical methods (e.g., [12,20]), and (3) experiments on the aircraft (e.g., [14,21]). The work of Bidanda et al. [22] reviews the literature dealing with the implementation of models aiming to optimize the boarding processes, achieving maximum efficiency.

Upon analyzing the literature results, Jaehn and Neumann [23] concluded that simple methods or even random boarding are more effective than the commonly used back-to-front strategy. The authors concluded that random boarding outperforms block strategies like back-to-front because it effectively channels the congestion caused by passengers stowing their carry-on baggage into a localized section of the airplane.

Concerning the impact of hand luggage, Nyquist and McFadden [24] showed that baggage restrictions may reduce boarding times. Later, Qiang et al. [25] developed a simulation model in which passengers carrying more luggage were allowed to board first. Kisiel [26] analyzed the sensitivity of the most common strategies regarding the number of priority passengers involved. Schultz [27] suggested modifying aircraft infrastructure to reduce the number of interferences between passengers.

Recently, Cotfas et al. [7] used a simulation to analyze the impact of the restrictions imposed or mooted worldwide on the boarding strategies used by the airlines, leaving the middle seat empty on each side of the aisle and compared their effectiveness with the classical airplane boarding methods. The authors concluded that the risk of contamination is reduced for most boarding strategies when the social distance between adjacent passengers advancing down the aisle is increased. Schultz and Soolaki [6] implemented passenger behavior in a stochastic cellular automata model, where passengers traveling together should be boarded and seated in a group, which is extended using a module to evaluate the transmission risk. This study shows that these groups significantly contribute to faster boarding and less transmission risk compared to the standard random boarding procedures when applied in a pandemic scenario.

Shultz et al. [28] studied the boarding problem in the context of COVID-19 using a stochastic agent-based model. They considered three scenarios regarding airplane occupation, namely 50%, 66%, and 80%. The authors sought to minimize the boarding time and the risk of contamination, first seating passengers next to the window and, lastly, next to the aisle. The results obtained were promising, with savings of more than 30% in the boarding time. In turn, Qureshi and Qureshi [29] developed a model using a Discrete Event Simulation (DES) under different policies and boarding strategies. The authors concluded that the most effective way to reduce contamination is Steffen's strategy, although it is the one that presents the greatest difficulties in practical implementation. On the other hand, they concluded that it becomes much easier to implement strategies such as the Reverse pyramid and Window Middle Aisle, with a marginal loss of effectiveness compared to Steffen's, also keeping the risk of COVID-19 contagion very low.

Qiang and Huang [30] studied the optimization of boarding in airplanes with a cabin that was equipped with side-slip seats. To assist the implementation of more complex strategies, the authors considered the development of a boarding assistant system. This system improves the process of automatically assigning seats to newly arriving passengers at an automatic seat distribution gate. Kobbaey et al. [31] address the issue of reducing boarding times through economic sustainability, given that airport occupancy is an important economic factor for airline companies and airport management. The authors used an autonomous agent-based simulation (ABS) to evaluate the impact of nine different boarding strategies. The results showed that a random strategy was the least affected by passenger non-compliance. They also concluded that the individual seating method is the one that performs better when the occupancy rate of the flight is high. When the flight occupancy rate is relatively low, all strategies perform acceptably. Withanachchi and Adikariwattage [32] also analyzed the different factors that impacted the boarding process considering variables such as the boarding strategy, the number of pieces of luggage, arrival rate, and average speed of passengers during boarding. The work made it possible to draw recommendations considering the parameters analyzed both for pre-pandemic and pandemic situations. Finally, Kobbaey and Bilquise [33] conducted a critical review of 12 studies that investigate the aircraft boarding problem using ABS, classifying the literature as follows: (a) studies that evaluated the efficiency of different boarding strategies, (b) studies that developed new boarding strategies, and (c) studies that analyzed the impact of restrictions imposed during the pandemic period.

Our study extends previous studies by considering an unoccupied middle seat in the implementation of boarding strategies. Furthermore, we also consider the situation of families that allows for the occupation of the middle seat by family members. This has social advantages for the family, who will be able to travel together, as well as economic benefits for the airline. The results generated by our study may be useful in the design of effective and safe intervention strategies.

