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OPTIMIZATION OF AIRCRAFT BOARDING PROCESSES CONSIDERING PASSENGERS' GROUPING CHARACTERISTICS

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ABSTRACT

Aircraft boarding is one of the critical processes affecting the turnaround time when a plane is at an airport. In this work, the aircraft boarding problem is studied with the aim of designing a boarding strategy that reduces the total boarding time considering the passengers' behavior as well as the underlying grouping relationships among them. Our analysis suggests that some of the strategies proposed in other studies are highly theoretical and do not consider the individual characteristics of the passengers or their grouping inside the plane. This limits their applicability and validity in real operations. We propose a novel boarding strategy that is designed to reduce the total boarding time while, at the same time, aims at guaranteeing an acceptable quality of service.

1 INTRODUCTION

The strong growth experienced by the air transportation industry in recent decades, along with its liberalization and the consequent increase in competition, has forced airlines to optimize all processes over which they have control to increase the efficiency of their operations and ensure its competitiveness in the market. Given that airlines will only generate income when their planes are flying, the time they are on ground must be minimized. This means trying to decrease the time scale at airports. The main purpose of this study, the optimization of the aircraft boarding process, is to provide new strategies to reduce the turnaround duration. This is achieved through the use of boarding policies that define the order in which passengers access the aircraft. As shown by the latest estimates made by organizations such as ICAO and IATA, as well as the main aircraft manufacturers (e.g., Airbus and Boeing); the air transportation industry expects an annual passenger volume growth of around 5% over the next 20 years. However, "the increase of the offer in air transportation is much slower than that of demand" (Tang et al. 2012). Thus, it is essential to increase the efficiency of existing operations.

It is possible to define the boarding process as the method used by the passengers of a flight to occupy its assigned seats. The boarding time encompasses the time needed to occupy the seats inside the aircraft cabin between the first and the last passenger. The boarding process is particularly critical in relation to the set of processes included in the scale operations. In fact, despite being one of the processes that determine the end of the scale, it usually requires a high percentage of the total time of the turnaround operation. As stated by some authors (Van Landeghem and Beuselinck 2002), the time associated with the scale operation usually takes between 30 and 60 minutes, and a large part of this time could be attributed to the passengers boarding process. In this paper, we analyze the problem of boarding passengers in aircrafts considering different boarding orders, so that the total boarding time is minimized. The problem of boarding passengers in an aircraft is of special interest for all those airlines that operate with short and medium flights and that, moreover, depend especially on the efficiency of their airport operations. This implies that the optimization of the boarding process is relevant for the so-called "low-cost "carriers. For this reason, our study will focus on the evaluation of different boarding strategies in single corridor aircrafts such as the Airbus A320 or the Boeing 737. According to some estimates (Nyquist and McFadden 2008), reducing the aircraft time scale by 1 minute implies a saving of approximately €22. Thus, for example, reducing in 1 minute the time scale for all flights of an airline with 300 daily flights involves an annual saving of €2,409,000. In addition, this paper aims at determining the optimal allocation of passengers' seats taking into account the location of the seats inside the aircraft as well as the passengers' individual characteristics –including the grouping relationships existing among them.

The paper is organized as follows: first, we will analyze the main boarding strategies in the literature. Next, Section 3 proposes a new boarding strategy, specially designed to take into account the individual characteristics of the passengers and the familiar or grouping relationships among them. In Section 4 and 5, we define the simulation experiment conducted. Based on the results obtained by the simulation experiment, Section 6 presents a series of statistical tests that allow us to study the behavior and the efficiency of each one of the boarding strategies considered. Finally, we present the main conclusions obtained from the study.

2 BOARDING STRATEGIES

In the scientific literature related to the passenger boarding problem, most of the works are focused on determining the best boarding strategies. However, as recognized by some authors, these studies usually do not take into account the variable properties of the movement of the passengers or their individual characteristics (Tang et al. 2012).

It is also important to note that any boarding strategy should be able to reduce the total time of boarding without negatively affecting the passenger's satisfaction, i.e., the quality of service being offered. This includes avoiding any type of discrimination. In addition, "the boarding strategies should be robust under the effects of different types of disturbances, such as delays of passengers, the aircraft size and the load factor" (Audenaert 2009). Finally, as noted by some authors, "(...)all efficient strategies have a tendency to separate neighbors from each other" (Ferrari and Nagel 2005). For these reasons, we consider that the individual and grouping characteristics of passengers are an essential factor which must be taken into account in order to guarantee the success of a boarding strategy. Before reviewing the different boarding strategies proposed in the literature, we describe the main conflicts and interferences that can appear in the boarding process.

