Improving passenger boarding in airplanes using computer simulations

The simulation of passenger's behavior while boarding reveals surprising results that will have considerable influence on present boarding policies. Time savings on the ground will be more and more indispensable.

It goes without saying that airplanes only make money when they are in the air. Considering today's tough competition and the pricing pressures in the passenger carrying business, this insight becomes especially important. On the one hand, airplanes have to work at full capacity and idle times have to be avoided. On the other hand, punctuality as an important contribution to the passenger's service has to be ensured. Masses of passengers waiting for hours in overcrowded airport facilities during the holiday season speak a different language, however.
Reducing idle times on the ground will lead to improved airplane utilization and a more flexible time management. How could these idle times be reduced? Optimizations of turn-around times can start at any point between arrival and departure. The deplanation process, aircraft cleaning, refueling, cargo (un-)loading and passenger boarding are main elements of the turn-around time. Passenger boarding is the part that takes the longest time and because cargo loading can be done at the same time it is also the most important one.

Different solutions for a common goal

To reduce times off passenger boarding, different solutions have been proposed in the past – their common goal is to get all passengers seated on their assigned seat in a fast and efficient way. Yet, the airplane interior does its best to prevent fast passenger movement and when hand luggage is carried the narrow aisle get congested, preventing travelers from passing.
Passengers are often divided into so-called boarding groups that enter the airplane sequentially one after another and are intended to avoid congestion. The call-off is realized by announcing the rows through speakers or by means of lamps corresponding to a color-coded boarding card. But do these devices really do their job? And what would a good boarding policy look like?

One possibility would be to conduct large-scale experiments with real passengers and real planes using different boarding policies. Such a project will generate high costs while permitting only few runs in an acceptable time frame. A cleverer approach is the use of computer simulations in a first stage. Passenger's behaviour will then be reproduced by software that allows close analysis of the boarding process.

Software reproducing passenger's behavior

Simulations of pedestrians' behaviour is not a new idea. People's movement in rooms, buildings, cities and even whole countries have already been simulated using different techniques such as genetic algorithms and high performance parallel computing.

To simulate the boarding process inside the aircraft we use a microscopic cell-based simulation, which means that every single individual is represented in a grid as an occupied cell that moves according to specified rules reproducing passenger's behavior.
All conditions having an influence on the simulation result are integrated into models and formulated mathematically – however. they can easily be described in words.
The aircraft model defines the dimensions of the airplane as well as the interior layout, e.g. the spacing between seats. For our considerations we use a typical short haul configuration, an airplane consisting of 123 seats that are distributed over 23 rows. Walking speeds of passengers and restrictions such as the one that passengers cannot pass in the aisle are included in the passenger model. The seating model contains movement decisions while seating – e.g. the fact that passengers occupying a middle seat have to get up for people with window seats. Last but not least with the bin occupancy model, carry-on luggage is taken into account. To every passenger, certain pieces of luggage are assigned in compliance with a predefined distribution (e.g. 60% of passengers are carrying only one piece). In the simulation it takes longer for a traveler to store more pieces of luggage.

Boarding patterns

The simulation models explained above will be applied to different boarding strategies. A boarding strategy determines how boarding groups – which enter the airplane separately – are arranged over the seats inside the aircraft. The result are patterns as those in figure 1. We built a simulation environment which not only enables us to take a closer look at existing solutions but lets us also easily implement every strategy imaginable. An often-used boarding scheme is to seat passengers from the back to the front in different quantities of blocks, groups are then announced e.g. as 'rows 10 to 15'. In addition these blocks can be divided by the aisle, means passengers sitting on the right and the left will board separately. Another approach is to form boarding groups according to seat letters, e.g., to first let people with window seats in, then those assigned to middle seats and finally passengers with aisle seats. This is intuitively a good idea, as this way passengers do not have to get out of their seat for their neighbor. We also implemented strategies where every boarding group is formed by one single passenger. The boarding sequence is then determined completely and simulations confirm that these strategies have the best average behavior. It is, however, too complicated for real-world use. All boarding schemes mentioned above can be alternated by changing the sequence of the boarding group. The simplest method is to use no boarding group at all. This corresponds in our simulation to one single boarding group – people enter the airplane unordered. We also implemented outside-in-back-to-front-strategies and simplified them by merging groups leading to pyramid-strategies, called after their shapes which become apparent in a top view while passengers are boarding.

