Efficiency of Aircraft Boarding Procedures

Michael Schultz
Institute of Logistics and Aviation
Technische Universität Dresden
Dresden, Germany
schultz@ifl.tu-dresden.de

Christian Schulz
Institute of Logistics and Aviation
Technische Universität Dresden
Dresden, Germany

Hartmut Fricke
Institute of Logistics and Aviation
Technische Universität Dresden
Dresden, Germany

Abstract—**Efficient boarding procedures are the basis for fast turnaround times. The boarding is an essential part of the critical path of the turnaround process, so time savings directly advance the overall process. Previous research results pointed out that the boarding time can be significantly reduced by using adapted boarding procedures. In this paper we present a comprehensive analysis of boarding procedures (A320-200, 174 passengers) considering different seat load factors, passenger acceptance of chosen boarding order, and arrival rates. The results of the analysis yield a lower boundary for an efficient boarding of approx. 40% acceptance rate, 50% seat load factor and an arrival rate of 7 passengers per minute. Furthermore, the use of the rear door has a substantial effect regarding the boarding efficiency. An enhancement of approx. 25 % is reached, without the disturbing influences of the strategy acceptance rate.**

Boarding; Critical path; Efficiency; Turnaround

I. INTRODUCTION

To manage future challenges in aviation the Advisory Council for Aeronautical Research in Europe (ACARE) provided the Strategic Research Agenda 2 in 2004 [1]. Herein, the ACARE asks for efficient procedures and processes, new standards for service, safety, security and quality, as well as decreasing operational costs at all levels. To achieve these objectives High Level Target Concepts (HLTC) are defined, whereas the safety regulations always have major importance. In this context, boarding processes have to be high time efficient, i.e. short turnaround times (see fig. 1).

Following Airbus' definition for the turnaround (fig. 1) the turnaround time is defined as the aircraft parking time, between on-block and off-block. While the aircraft is at the position (at the gate or apron) processes like (un-) loading, catering, cleaning, refueling, and (de-)boarding are executed. Due to safety regulations and logistic requirements some processes run parallel to others and others have to be executed sequentially. The overall turnaround time is defined by the termination of the last process. According to fig. 1 the moving of passenger bridges, the boarding and the refueling are part of the critical path. Shortening the processes on the critical path implies a shortening of the overall turnaround process as well. Reduced turnaround times achieved by improved operational procedures have several positive effects. The airline reduces the ground idle time and saves ground costs while the airport benefits from the reduced gate (apron) occupancy time.

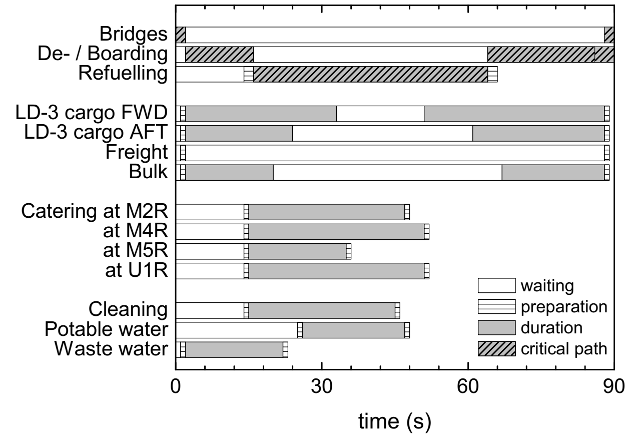

Figure 1. Turnaround time schedule of A380 (90 min, baseline) [2]

Various research studies were performed on the field of efficient boarding procedures. They as a typical reference apply analyses for single aisle aircraft, such as the A320. Airbus and Boeing expect a business volume of single aisle aircraft of 40 % and 42.5 % respectively until 2026. Both aircraft manufacturer plan to deliver approx. 17000 single aisle aircraft each (68 %, 62 % of production) [3, 4]. These aircraft often come into operation for low cost airlines, where the market pressure forces the airlines to be highly competitive and to achieve high efficiency at all operational levels. In this context the optimization of the boarding procedures could be one deciding competitive factor.

There are different disturbances during the passenger boarding process. Landeghem and Beuselinck [5] divided the disturbances into three operational parts: calling passengers, boarding pass control at the gates, and passenger installation within the aircraft. An adequate strategy for reducing the boarding time is to split the passengers into groups, whereas these groups are separately called to enter the aircraft. Due to the high quantity of possible parameter variations, such as block size, block sequence or block affiliation Marelli et al. [6] highlight the importance of model driven evaluations to optimize the boarding procedures. These boarding evaluations provide an insight into the associated mechanisms. However, a simulation environment is only capable to run pre-defined scenarios, but it does not provide autonomous algorithms for developing the most efficient strategy (van den Briel et al. [7]).