2.1 Conflicts and interferences

Throughout the boarding process, given that passengers access to the aircraft together and due to the limitations of space established by the cabin dimensions, a series of interferences or conflicts among passengers will appear. Specifically, two types of conflicts among passengers can be distinguished: seat conflicts and aisle conflicts.

The aisle conflicts take place when a passenger tries to access the seat to which he/she has been assigned and is hampered by another passenger in the cabin corridor. Figure 1 (left) shows an example in which passenger 2, who has been assigned to seat 5A, is hampered by passenger 1, who has been assigned to seat 3F and is storing the hand luggage. In this case, passenger 2 is forced to wait until passenger 1 "releases" the path. Seat conflicts occur in those cases in which passengers are not allowed to access their destination seat because other passengers, who are already seated in the same row, are blocking the destination seat, as shown in Figure 1 (right).

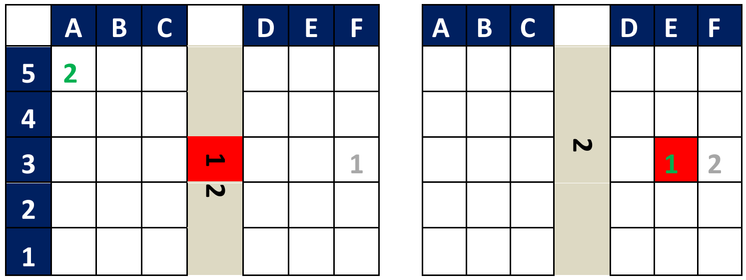


Figure 1. Examples of an aisle conflict (left) and a seat conflict (right).

2.2 The “at random” boarding strategy

As the name itself suggests, the strategy “at random” (see Figure 2) is based on using a uniformly random order to manage the boarding process. This means that passengers can access to the aircraft cabin, to occupy the seats to which they have been assigned, in the same order in which they are waiting at the boarding gate queue.

The at-random boarding strategy is especially popular among the “low cost” airlines due to its efficiency (Audenaert 2009) and the fact that it is a very appropriate strategy for companies that operate aircrafts with a single cabin configuration (“full economy”). Some airlines that use this boarding strategy are Jet2.com, JetBlue, Ryanair and WOW air.

A	B	C		D	E	F
1	1	1	AISLE	1	1	1
1	1	1		1	1	1
1	1	1		1	1	1

Figure 2. Boarding at random.

Note that the at-random boarding strategy must not be confused with the free-for-all or free-seating strategy. The latter differs from the former because on the free-seating strategy passengers are not assigned to a seat, but they access to the cockpit of the aircraft in the order in which they are waiting at the boarding gate queue and take the seat they prefer. A good example is the case of Southwest airlines, where passengers are assigned to three possible groups (A, B, or C) depending on the time in which they made the flight booking, and they are free to choose the seat they find most convenient accordingly.

2.3 The “back-to-front” boarding strategy

In the “back-to-front” boarding strategy, passengers are expected to board the aircraft in descending row order. This is achieved by starting the boarding process with the rows located in the rear of the aircraft, with the aim of eliminating any conflict in the corridor. This leads to a minimization of the total boarding time. However, in order to minimize corridor conflicts, passengers should be ordered on the boarding queue depending on the row they have been assigned to. This fact makes the back-to-front strategy mainly a theoretical strategy, given the complexity of implementing it in a real-life scenario.

Since it is not easy to sort passengers in the boarding gate queue according to the row in which they have been assigned, the back-to-front boarding strategy is usually simplified by aggregating rows of seats in blocks. This allows to define the order in which passengers board each one of the parts of the aircraft, although it will not be possible to guarantee the complete elimination of the aisle conflicts due to the fact that the boarding process within each group will be at random (see Figure 3). As an example, some of the airlines that use the strategy back-to-front with blocks in operations include: Air Canada, British Airways, Virgin Atlantic, and Vueling.