Ranking of Boarding strategies

For airlines introducing new boarding strategies not only the average boarding time is of interest but above all the possibility of very bad boarding times. Taking this into consideration, we will not rate boarding strategies according to the average boarding time but in view of the average worst case of the boarding time over 50 replications. A plausible interpretation of our measure is that approximately 95% of all boarding events are faster than our number. All of our results are given in simulation time steps that behave proportional to absolute boarding time.
In general a strategy will show good performance when it reduces conflicts. (Conflicts are defined as all constellations in which passengers can't move forward or sit down because of others.)

A good strategy has to show good performance, has to work if passengers are arriving early or late and should be suitable for different airplanes with varying interior layout. As airplanes are not always full, boarding strategies should be efficient with smaller occupancies. However, boarding using the same scheme but fewer passengers will in the average always be faster than with a full plane. As long as the flight schedule is not adjusted to the expected load, there is little need to test reduced occupancies.

Our simulation in action

We implemented about 60 boarding strategies and benchmarked them according to their robustness against disturbances.
If passengers are divided into boarding groups, it will often occur that some arrive late or early. Results show that there is no significant difference between the two possibilities. In other words: If 20% of the passengers are off-time, half of them early and half of them late, then the effect of the disturbances can be reduced to 10% if all early boarding attempts are rejected at the ticket reader system.
We tested how much the percentage of passengers not arriving in time will influence the quality of the boarding strategies. In figure 2 the resulting performance-profile can be seen for 0%, 20%, 40% and 80% of passengers arriving off time. The simulations show that under disturbances block-strategies (e.g. from back-to-front-boarding) continue to perform worse than plain random boarding ('using no boarding strategy') indicated by the red-colored part in figure 2. More importantly, this corresponds to the troubling result, that the more passengers do not follow their boarding groups, the better these strategies become. Since this contradicts common-sense reasoning, we will expand on this point a bit more. Boarding back-to-front essentially means that there is a lot of conflict-causing loading activity in the current boarding block – while there is no loading in other parts of the airplane. In this situation, passengers boarding at times when they are not called lead to a situation where loading occurs in areas of the airplane with little current activity, thus increasing the amount of loading that can occur simultaneously. We conclude that there is no justification for airlines to use this kind of boarding from the viewpoint of reducing boarding time.
The boarding time of the row-strategy – that fills the airplane row-wise from back to front – exceeds the results of all other strategies. It maximizes the number of conflicts in the current block, resulting in very bad performance. Alternating row-strategies (skipping rows) helps massively when the number of jammed passengers that are waiting because of their man in front fits in between the busy rows. Refer to the green highlighted parts in figure 2. Obviously, such strategies are highly dependent on airplane layout and thus not recommended.
Strategies that fill the airplane by seat letters from window to aisle show good performance and are also robust against disturbances (dark-blue colored part in figure 2). They are proposed although they can be expected to split passengers travelling in groups such as families.
The lowest peak in figure 2 corresponds to the case where the sequence of boarding passengers is determined by the individual, every boarding group consists of only one member, so to speak, and interferences between passengers can be minimized by lining them up in the right order (light-blue shaded part of figure). Because of the exorbitant number of boarding groups, these types of strategies are also not usable.
Seatgroup-strategies try to reduce the amount of boarding groups building by using small groups of passengers instead of single passengers. As expected, this strategy shows also good performance and acceptable robustness, but still requires too many boarding groups.
For a further reduction of boarding groups, merging boarding groups diagonally leads to pyramid strategies that retain the good efficiency and promise robust behaviour against airplane layout changes and other disturbances. These strategies are also recommended.