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II. SIMULATION APPROACH

Our research project mainly focused on disturbances occurring during passenger installation, namely the congestion in the aisle, the storage of hand baggage, and number of occupied seats between the aisle and the assigned passenger seat. However, disturbances based on passed rows are not taken into account.

A. *Aircraft*

For the simulation environment an A320-200 aircraft seating layout is chosen, which is used within the airline Air Berlin [8]. The aircraft is a regular single aisle aircraft with three seats on each side of the aisle and with a seating capacity of 174 seats in 29 rows (see fig. 2).

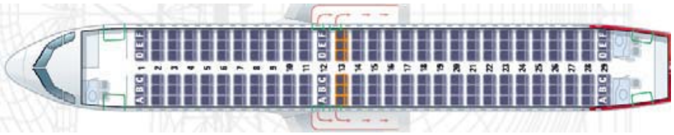

Figure 2. Aircraft seat layout

B. *Model*

In contrast to the mixed integer linear program approach introduced by Bazargan [9] or the multi-parameter discrete random process from Bachmat et al. [10], our simulation model is based on the so called asymmetric simple exclusion process (ASEP). The ASEP was successfully used for road traffic investigations. The boarding can be described as a stochastic forward directed, one dimensional, and discrete (time and space) process as well [11-13]. For this purpose the aircraft layout will be transferred into a regular grid as shown in fig. 3. The regular grid consists of cells with a size of 0.4 x 0.4 m. Each cell can either be empty or contain exactly one passenger.

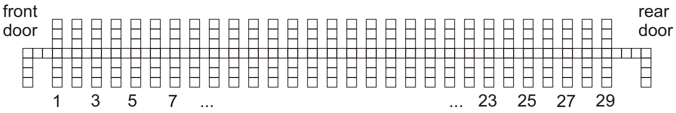

Figure 3. Grid based simulation model

To move forward the passenger can enter an empty cell at one timestep only. If the cell in front of is occupied the passenger has to wait in this timestep (probability to overtake passengers is set to zero). Assuming a maximum speed of 0.8 ms^{-1} at the aisle (60 % of maximum passenger speed), the timestep has a width of 0.5 s. At each timestep during the simulation the position of all passengers is updated via a sequential shuffled update procedure [14, 15].

The passengers enter the aircraft at the front (rear) door and move from cell to cell along aisle until they reaches the assigned seat row. For each simulation run the arrival time at the aircraft is determined as a constant factor (*n* passengers per minute (PPM)). Before entering the aircraft all arriving passengers join the aircraft queue. If the queue is empty, they proceed directly into the aircraft; while otherwise they have to wait until all passengers arrived earlier have entered the aircraft. If both, front and rear door are used for boarding, the passengers from seat row 1-15 use the front door and passengers with seat row 16-29 use the rear door.

Additionally to the general ASEP model, we assumed that a passenger leave this one dimensional process (walking at the aisle), if he has reached the assigned seat row. The time t, which the passenger needs to take his seat, depends on several factors. First, t depends on time of baggage storage t_B, (related to the number of baggage) as well as on the time for handling occupied seats t_S and on the response time t_R of all involved persons. For all of the time components a statistical probability (triangle distribution) is defined (compare [5, 11]). The distribution values are determined in tab. I.

TABLE I. PROBABILITY DISTRIBUTIONS

Distribution	**Time values (s)**				
	min. value	***modus value***	***max. value***	***mean Value***	***standard deviation***
store one piece of baggage	5.0	10.0	20.0	11.67	13.23
time for one seat movement	1.8	2.4	3.0	2.40	1.04
Reaction	6.0	9.0	20.0	10.5	12.77

The response time t_R can be directly calculated from the given probability distribution without any further input data. The storage time t_B is calculated by adding a random value for each piece of baggage, generated with the determined baggage storage distribution function. To determine the number of baggage pieces the distribution in tab. II is consulted.

TABLE II. BAGGAGE DISTRIBUTION

	Number of baggage pieces			
	0	***1***	***2***	***3***
ratio (%)	0	60	30	10

To determine t_S the character of the seat row state has to be clarified. At the chosen layout with a 3-3 seat configuration four different kinds of seat row states are possible:

- Seat access without any disturbances, (state *A*)
- Blocked aisle seat, (state *B*)
- Blocked middle seat, and (state *C*)
- Blocked aisle and blocked middle seat. (state *D*)

This disturbance list is sorted by the degree of arrangement complexity, by meaning of increasing time consumption. For example, to take a seat at the window with a blocked middle seat, the passenger at the middle seat has to move to the aisle seat and from there to the aisle itself (the aisle is blocked during the whole seating process). Now the window-seated passenger enters the seat row followed by the middle seat passenger (7 movements in total).