A	B	C		D	E	F
6	6	6	AISLE	6	6	6
5	5	5		5	5	5
4	4	4		4	4	4
3	3	3		3	3	3
2	2	2		2	2	2
1	1	1		1	1	1

A	B	C		D	E	F
2	2	2	AISLE	2	2	2
2	2	2		2	2	2
2	2	2		2	2	2
1	1	1		1	1	1
1	1	1		1	1	1
1	1	1		1	1	1

Figure 3. Boarding sequence established in the strategy back-to-front by rows (left) and blocks (right).

2.4 The "front-to-back" boarding strategy

The "front-to-back" strategy (see Figure 4) consists in boarding the aircraft using an ascending rank order. In this case, for the same reasons outlined above, the passengers are divided into several boarding groups, depending on the row corresponding to the seat assigned to them. Passengers access then the aircraft in the order established by the airline.

A	B	C		D	E	F
1	1	1	AISLE	1	1	1
2	2	2		2	2	2
3	3	3		3	3	3
4	4	4		4	4	4
5	5	5		5	5	5
6	6	6		6	6	6

A	B	C		D	E	F
1	1	1	AISLE	1	1	1
1	1	1		1	1	1
1	1	1		1	1	1
2	2	2		2	2	2
2	2	2		2	2	2
2	2	2		2	2	2

Figure 4. Boarding sequence established in the strategy front-to-back by rows (left) and blocks (right).

Note that the front-to-back strategy is typically used in conjunction with the back-to-front strategy because it is particularly useful for all those companies that offer different classes in their flights. A good example of this is the case of American Airlines (Figure 5), in which the first passengers on board are those that have an "elite" status.

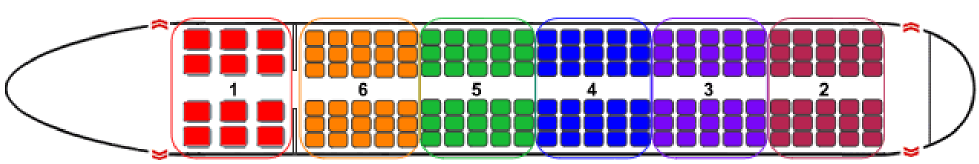


Figure 5. Boarding sequence used by American Airlines

2.5 The WILMA boarding strategy

The goal of the WILMA (windows, middle, aisle) boarding strategy, or "outside-in", is to reduce the seat conflicts caused among passengers assigned to the same aircraft row. In order to achieve this, passengers are assigned to the boarding groups according to their assigned seats, and then access the aircraft in the following order (see Figure 6): first, passengers with seats placed next to the windows (seats A or F); next, passengers with seats located in the middle of each half-row (seats B or E); and finally, passengers with seats located next to the aisle (seats, C or D).

A	B	C		D	E	F
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3	AISLE	3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1

Figure 6. Boarding sequence established in the WILMA strategy.

While the elimination of seat conflicts can result in a significant reduction of the total boarding time, the WILMA strategy is hardly applicable in real-life operations because it does not take into account the existing relationships among passengers. Passengers travelling together, who have been assigned to adjoining seats, will be forced to enter the plane at different times, which will result in a low level of passenger satisfaction.

2.6 The "reverse pyramid" boarding strategy

One might consider the "reverse pyramid" strategy as a combination of the back-to-front with blocks strategy and the WILMA strategy. It combines boarding in descending row order and from the window seats towards the interior seats (see Figure 7).

A	B	C		D	E	F
3	4	5		5	4	3
3	4	5		5	4	3
2	3	5		5	3	2
2	3	5		5	3	2
2	3	5		5	3	2
1	3	5	AISLE	5	3	1
1	2	4		4	2	1
1	2	4		4	2	1
1	2	4		4	2	1
1	2	4		4	2	1
1	2	4		4	2	1

Figure 7. Boarding sequence established in the reverse pyramid boarding strategy.

The reverse pyramid boarding strategy was designed by van den Briel et al. (2005). These authors noticed that block boarding strategies often leave aircraft cabin areas under-utilized, which resulted in a high level of idleness. In order to solve this problem, the reverse pyramid strategy combines aspects of existing strategies with the aim of boarding the aircraft from exterior to interior seats without underutilizing any cabin area in the aircraft. This is achieved by assigning, inside the same group, passengers with seats located in different parts of the aircraft, which allows to maximize the level of activity in all parts of the aircraft. In addition, boarding the aircraft from the outside towards the interior seats minimizes potential seat conflicts among the passengers, which leads to a reduction of the total boarding time. While various studies conclude that the reverse pyramid boarding strategy is highly efficient and enables to obtain low boarding times (Nyquist and McFadden 2008; van den Briel et al. 2005), one of the main disadvantages is its low applicability in real-life operations. Similar to the WILMA strategy, the reverse pyramid does not take into account the existing relationships among passengers. Boarding the aircraft from exterior to interior seats implies that passengers travelling together, and often assigned to adjoining seats, must enter the aircraft at different times.