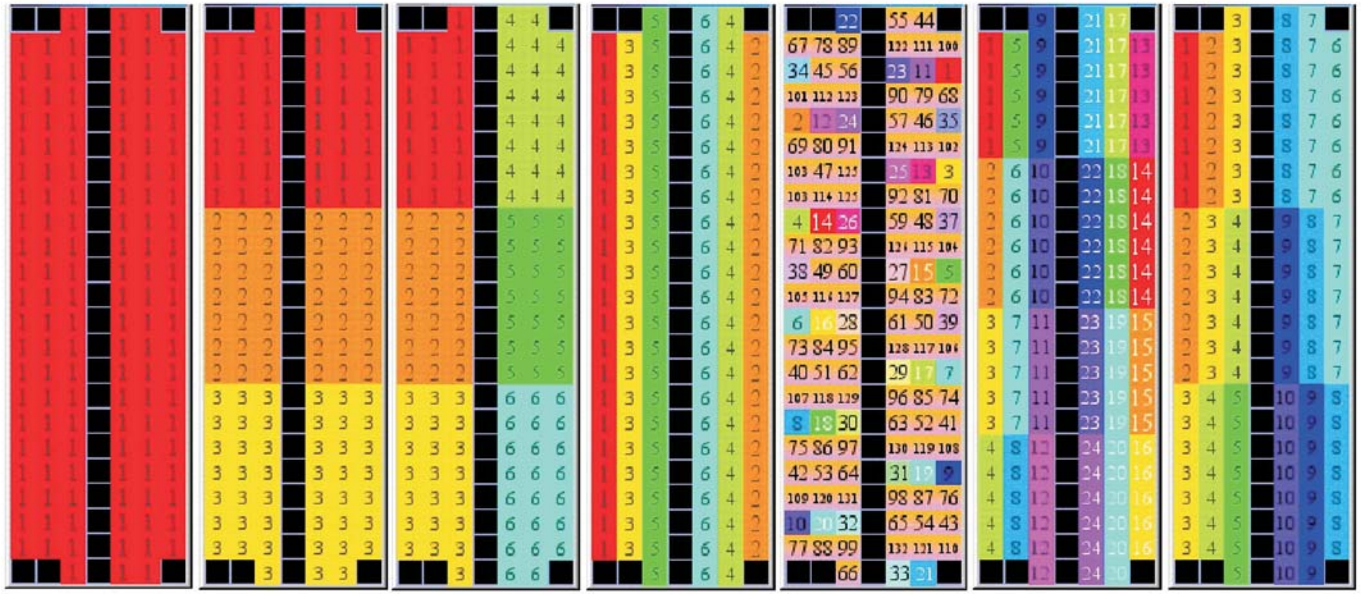
Conclusion

The simulation results confirm the expected result that using a suitable strategy airplane boarding can be improved considerably (refer to figure 3). Even simple boarding strategies would save over 20% of boarding time in the average.
The often used block-strategies are inefficient as they delay the boarding process compared to random boarding. In fact travelers not obeying the boarding calls will improve those strategies.
An interesting observation is that the amount of carry-on luggage has strong influence on boarding times, restrictions will also lead to faster boarding.
There exist strategies that show great sensitivity to airplane interior layout changes, those strategies will be a good choice.
Recommended strategies are letter-, seatgroup- and pyramid-strategies, they all show good efficiency and robustness.
All proposed schemes are only applicable in combination with call-off systems and direct access (boarding through a finger dock).

figure 1: patterns.jpg
caption: "Figure 1: Graphical representation of boarding strategies"