3. Method

Discrete event simulation is a powerful tool that allows for the modeling and analysis of complex processes and systems [34–37] for which analytical models are not available. It allows for developing models based on real or hypothetical systems, predicting events from collected data, and evaluating the impact of different operating strategies [38–40]. It has been used by authors such as Qureshi and Qureshi [29], Milne and Kelly [41], Steffen [42], Tang et al. [20], and Briel et al. [43], among others, to address the aircraft boarding problem. Therefore, to identify the best boarding strategies, a discrete event simulation model for the boarding of an Airbus A320, one of the most used by commercial companies, was developed. Arena® 14.0 software was used to develop the logical model, animation, and graphical interface. The latter was developed using the Arena Visual Basic for Applications (VBA) to allow users to select the boarding strategy to test and define the strategy parameters.

3.1. Model and Parametrization

Three main parameters have been considered for each boarding strategy. These are as follows:

- Interarrival time: Time interval between passengers entering the boarding gate.
- Hand luggage delay: Time delay required for a passenger to stow their hand luggage in the desired compartment, which may cause aisle interference.
- Seat delay: Time delay caused by type 3 seat interference (refer to Section 2).

In our study, interarrival times between passengers at the boarding gate follow the Normal (6, 3) s. distribution, hand luggage delay follows the Normal (20, 10) s. distribution and seat delay follows the Triangular (10, 9, 12) s. distribution. Following previous works, such as Milne et al. [44], Salari et al. [45], and Schultz [46], among others, we assume that a jet bridge is used to transfer passengers from the boarding gate to the aircraft, with passengers boarding through one door.

An Airbus A320 model was used as a base for this study. The cabin of this aircraft consists of 30 passenger rows and 156 seats, with the following layout: the first-class seat between rows 1 and 6, each of which has four seats; rows 7 and 8 have no seats available, thus separating the economy class from first-class; economy class seat in the remaining cabin rows, each of which has six seats. The seats show the row number and one of the letters from A to F. In compliance with the rules imposed by the IATA, the aircraft capacity was reduced to 112 seats in compliance with the 'empty middle seat' policy'. However, in our experiments, when the family situation is considered, the aircraft capacity is increased according to the number of families.

Therefore, in addition to boarding strategies parameters (interarrival time between passengers, hand luggage delay, and seat delay), passenger population parameters concerning the number of passengers, the number of priority passengers, the number of families, and the percentage of passengers with hand luggage, and simulation parameters may also be adjusted by the user in the graphical interface (see Figure 3).