2.7 The Steffen and Kautzka-3 boarding strategies

From the discussion above it is clear that, apart from the interferences caused among passengers inside the cabin, one of the most relevant factors regarding the boarding time is the time required to store the hand luggage. Steffen (2008) developed a new strategy with the aim of maximizing the number of passengers that can load their luggage simultaneously. In order to achieve this, Steffen found that the optimal way to maximize the level of activity in the cabin of the aircraft was through a combination of the WILMA and back-to-front strategies, leaving a separation row between each group of boarding passengers in order to guarantee that there is enough space to carry out the boarding process. In this way, the allocation of passengers boarding groups is carried out according to the seat and the row assigned to each passenger, as illustrated in Figure 8 (left).

A	B	C		D	E	F
3	7	11		12	8	4
1	5	9		10	6	2
3	7	11		12	8	4
1	5	9		10	6	2
3	7	11		12	8	4
1	5	9	AISLE	10	6	2
3	7	11		12	8	4
1	5	9		10	6	2
3	7	11		12	8	4
1	5	9		10	6	2
3	7	11		12	8	4
1	5	9		10	6	2

A	B	C		D	E	F
3	3	6		6	4	4
1	1	5		5	2	2
3	3	6		6	4	4
1	1	5		5	2	2
3	3	6		6	4	4
1	1	5	AISLE	5	2	2
3	3	6		6	4	4
1	1	5		5	2	2
3	3	6		6	4	4
1	1	5		5	2	2
3	3	6		6	4	4
1	1	5		5	2	2

Figure 8. Boarding sequence established in the strategy proposed by Steffen (left) and boarding sequence established in the Kautzka-3 strategy (right).

Understanding that the strategy proposed by Steffen does not allow to keep together passengers traveling together in pairs, Cimler et al. (2012) developed a new version of this strategy called Kautzka-3. In the Kautzka-3 boarding strategy, each boarding group is composed by pairs of passengers assigned to adjacent seats in the same row, as shown in Figure 8 (right).

3 THE ABP_SOLGEN BOARDING STRATEGY

The following section explains in detail the sequence of steps that defines our ABP_SolGen ("Aircraft Boarding Problem Solution Generator") boarding strategy. This strategy takes into account the passengers individual characteristics as well as the grouping relationships existing among them.

Unlike other strategies, our ABP_SolGen strategy allows to sort and sit passengers taking into account their grouping preferences. Thus, our strategy tries not to separate, during the boarding time, passengers who travel together. The algorithm first starts with the extraction and pre-processing of the input data. In this step, data related to the passengers of a particular flight (inputs of the problem) is obtained from a standard file. This data is stored in a text file containing the booking code (the Locator PNR) for each passenger, as well as his/her date of birth. Each line in this file represents a passenger, and for each passenger, an object is generated. In addition, for each passenger some attributes are initialized depending on the booking code and birth data. Thus, for example, the passenger's type, age, and speed at which he/she can walk during the boarding process can be stored as data into the object. Next we define the creation of passengers' groups based on the booking code. All passengers holding the same booking codes belong to the same PNR (Passenger Name Record), so it is assumed that they travel together and, therefore, cannot be separated at any point of the boarding. Figure 9 shows a group composed of three passengers (with code 43F5FJ), three groups composed of two passengers each, and twelve groups comprising a single passenger. Finally, three lists of boarding groups are constructed: individual passengers, groups of two members, and groups with more than two members. Each group of passengers is then assigned to one of these three lists.