However, the number of required movements to ensure the aisle availability is lower than 7, because following passengers can pass the row 2 movements earlier: passenger one (on middle seat) need 2 moves to the aisle, passenger enters the

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row and reaches the middle seat (2 moves), at this moment passenger one clears the aisle by entering the seat row as well (1 move). The further seat row arrangements (get to the corresponding window seat and middle seat) will be proceed without influencing the aisle passengers.

In the simplest case (state *A*) a passenger needs only *1* move to enter the row, *B* requires *4* movements, the third state *C* consumes *5*, and the most complex row state *D* requires not less than *9* movements. Finally, t_S is calculated as a product of required movements and a random number given by the probability distribution (tab. I). In order to speed up the boarding process, it seems obvious to eliminate the most time consuming disturbances first.

C. Boarding strategies

For prearranging the passengers before entering the aircraft a call-of-system is used at the boarding counter. To determine the efficiency of boarding strategies, four different strategies are chosen:

- *Random*: the passengers get into the aircraft without a special order.
- *Outside-In*: passengers with window seats enter the aircraft first, followed by passengers with middle seats, and passengers with aisle seats.
- *Back-to-Front*: the aircraft is parted into blocks, whereas the block with the highest distance is boarded at first.
- *Block* boarding (best sequence): the aircraft is parted into blocks, whereas the fastest sequence of the blocks is used for boarding.

The *random* strategy is used as a baseline scenario to allow a target-performance analysis. Former studies pointed out, that the *outside-in* procedure is one of the fastest and suitable boarding strategies (see van den Briel et al. [7]). Therefore it is used to mark the upper limit of the boarding time. The *back-to-front* method is often determined as an unfavorable procedure, because the effort for arranging passengers is disproportionate to the expected time savings.

Finally, the common *block* boarding (fig. 4) is part of the analysis, although Landeghem [5] and Ferrari et al. [11] showed that *block* (or *half-block*) strategies are not significantly faster than *random* boarding procedures. However, a first evaluation with our simulation model yields different results, even considering several block sizes, block sequences, acceptance rate of boarding procedure, and seat load factors. Additionally, the use of the rear aircraft door is taken into account. An example of the block classification (6 blocks) is given at the following figure (fig. 4).

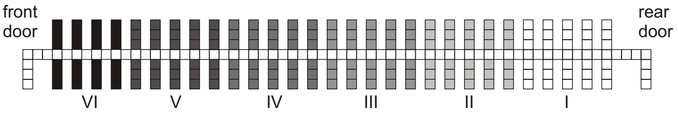

Figure 4. Block classification at grid model

Attention should be paid to the numbering sequence at fig. 4, which starts at the end of the aircraft. Consequently, the *back-to-front* procedure is equivalent to a *block* boarding procedure with the sequence 123456.

D. Simulation runs

The parameters AR (acceptance rate), SLF (seat load factor) and PPM (arrival rate - passenger per minute) are varied within the boarding simulation environment. The simulation scenarios are generated by the combination of the following factors, whereas the default values are declared in braces.

- SLF and AR from 20% to 100% {85%}
- Arrival rate from 1 to 40 (PPM) {85%}
- 4 different boarding procedures {random}
- One and two door configuration {one door}

Each scenario is simulated 10000 times, to allow a significant statistical analysis of the results.

III. RESULTS

Waiting times arising from boarding disturbances are primarily caused by suboptimal seat row states. At *random* boarding the probability of seat row state *A* (no blocked seats) is about 66% (tab. III), whereas the *outside-in* boarding increase the quota to nearly 91%. Even the state *C* could be reduced to a marginal quantity of 1%. Thus, the change-over from the *random* to the *outside-in* boarding procedure results in system enhancements up to 20% (see fig. 11, 12).

TABLE III. SEAT ROW STATE FOR BOARDING PROCEDURES

Procedure	**Seat row state (%)**			
	A	***B***	***C***	***D***
Random	65.6	20.3	6.1	8.0
outside-in (AR=0.85)	90.8	5.2	2.9	1.1
outside-in (AR=1)	100	0	0	0

The influence of the row disturbances is not limited to the local row. Depending on the number of passengers which are not able to pass this critical row the local disturbance affects the whole boarding process and therefore the boarding time. In the next picture (fig. 5) the overall waiting time with respect to aisle position is shown, where $x = 0$ is marked as the aircraft door. If a passenger is not able to move forward a marker is left on this particular position at each timestep.