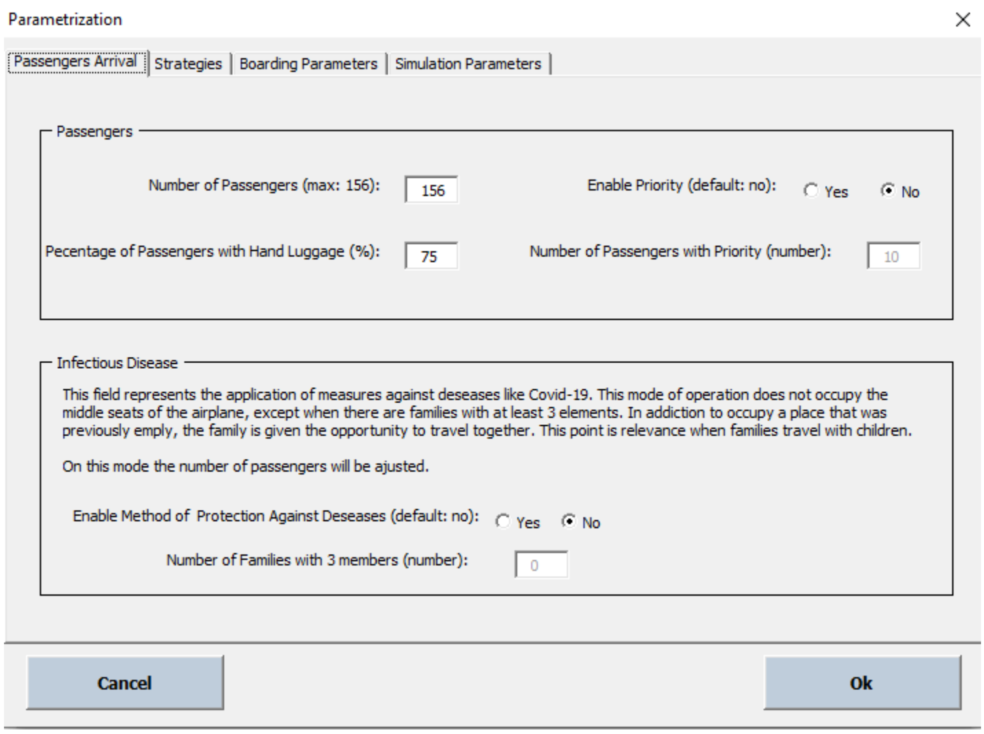

Figure 3. Graphic interface: passenger population parametrization.

A simplified model of the boarding process, containing the main decisions, is presented in Figure 4.

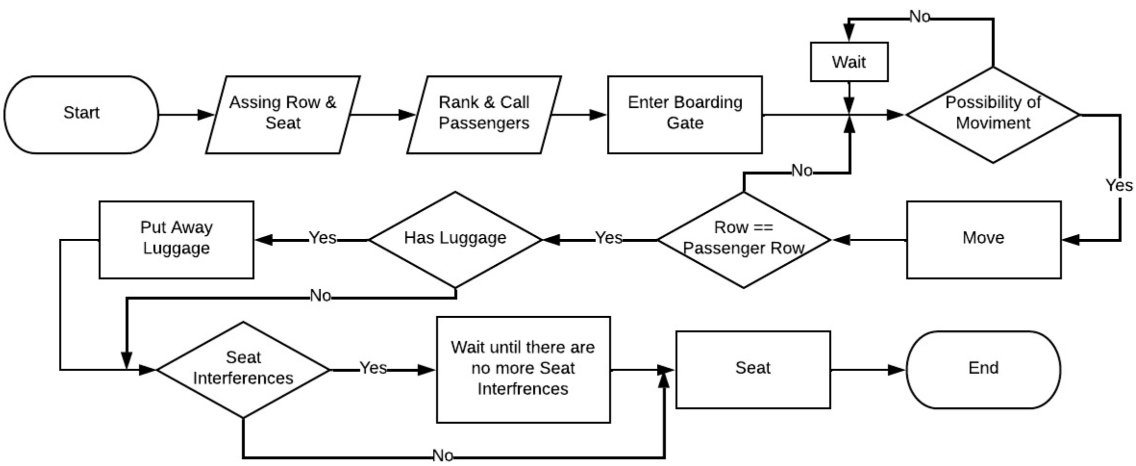

Figure 4. Simplified model of the boarding process.

3.2. Experimental Setup and Model Validation

The experimental factors and levels considered in our study are as follows: (i) the boarding strategies (*random*, *back-to-front*, *outside-in*, *reverse pyramid*, *blocks*, *Steffen*, and *modified optimal*), (ii) the arrival of passengers to the boarding gate (continuous arrival of passengers, and all passengers available), (iii) the number of priority passengers (0, 10, 20, 30, 40, and 50), (iv) the percentage of passengers with luggage (0%, 25%, 75% and 100%), and (v) the number of families in the flight (0, 5, 10, 15 and 20). Each experimental scenario was replicated 100 times.

Our main performance criterion is the total boarding time, which is the time between the first passenger entering the aircraft and the last passenger seated in the plane. In addition, we also collected the boarding time per passenger and seating rate, i.e., the inverse of time between passengers' seating.

Model validation constitutes an important phase of the simulation methodology [47,48]. It ensures the simulation model is a true representation of the real or hypothetical system and thus can be used in decision making. To this end, simulation results from our model have been compared with those of the literature in similar conditions (i.e., for the maximum aircraft capacity and under no empty middle seat policy). Model validation was also carried out using graphics and animation to check if the model was following the correct operational logic whilst running the simulation and using degenerate testing, where the model was run in extreme conditions to check if the model was behaving as expected for each one of the boarding strategies.