The algorithm continues with the assignation of seats to passengers travelling in groups including more than two people. We start by sorting the list of groups including more than two passengers in ascending order. Next we assign seats to passengers in increasing size order and in decreasing row order starting from the rear of the aircraft and, in accordance with the seat allocation sequence A-B-C-F-E-D. This allows to reduce seat-interference conflicts. Next, we proceed to assign seats to passengers travelling in pairs. We sort the list of groups formed by pairs of passengers according to the passenger's typology. Thus, if we classify passengers according to two different walking speeds (e.g., standard and slow), the list will be headed by groups formed by standard-standard passengers, then there will be groups formed by standard-slow passengers, and finally those formed by slow-slow pairs. With this information, we can start the allocation of seats in pairs of passengers taking into account: (a) the passenger's type in each group; and (b) the allocation-of-seats sequence, i.e., A-B-C-D-E-F. In this case, we assign the nearest possible seats to passengers with slow movement speeds, so that these passengers do not need to walk long distances to occupy their seats. Moreover, given that the number of seats per row is even, the sequence of allocation allows us to keep pairs of passengers together. Finally, we proceed to the boarding of passengers traveling alone. We start by sorting the individual passengers list according to each passenger's type. Again, the closer seats are assigned to the slower passengers, in order to minimize the effect of possible seat conflicts. Figure 9 shows an example of seats allocation.

Once the assignment process has been completed, the algorithm defines the boarding groups to be used during the boarding process. The first passengers accessing the aircraft will be those who travel in groups consisting of more than two passengers. Those passengers will be assigned to the last rows of the aircraft. Passengers travelling in pairs will be allocated to boarding groups according to the row and seat numbers assigned following these policies:

1. Passengers with even row and seat A or B will be allocated to the second boarding group.
2. Passengers with odd row and seat A or B will be assigned to the third boarding group.
3. Passengers with even row and seat E or F will be assigned to the fourth boarding group.
4. Passengers with odd row and seat E or F will be assigned to the fifth boarding group.
5. Passengers with even row and seat C or D will be assigned to the sixth boarding group.
6. Passengers with odd row and seat C or D will be assigned to the seventh boarding group.

	A	B	C		D	E	F
1	x	x	x		x	x	x
2	x	x	x		x	x	x
3	x	x	x		x	x	x
4	x	x	x		x	x	x
5	x	x	x		x	x	x
6	x	x	x		x	x	x
7	x	x	x		x	x	x
8	x	x	x		x	x	x
9	x	x	x		x	x	x
10	x	x	x		x	x	x
11	x	x	x		x	x	x
12	x	x	x		x	x	x
13	x	x	x		x	x	x
14	x	x	x		x	x	x
15	39	39	x	AISLE	x	x	x
16	36	36	37		37	38	38
17	33	33	34		34	35	35
18	30	30	31		31	32	32
19	27	27	28		28	29	29
20	24	24	25		25	26	26
21	21	21	22		22	23	23
22	18	18	19		19	20	20
23	15	15	16		16	17	17
24	12	12	13		13	14	14
25	9	9	10		10	11	11
26	6	6	7		7	8	8
27	5	5	5		x	x	5
28	4	4	4		5	5	5
29	3	3	3		4	4	3
30	1	1	1		2	2	2

	A	B	C		D	E	F
1	2	3	6		7	5	4
2	2	3	6		7	5	4
3	2	3	6		7	5	4
4	2	3	6		7	5	4
5	2	3	6		7	5	4
6	2	3	6		7	5	4
7	2	3	6		7	5	4
8	2	3	6		7	5	4
9	2	3	6		7	5	4
10	2	3	6		7	5	4
11	2	3	6		7	5	4
12	2	3	6		7	5	4
13	2	3	6		7	5	4
14	2	3	6		7	5	4
15	3	3	6	AISLE	7	5	4
16	2	2	6		6	4	4
17	3	3	7		7	5	5
18	2	2	6		6	4	4
19	3	3	7		7	5	5
20	2	2	6		6	4	4
21	3	3	7		7	5	5
22	2	2	6		6	4	4
23	3	3	7		7	5	5
24	2	2	6		6	4	4
25	3	3	7		7	5	5
26	2	2	6		6	4	4
27	1	1	1		7	5	1
28	1	1	1		1	1	1
29	1	1	1		1	1	1
30	1	1	1		1	1	1

```
#book_ref year
23Z7ZB  1972
78G6BB  1963
43F5FJ  1927
43F5FJ  1998
43F5FJ  1991
98L6CN  1980
74S5DD  1965
74S5DD  1968
11F9QA  1988
11F9QA  1988
22F5JK  1957
13L4PX  1960
88G9GF  1985
93H9JC  1992
74K3LM  2000
46V1DE  1972
77H4SL  1974
77H4SL  1995
56B5XS  1978
91J2AP  1930
32H8BA  1981
```

Example of input file.