After the finishing the simulation all markers of each aisle position are counted. With increasing aisle length the waiting time declines. In the vicinity of door the waiting time is very high, indicating that the passengers could not move forward due to indirect disturbance in front of them. With increasing rate of arrival, this effect has greater influence. A large waiting time at the door is connected to a high queue length. If the gradient of the waiting time is nearly linear the optimal system load is reached. For the *random* boarding configuration with one door, AR = 0.85, and SLF = 0.85 the optimal system load is achieved at an arrival rate of approx. 9 PPM.

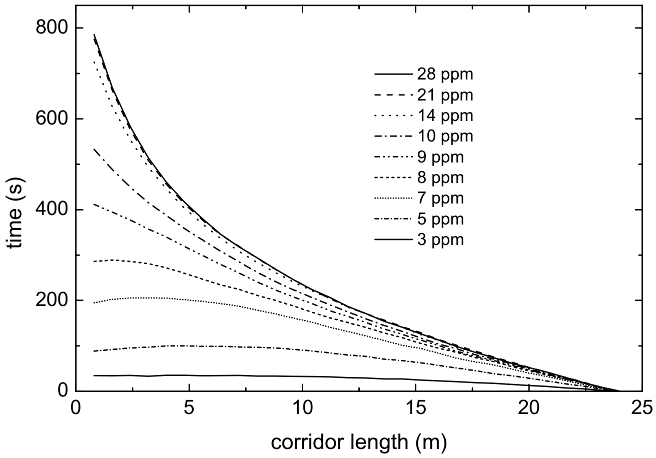

Figure 5. Waiting time

To solve the increasing door-handed waiting time distribution the second door is used for the boarding process as well (fig. 6). Passengers with seat rows from 15 to 29 could leave the front door queue and are directly guided to the rear part of the aircraft, without disturbing the passengers from seat row 1 to 14. Due to the queue shifting and the enhanced passenger segmentation the optimal system load is increased from 9 PPM to approx. 14 PPM in the *random* configuration. The small discrepancy between the left and the right shape of the curve in fig. 6 is caused by the different assigned row numbers for each door (front: 15 rows, back: 14 rows).

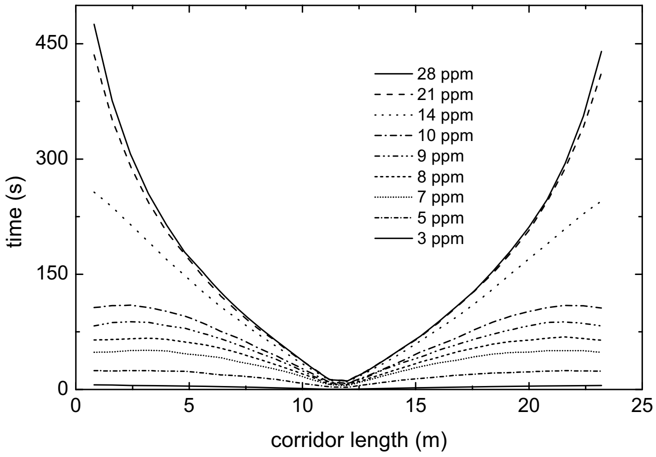

Figure 6. Waiting time (2 doors)

Generally, the passenger waiting time inside the aircraft can be separated into a direct and an indirect contribution. The direct part is only attributed to the number of baggage and the individual time for stowing the baggage. The indirect part depends on the seat row state and the aisle blocking time due to other passenger's activities (stowing baggage, waiting for seating, or waiting for passing). In fig. 7 the accumulated waiting time characteristics is shown. The internal waiting time has only a small impact on the passenger itself. Due to the passenger interactions the external waiting time is the main contribution to the overall waiting time. (46 passengers wait 99.8 s or less, whereas the direct part has a size of 16.9 s and the indirect part a size of 73.9 s.)

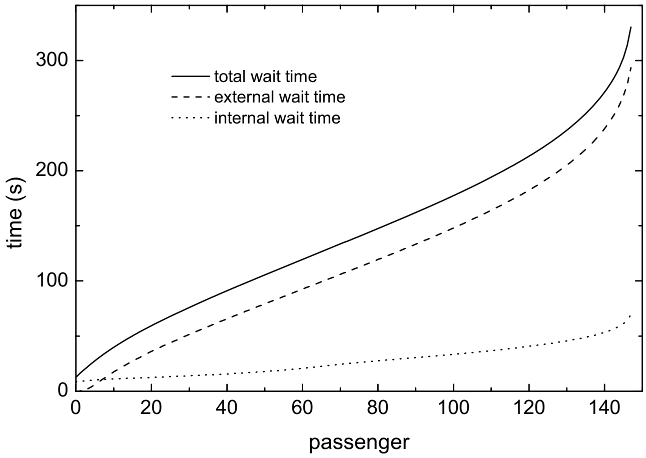

Figure 7. External, internal and overall waiting time

During the boarding the number of passengers without a seat is continuously decreasing. In fig. 8 the center line represents the mean value and outward lines are the 75th percentile, 90th percentile and the maximum (25th percentile, 10th percentile and minimum, respectively). Depending on the stochastic model assumptions the overall boarding time varies between approx. 925s and 1550s (see fig. 8 at 0 passengers without seat). The shape of the boarding time corresponds to a normal distribution with $\mu \approx 1191$ s and $\sigma \approx 83.8$ s. From 100 s to 900 s simulation times a nearly constant ratio of approx. 7.2 s per passenger seating rate is observed.