4. Simulation Results

4.1. Performance Assessment of Strategies

Figure 5 presents the results concerning the total boarding times of each boarding strategy, i.e., the time between the first passenger entering the aircraft and the last passenger seated in the plane for both of the following: (a) the continuous arrival of passengers during the boarding process, following the predefined interarrival time and (b) all passengers available at boarding time. Simulations were carried out considering the 'empty middle seat' policy, thus assuming the aircraft to have a maximum capacity of 112 available seats. It was also assumed there are 75% of passengers carrying hand luggage and no priority passengers.

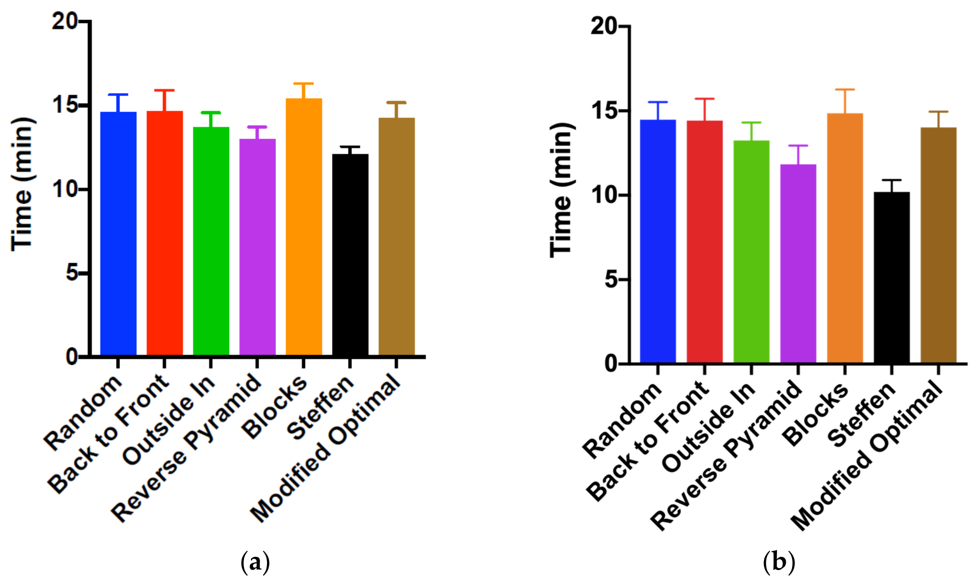

Figure 5. Average and maximum total boarding time for (**a**) continuous arrival of passengers during boarding and (**b**) all passengers available at boarding time.

As observed, the *Steffen* strategy results in the lowest total boarding time. However, the boarding time, as measured here, does not include the waiting time at the gate. *Steffen's* strategy tends to cause large queues at the boarding gate, as pointed out by, e.g., Jaehn and Neumann [23]. This derives from the procedure of boarding passengers one by one, in descending order, according to the seat number (except for first-class passengers). The strategy that performs closest to this is the *reverse pyramid* strategy, followed by the *outside-in* strategy. The *blocks* strategy results in the worst performance, whereas the *random*, *back-to-front*, and *modified optimal* strategies performed identically. While Stefan's strategy performs slightly better when all passengers are available at boarding time, the results concerning the relative performance of boarding strategies are identical for both the continuous arrival of passengers during the boarding process and all passengers available at boarding time.

Table 1 shows the average boarding times per passenger with the corresponding 95% confidence intervals under continuous arrival of passengers during the boarding process. It also presents the boarding time per passenger by type of passenger (with vs. without hand luggage) and the seating rate. The boarding time per passenger reflects the level of aisle and seat interference that results from the boarding process. The major difference in boarding times per passenger is found between strategies where seat interference occurs (*random*, *back-to-front*, *block*, and *modified optimal*) and those where seat interference does not occur (*outside-in*, *reverse pyramid*, and *Steffen*). In the latter strategies, only aisle interference occurs. Therefore, when comparing strategies where seat interference does not occur, the observed difference is caused by the amount of passenger overcrowding in the aircraft aisle area.