Groups>2 PAX	X
Couples	X
Individual PAX	X

Figure 9. Example of seat allocation to passengers (left) and example of boarding sequence (right) through the ABP_SolGen strategy.

All in all, the proposed policy allows not to split couples during the boarding process, reduces seat conflicts, and guarantees the existence of some space among consecutive passengers so that the boarding is carried out in a smooth and comfortable manner. Finally, individual passengers will be assigned as described below:

1. Passengers with seat A will be assigned to the second boarding group.
2. Passengers with seat B will be allocated to the third boarding group.
3. Passengers with seat C will be assigned to the sixth boarding group.
4. Passengers with seat D will be assigned to the seventh boarding group.
5. Passengers with seat E will be assigned to the fifth boarding group.
6. Passengers with seat F will be assigned to the fourth boarding group.

4 MODEL HYPOTHESES

The hypotheses on which the simulator has been developed are described next. Firstly, it is assumed that the level of punctuality of passengers at boarding gates is 100%. This means that all passengers are in the queue when they are called to board the aircraft. Second, the level of compliance of passengers to the boarding strategy used is 100%, so all passengers occupy the seats to which they have been assigned and access the aircraft at the time established according to the boarding group to which they belong. Third, it is assumed that the passenger's movement speed is constant inside each passenger's type. Fourth, given that the study focuses on low-cost airlines, it is assumed that all passengers carry one piece of hand luggage. Finally, no breakthroughs occur among passengers.

Additionally, with the aim of obtaining realistic boarding times, different triangular probability distributions have been used to model both the walking speeds as well as the times required to save the hand luggage. Given the limitations of space in the cabin of the aircraft, it is assumed that individuals will move more slowly than when they walk under "normal" conditions. The parameters used for the triangular distributions have been estimated in accordance with the following assumptions (see Table 1): (i) the average speed of a young individual ranges between 1.47 m/s and 1.51 m/s; (ii) the average speed of an individual of advanced age ranges between 1.25 m/s and 1.31 m/s; and (iii) the distance between rows in low-cost airlines is approximately 75 cm.

Table 1. Parameters used to define the time needed (in sec.) to store luggage and move on the aisle.

	Speed in aisle (Triangular distribution)			Storage speed (Triangular distribution)		
	Lower Bound	Mode	Upper Bound	Lower Bound	Mode	Upper Bound
Type 1 PAX	0.8	1	1.2	5	7.5	10
Type 2 PAX	1	1.25	1.5	7.5	11.25	15

5 SCENARIOS DEFINITION

We have considered three factors in our experiments. These factors are described next. The occupation factor is a value between 0 and 1that indicates the relationship between the total number of passengers in a flight and the maximum capacity of the aircraft. In Audenaert (2009), the author concluded that below an occupation factor of 66% there are not significant differences in the boarding time associated with different strategies. Thus, in our experiments we have considered two-tier occupation factors: 90% and 100%.

Regarding the level of relationship among passengers, we have distinguished two different levels: 70% and 85%. These high levels of relationship are due to the fact that our study focuses on low-cost airlines, where it is assumed that the majority of routes are for leisure and tourism, so that the number of passengers who travel individually is relatively low. Finally, we consider two types of passengers depending on their movement speed (type 1 or "standard PAX", and type 2 or "slow PAX"). Table 2 shows a summary of the different values used for each of the factors previously outlined. Also, Table 3 shows details on some of the parameterizations being considered. For each parameterization, 100 replications are conducted, resulting in a total of 3,200 different executions.

Table 2. Factors of our experimental design.

Occupation factor	Level of relation between passengers			Passengers type	
	% PAX (individuals)	% PAX (couples)	% PAX (groups)	% Type 1 PAX	% Type 2 PAX
100% (180 PAX)	30%	40%	30%	60%	40%
90% (162 PAX)	15%	40%	45%	80%	20%

Table 3. Experiments to be conducted on the simulation study.