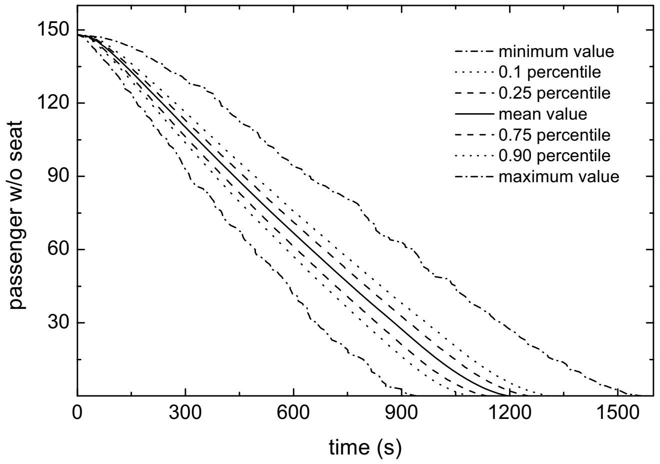

Figure 8. Passengers without seat during boarding process

After analyzing one single scenario, we focused on the comparison of different boarding strategies and parameter variations in the next paragraphs.

A. Block boarding and optimal block sequence

To determine the efficiency of *block* boarding two parameters have to be defined. The first parameter is the block size, which is similar to the number of rows which are boarded at the same time. Regarding to the A320 layout (fig. 4), the restriction to integer values, and the almost equal block size, the block number have to be element of $\{1,2,3,4,5,6,7,9,15\}$. In the following table (tab. IV) the simulation results for all possible 3-block-sequences are shown in relation to the *random* boarding. Due to the fact that the *back-to-front* boarding (sequence 123) is defined separate boarding procedure, it is separated from the *block* sequences. The simulation analysis yields in no significant benefit of the *block* sequences over the *random* boarding procedure.

TABLE IV. BOARDING TIME FOR ALL 3-BLOCK SEQUENCES

Sequence	Mean value (s)	Standard deviation (s)	Efficiency (%)
1-2-3	1173.9	81.9	+ 1.4
2-1-3	1246.5	89.5	- 4.6
1-3-2	1332.4	96.4	-11.8
3-1-2	1378.8	100.6	-15.7
2-3-1	1419.8	96.0	-19.1
3-2-1	1612.6	103.3	-35.4
random	1191.0	83.8	0

The characteristics of the best sequence *block* boarding shown in fig. 9 points out a significant relationship between block size and boarding efficiency. The creation of two separate blocks could improve boarding procedure by 3.9 %, whereas the efficiency decreases by using three blocks to 1.4 % for *back-to-front* and reaches even negative values of -4.6 % for *block* procedure.

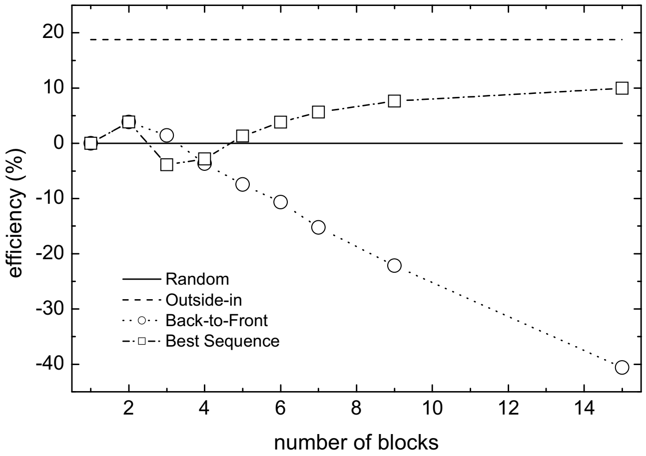

Figure 9. Efficiency of different block numbers

Using an appropriate block size of 6 blocks (approx. 5 rows per block with 30 passengers) the efficiency of *back-to-front* drops to -10.7 %, but increases for *block* to the prior level of 3.9 %. A further seat row segmentation finally results in efficiency measurements of -40.6 % and 10 % respectively. To evaluate the best *block* sequence, all possible sequences were tested; an *n* block configuration produces *n!* specified sequences. The 720 sequences for a 6 block configuration are shown in fig. 10, whereas the variance is exemplary highlighted by error bars. Obviously, the sequence 246135 (compare fig. 4) with $\mu = 1133.5$ s, $\sigma = 72.52$ s is significantly faster than all other sequences and the sequence 654321 is the slowest sequence (μ = 2005.4 s, σ = 122.4 s). Even though the sequence 135246 should be as fast as 246135, the impact of the reduced row number at block 6 (only 4 rows instead of 5) results in different values of μ = 1141 s and a σ = 78 s.