Table 1. Simulation results for 75% of passengers with hand luggage (continuous arrival of passengers).

Boarding Strategy	Boarding Time p.p. (min)	Boarding Time p.p. with Hand Luggage (min)	Boarding Time p.p. without Hand Luggage (min)	Seating Rate (Passengers/min)
Random	2.28 ± 0.093 *	2.37 ± 0.092	2.06 ± 0.103	7.81
Back-to-front	2.64 ± 0.126	2.69 ± 0.119	2.37 ± 0.116	7.78
Outside-in	1.85 ± 0.089	1.94 ± 0.090	1.60 ± 0.091	8.32
Reverse-Pyramid	1.78 ± 0.074	1.86 ± 0.072	1.55 ± 0.084	8.77
Blocks	2.43 ± 0.079	2.48 ± 0.089	2.10 ± 0.101	7.37
Steffen	1.22 ± 0.039	1.31 ± 0.039	0.99 ± 0.044	9.48
Modified Optimal	2.17 ± 0.092	2.22 ± 0.091	1.87 ± 0.098	7.98

* 95% confidence interval on the mean.

The next section's results are based on the continuous arrivals of passengers, as considering the availability of all passengers at the beginning of the boarding process does not lead to different conclusions.

4.2. Impact of the Percentage of Passengers Carrying Hand Luggage

Figure 6 shows a sensitivity analysis of the impact of the percentage of passengers with hand luggage on each boarding strategy. In this Figure, the percentage of passengers with hand luggage varied from 0% to 100% in steps of 25%. For all strategies, we can observe a positive correlation between the percentage of passengers with hand luggage and the total boarding time. That is the total boarding time increase with this percentage. However, the rate of increase is not the same for all strategies. The back-to-front strategy tends to degrade more than the remaining strategies. This is because boarding in the back-to-front strategy is made by blocks of rows, which tends to increase passenger interference within each block for a higher percentage of passengers carrying hand luggage. The *Stefan* strategy, on the other side, is not impacted by the percentage of passengers carrying hand luggage. This is because interference between passengers is practically non-existent once passengers are boarded one by one. Concerning the remaining strategies, the *reverse pyramid* presents a lower rate of increase, while the *blocks* strategy presents the highest. It should also be noted that the *back-to-front* strategy performed well when the percentage of passengers carrying hand luggage is lower than 50% while deteriorating its relative performance when this percentage approaches 100% due to the increase in aisle and seat interferences.

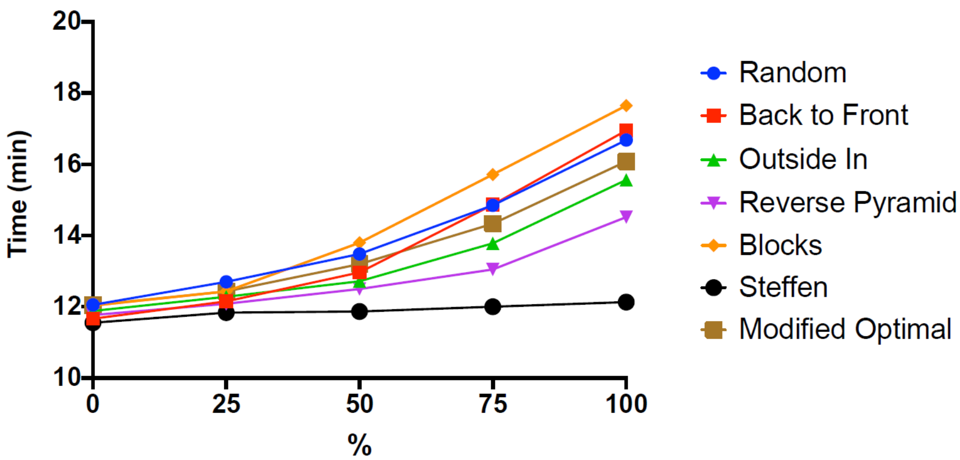

Figure 6. Total boarding time for different percentages of passengers carrying hand luggage.