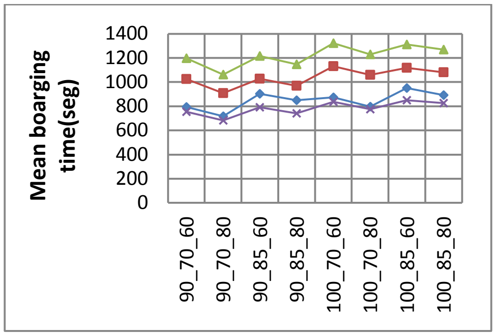
Random_100_70_60	BackToFront_100_70_60	FrontToBack_100_70_60	ABPSolGen_100_70_60
Random_100_70_80	BackToFront_100_70_80	FrontToBack_100_70_80	ABPSolGen_100_70_80
..	..	..	..
Random_90_85_80	BackToFront_90_85_80	FrontToBack_90_85_80	ABPSolGen_90_85_80

6 RESULTS

For each one of the different scenarios, we conducted an ANOVA to compare the different boarding strategies. Firstly, it is possible to observe that, in all the instances of the problem, the p-value obtained for the overall test is less than 0.05. Therefore, we have to reject the null hypothesis that the average boarding time is the same for all strategies. Furthermore, the confidence intervals for the average boarding times associated with each strategy do not intersect each other. All in all, it is possible to conclude that there are significant differences in the average boarding times associated to different strategies. In short, the use of a proper boarding strategy is a decisive element to reduce the total boarding time. Figure 10 summarizes the results obtained from all the different strategies.

Another important observation is that the order of the different boarding strategies, regarding the mean boarding times, remains the same for all instances of the problem. Specifically, in all cases, the random strategy provides the smallest average boarding times, followed by our ABP_SolGen strategy, the back-to-front strategy, and finally the front-to-back strategy. This fact suggests that the different proposed factors do not affect the performance of each boarding strategy in relation to the others. As it can be observed in Figure 10, the smallest boarding times take place in those cases in which: (a) the occupation factor and the relationship level between passengers are lower; and (b) the number of passengers of type 1 is higher (see parameterization 90_70_80 on Figure 10, left). Also, it is interesting to study the results obtained in relation to the total number of seat conflicts generated in each scenario.

As can be seen in the Figure 10 (right), the number of seat conflicts caused by the ABP_SolGen strategy is smaller than those caused by other strategies. This is due to the fact that this is a strategy specifically designed to reduce this type of conflicts. The ABP_SolGen strategy is the one that will result in a better quality of service perceived by the passengers, which will improve the level of satisfaction of these and will increase the value of the service offered by the air carrier. As we could expect, the occupation factor affects, in a very significant way, to the total number of seat conflicts. However, the behavior observed in the case of the ABP_SolGen strategy is very different. In this case, the determining factor that affects significantly the number of seat conflicts is the level of relationship among passengers. This is due to the fact that, in the ABP_SolGen strategy, seat conflicts appear in the case of passengers who travel in groups of three or more persons.



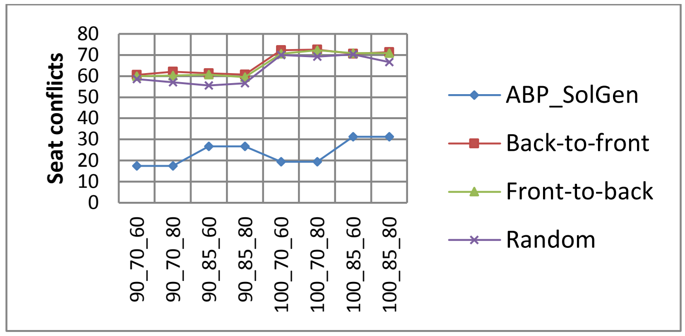


Figure 10. Mean boarding times for each strategy and instance (left), and mean number of seat **confli**cts for each strategy and instance (right).

7 CONCLUDING REMARKS

First, according to the results obtained using the at-random strategy we can note that, despite of not being the strategy with fewer seat conflicts, it is the most efficient strategy in terms of total boarding time. This allows us to say that a higher number of interferences (conflicts) between passengers does not necessarily imply an increase on the boarding times. However, it is possible to conclude that the impact caused by the passengers' conflicts on the boarding time depends, mainly, on the location of these inside the aircraft cabin, that is to say, on how they affect to the rest of the passengers.

Secondly, it is possible to observe that, while the strategy ABP_SolGen is slightly slower than the at-random strategy, it also shows a significantly lower number of interferences. This makes the ABP_SolGen boarding strategy highly efficient due to the fact that not only provides similar boarding times as the at-random strategy, but it also achieves a significantly smaller number of conflicts between passengers –which results in a more positive perception of the service from passengers' experience. For this reason it is possible to conclude that the ABP_SolGen strategy would be a good solution for the problem of boarding passengers in aircrafts.

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