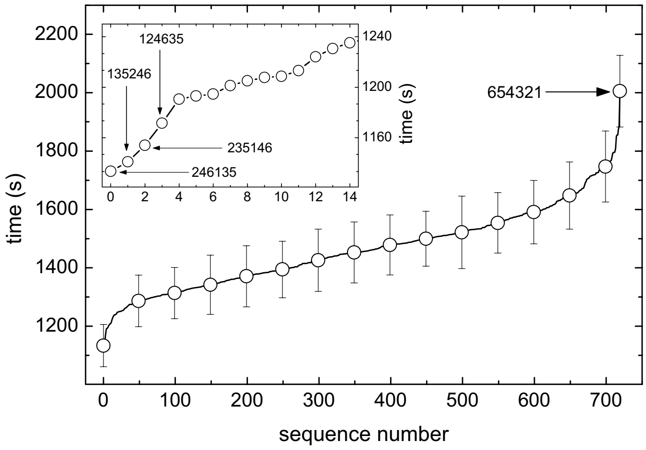

Figure 10. Sequences (720) for 6-block boarding procedure

The simulation runs for the different block sizes points out, that alternating block sequences are much faster than other sequences. If the passenger group of the first block enters the aircraft they are queued in the aisle segment of the prior block. This prior block with occupied aisle should not be used for boarding and therefore one block is skipped in the *block* boarding sequence. Furthermore, the most efficient sequence starts always even numbered (246...) and followed by the odd numbered blocks (135...). In our further analysis the 6 block classification is used. In this context the *back-to-front* and the *block* nomenclature represent the block sequence 123456 and 246135 respectively. For the two door configuration this nomenclature has to be adapted. The blocks 123 are boarded through the rear door and 456 are boarded at the same time through the front door. Hence, the sequence for *back-to-front* is 342516 and for *block* 253416. In contrast to the one door boarding passengers, the effective block size is reduced to 3, because the passenger from blocks 123 do not disturb passengers from blocks 456.

B. *Comparison of boarding procedures*

To analyze the different boarding strategies one parameter (SLF, AR, PPM, number of doors) varies and the other parameters are kept constant at their default values defined in section II.D. For the comparison of the different boarding procedures the *random* procedure acts as a baseline indicator. This procedure is always marked with a solid line in the following figures. The investigation starts with a one door configuration, but the results of the two door configuration are already shown on the opposite. Due to the use of the same scale gradations an overall evaluation of the efficiency can be ensured. The inserted diagrams show the corresponding standard deviation characteristics.

With the increment of the acceptance rate (AR) from 0.2 to 1.0 (see fig. 11, 12) the boarding time of the *outside-in* procedure decreases at an average of 44.8 s per 0.1 acceptance rate for one door configuration and 23.4 s for two door configuration. At AR = 0.32 the *outside-in* procedure reaches the breakeven point. As expected, the *random* boarding times are constant, whereas the two door configuration shows an improvement of 25.9 % regarding to the boarding time and a reduced standard deviation of 28.4 s.