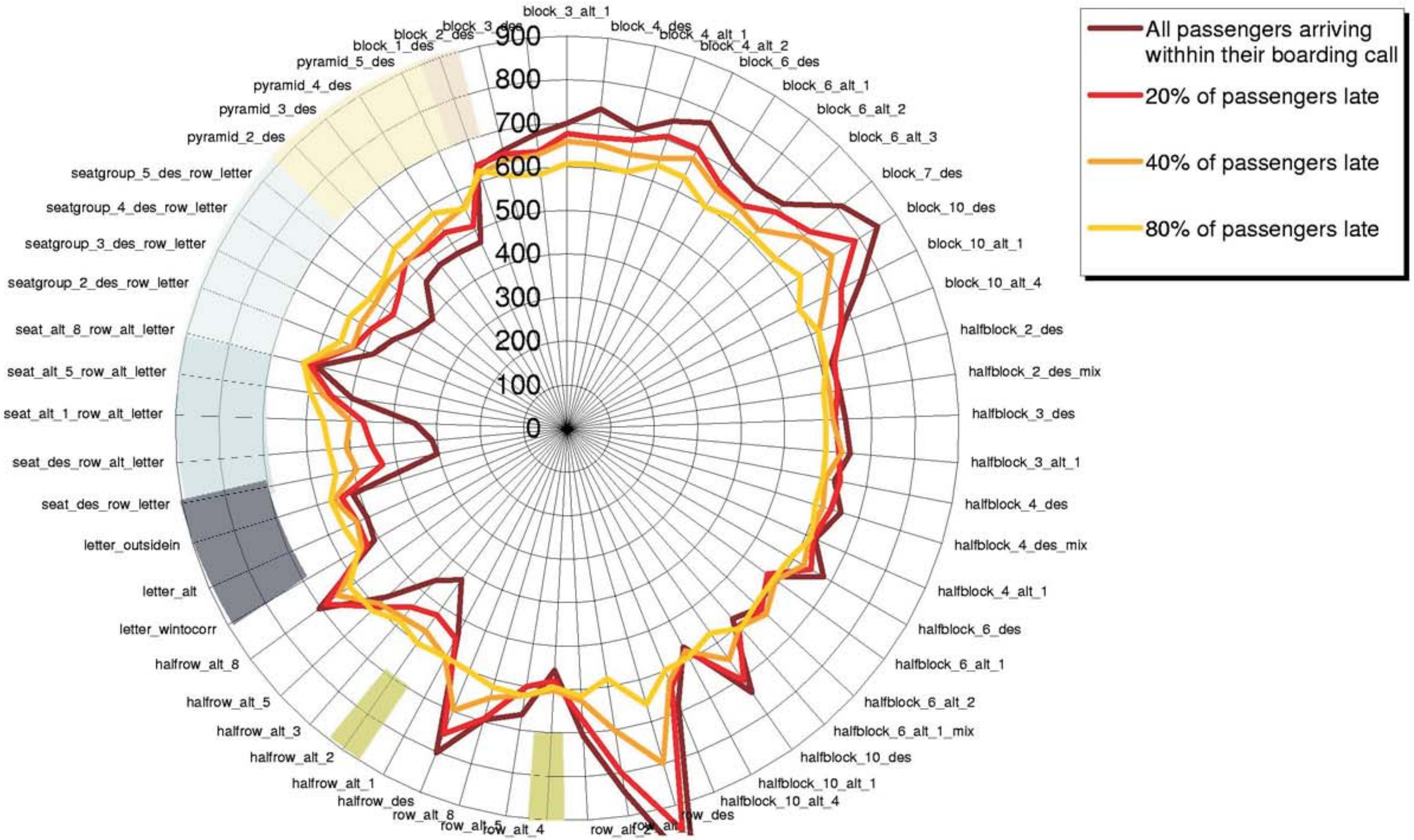
figure 2: performanceprofile.jpg
caption: "Figure 2: Performance profile of boarding strategies for different percentages of disturbances. Values are given in simulation timesteps"