Table 2 presents the boarding time per passenger and the seating rate for both situations: all passengers without hand luggage and all passengers with hand luggage. As can be seen, the boarding time per passenger greatly increases for all strategies when all passengers have hand luggage. In this case, differences between the performance of the boarding strategies become more visible. *Steffen's* strategy remains the best-performing strategy, followed by the *reverse pyramid* strategy, while *back-to-front* performs worst. When all passengers have hand luggage, this strategy results in the longest boarding time per passenger.

Table 2. Simulation results for all passengers with and without hand luggage (continuous arrival of passengers).

Boarding Strategy	All Passengers without Hand Luggage		All Passengers with Hand Luggage	
	Boarding Time p.p. (min)	Seating Rate (Passengers/min)	Boarding Time p.p. (min)	Seating Rate (Passengers/min)
Random	0.64 ± 0.003 *	9.26	3.01 ± 0.070	6.86
Back-to-front	0.64 ± 0.002	9.68	3.57 ± 0.104	6.73
Outside-in	0.59 ± 0.001	9.38	2.77 ± 0.077	7.35
Reverse-Pyramid	0.59 ± 0.001	9.60	2.58 ± 0.082	7.92
Blocks	0.64 ± 0.003	9.42	3.24 ± 0.085	6.46
Steffen	0.59 ± 0.001	9.76	1.52 ± 0.047	9.49
Modified Optimal	0.63 ± 0.002	9.33	2.87 ± 0.065	7.10

* 95% confidence interval on the mean.

For the situation with all passengers without hand luggage, there are no significant performance differences between strategies where seat interference occurs (random, back-to-front, block, and modified optimal) and between strategies where seat interference does not occur (outside-in, reverse pyramid, and Steffen).

4.3. Impact of the Number of Priority Passengers

Figure 7 presents a sensitivity analysis of the impact of the number of priority passengers. For most of the boarding strategies, there is not a (strong) impact on the number of priority passengers and boarding time. However, while the *reverse pyramid* tends to have a slight increase in the boarding time when the number of priority passengers increases, the *Steffen* strategy presents a strong increase. This is because these strategies are designed to eliminate seat interference; yet, with the inclusion of priority passengers, these interferences emerge once again. The *blocks* strategy showed a slight improvement in its performance as the number of priority passengers increased, while the back-to-front strategy presented a significant decrease. This is due to the reduction of passenger congestion in the same zone of the aircraft. If the number of priority passengers is equal to the number of seats available for the economy class (88, without middle seats), then all strategies will have the same time as random boarding because their behavior is identical; namely, there is only one boarding group.

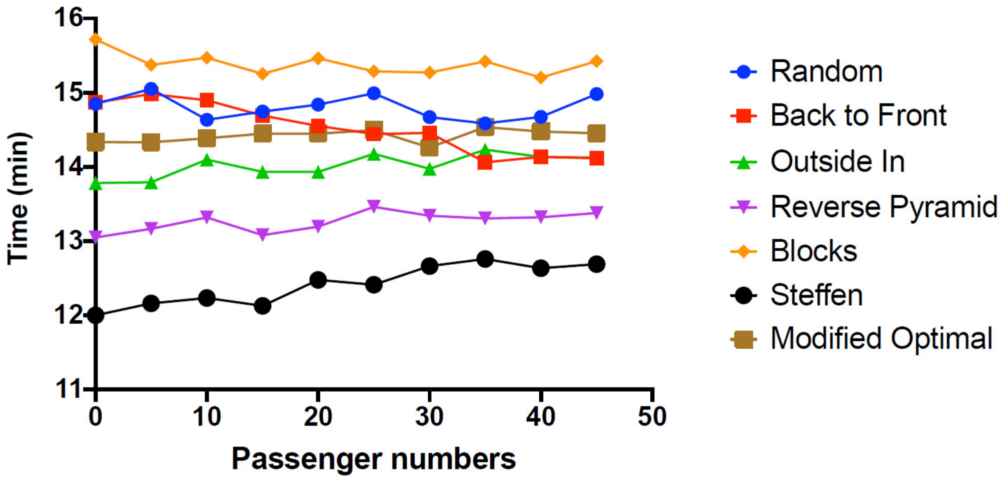

Figure 7. Boarding time for different numbers of priority passengers onboard.