1) One-Door Boarding

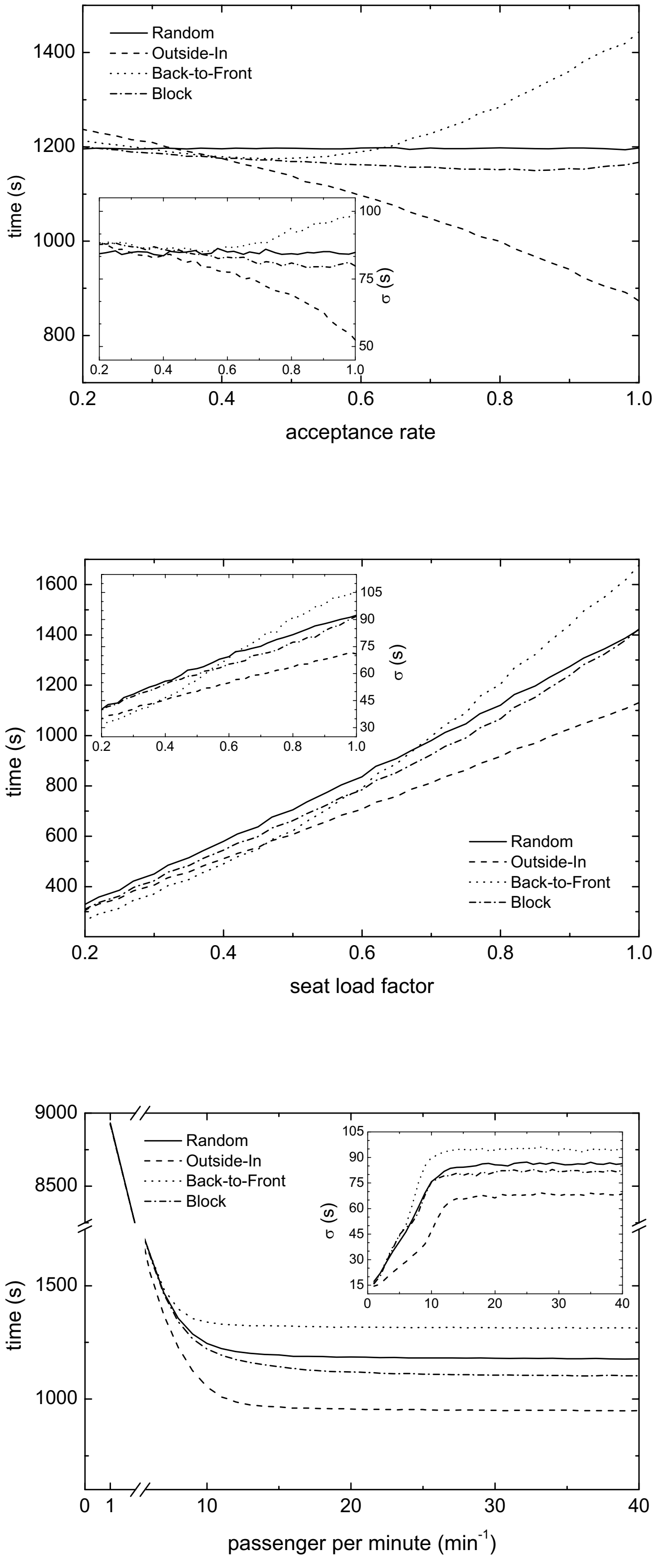

Figure 11. Boarding results using one door (acceptance rate *AR*, seat load factor *SLF*, and passenger per minute *PPM* vs. time)