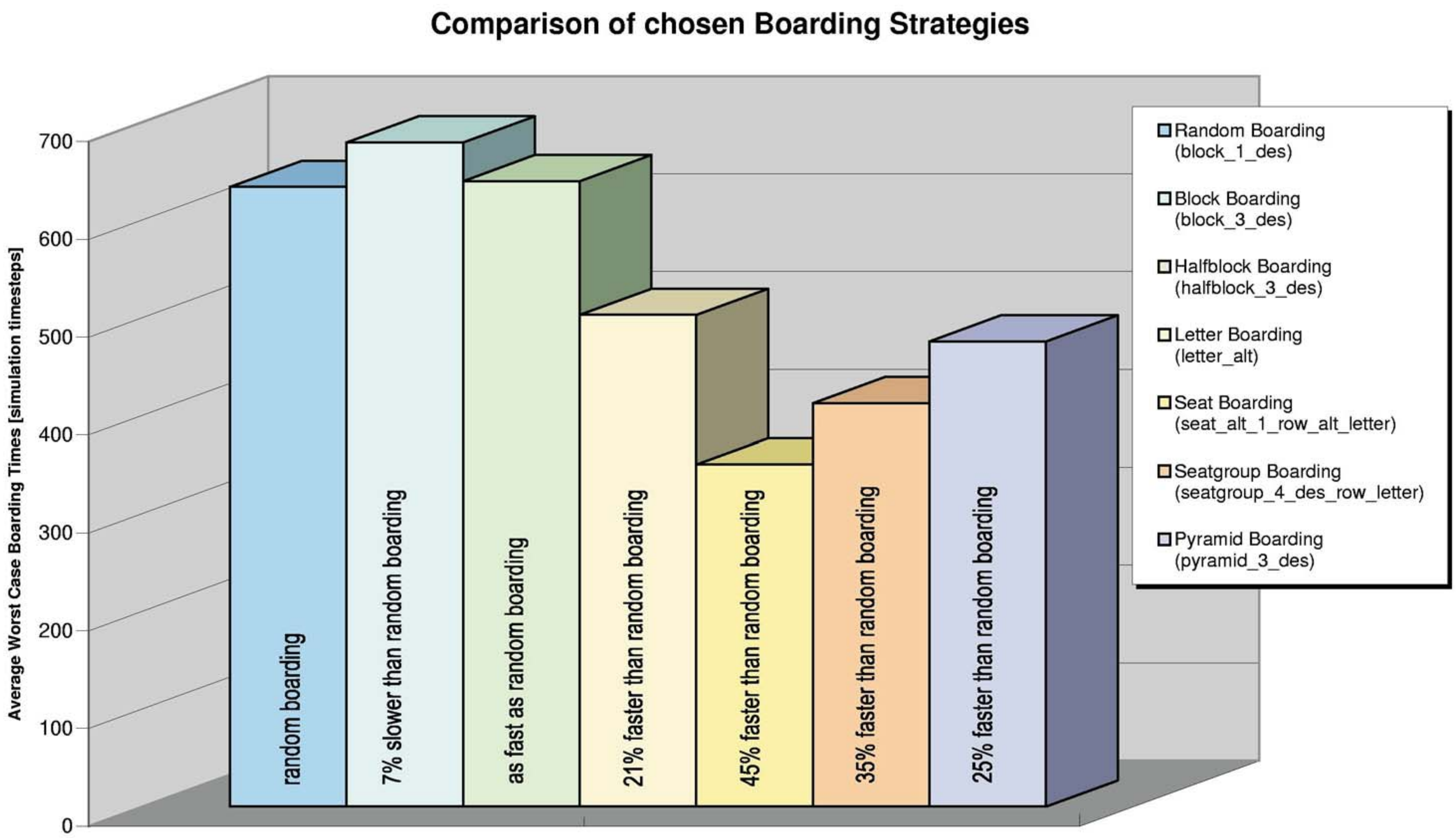
figure 3: comparison.jpg
caption: "Figure 3: Comparison of chosen boarding strategies. Values are given in simulation timesteps"



Random Boarding (no Boarding Strategy) | Block Boarding (Block_3_des) | Halfblock Boarding (Halfblock_3_des) | Letter Boarding (Letter_alt) | Seat Boarding (seat_alt1_row_alt_letter) | Seatgroup Boarding (Seatgroup_4_des_row_ltr) | Pyramid Boarding (Pyramid_3)

Performance-Profile of Boarding Strategies under Disturbances




Comparison of chosen Boarding Strategies
Average Worst Case Boarding Times [simulation timesteps]
0
100
200
300
400
500
600
700
random boarding
7% slower than random boarding
as fast as random boarding
21% faster than random boarding
45% faster than random boarding
35% faster than random boarding
25% faster than random boarding
Random Boarding (block_1_des)
Block Boarding (block_3_des)
Halfblock Boarding (halfblock_3_des)
Letter Boarding (letter_alt)
Seat Boarding (seat_alt_1_row_alt_letter)
Seatgroup Boarding (seatgroup_4_des_row_letter)
Pyramid Boarding (pyramid_3_des)