4.4. Impact of the Number of Families

Figure 8 presents a sensitivity analysis of the impact of the number of families on board, thus allowed to occupy the middle seat, on the performance of boarding strategies. As can be seen, the *Steffen* strategy is the only one that does not have an impact on the boarding time when families are added. All the other strategies tend to deteriorate their performance concerning the boarding time as the number of families increases. This results from the fact that when there is a greater number of families, there are also more passengers; this, in turn, leads to more interference.

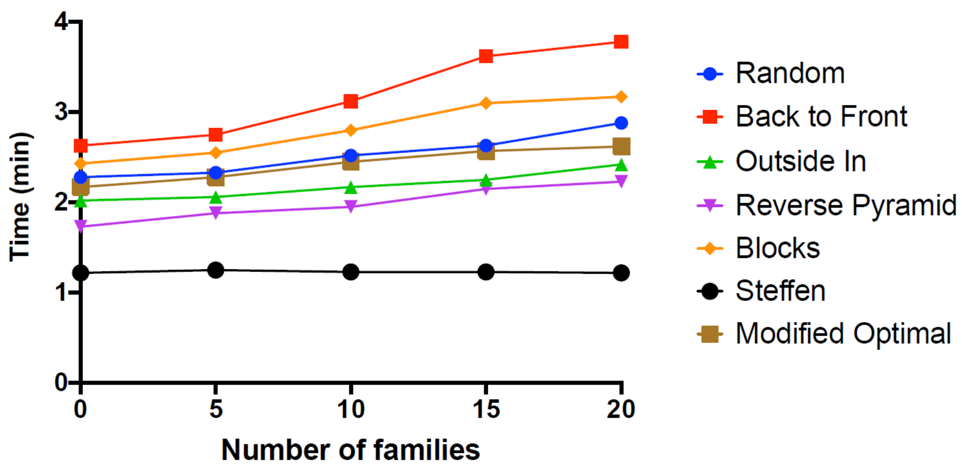

Figure 8. Boarding time per passenger for different numbers of families.

5. Conclusions and Future Research Work

In this work, a study on the performance of passenger boarding strategies on an Airbus A320 was carried out using discrete event simulations. Seven boarding strategies have been considered in this study: *random*, *back-to-front*, *outside-in*, *reverse pyramid*, *blocks*, *Steffen*, and *modified optimal*. This study extends previous research on boarding strategies in the context of physical distance measures to deal with pandemic situations by considering the occupation of the middle seat only by elements of the same family. This allows for an increase in aircraft capacity, thus reducing the economic loss of unoccupied seats while keeping passengers safe.

The *Steffen's* and the *reverse pyramid* strategies resulted in the shortest boarding times, while the *blocks* strategy showed to be the worst of the seven strategies tested concerning this performance measure. The *reverse pyramid* strategy achieved a 11% improvement compared to the random strategy considering that 75% of passengers carried hand luggage and the continuous arrival of passengers during the boarding process. Compared to the *blocks* strategy, the *reverse pyramid* achieved a 16% improvement under the same conditions. In the case of all passengers carrying hand baggage, the *reverse pyramid* strategy achieved an improvement of 15% compared to the random and 21% when compared to the *blocks* strategy. Moreover, considering the availability of all passengers at the beginning of the boarding process does not lead to different conclusions.

From this study, we may conclude that *Steffen* and *reverse pyramid* strategies lead to the least contact among passengers, thus reducing the possibility of contagion and lower boarding time. Our results are in line with previous results from the literature that ignore the impact of the middle seat occupancy by family members in a pandemic scenario. *Steffen's* strategy mainly is a theoretical strategy, given its implementation complexity. However, digitalization concerning the exchange of information between passengers and boarding operators may be used to find ways to implement it in practice. Future research is also needed to validate these results in a real environment and extend this study to other aircraft and aircraft capacities. Other considerations for future research work may include the physical agility of passengers and the counterflow movement of some passengers.

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