2) Two-Door Boarding

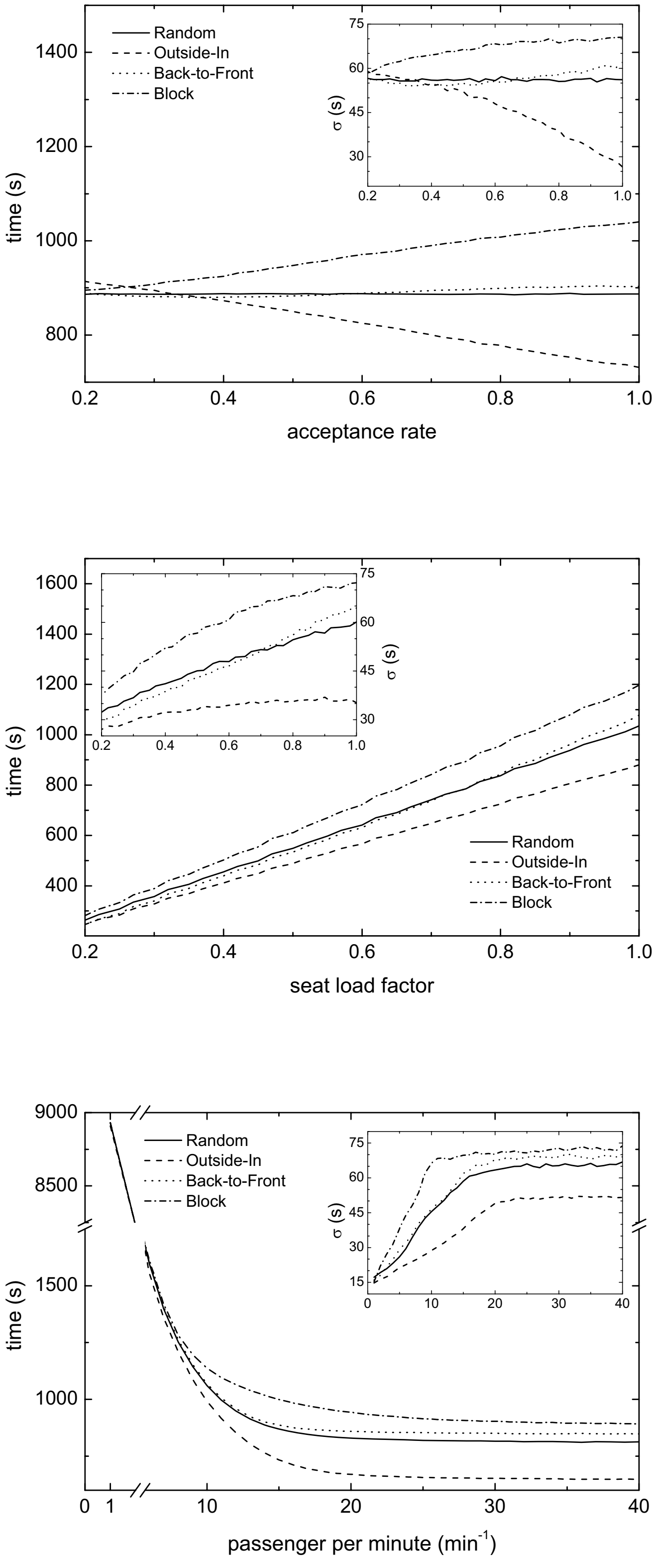

Figure 12. Boarding results using two doors (acceptance rate *AR*, seat load factor *SLF*, and passenger per minute *PPM* vs. time)

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The *block* boarding reaches the maximum efficiency of 3.9 % at AR = 0.85 (one door). In contrast, the *block* boarding is not efficient at the two door configuration. If the AR exceeds the 0.62 level at the one door configuration the *back-to-front* procedure gets inefficient, and induces no significant efficiency enhancements at the two door configuration. This inverse effect of *block* and *back-to-front* procedure was already point out in section III.A (see fig.9). The analysis of the SLF variation yields nearly linear correlations between the SLF and the boarding time, except the *back-to-front* procedure in the one door configuration. Analogue to the acceptance rate the boarding time gets inefficient at a certain point (SLF = 0.68), whereas the standard deviation already indicates this trend at SLF = 0.37.

The analysis of the increasing arrival rate provides no additional information about the comparison of different strategies. However, the direct comparison of the one door versus a the two door configuration shows that the arrival rate of approx. 11 PPM (one door) and 16 PPM (two door) assign an upper value for the arrival rate regarding to the boarding efficiency. From this point of view a further increment of the arrival rate will only have a marginal influence on the boarding time. This result corresponds to the waiting time analysis at the beginning of section III.

Finally, the comparison of the one door versus the two door configuration yields the results shown in tab. V. The parameter AR, SLF and PPM are kept at their default values of 0.85 %, 0.85 % and 14 PPM respectively. The standard deviation percentage refers to the procedure regarding mean value, whereas the efficiency refers to the *random* boarding with a one door configuration.

TABLE V. COMPARISON OF ONE DOOR VS. TWO DOOR CONFIGURATION

	procedure	**mean (s)**	**standard deviation**		**Efficiency (%)**
			(s)	**(%)**	
1 door	random	1191.0	83.8	7.0	0.0
	outside-in	968.3	65.8	6.8	18.7
	back-to-front	1324.3	94.8	7.2	-11.2
	block	1151.7	80.8	7.0	3.3
2 door	random	886.8	55.6	6.3	25.5
	ouside-in	764.3	35.8	4.7	35.8
	back-to-front	901.2	57.7	6.4	24.3
	block	1018.8	69.2	6.8	14.5

The utilization of the second aircraft door results in an enhanced efficiency of 25.5 %, without even considering particular boarding procedures. In comparison to the *outside-in* procedure (one door) an additional improvement of 7 % and reduction of the standard deviation by 0.5 % is realized. Furthermore, the result points out that *back-to-front* and *block* boarding are not recommended procedures. A marginal efficiency value of 3.3 % with a nearly unchanged standard deviation does not legitimate the application of the *block* boarding at the one door configuration. Looking at the two door configuration, the *outside-in* procedure achieves the best efficiency of 35.8 % with the smallest standard deviation of 4.7 %.

IV. CONCLUSION

This paper presents a simulation model to evaluate different boarding procedures and the influence of the variation of the corresponding input parameter (seat load factor, passenger acceptance rate of boarding procedure and arrival rate). The results of the simulation runs show the expected high efficiency of the *outside-in* boarding procedure and the marginal advantage of adjusted *block* procedures. With the utilization of the second aircraft door further enhancements are achieved. Airlines with apron-parking aircraft could easily use a second door for boarding. To achieve an efficiency enhancement of approx. 25% (see tab. V), the passengers have to split up in two groups only, regarding their assigned seat row.

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