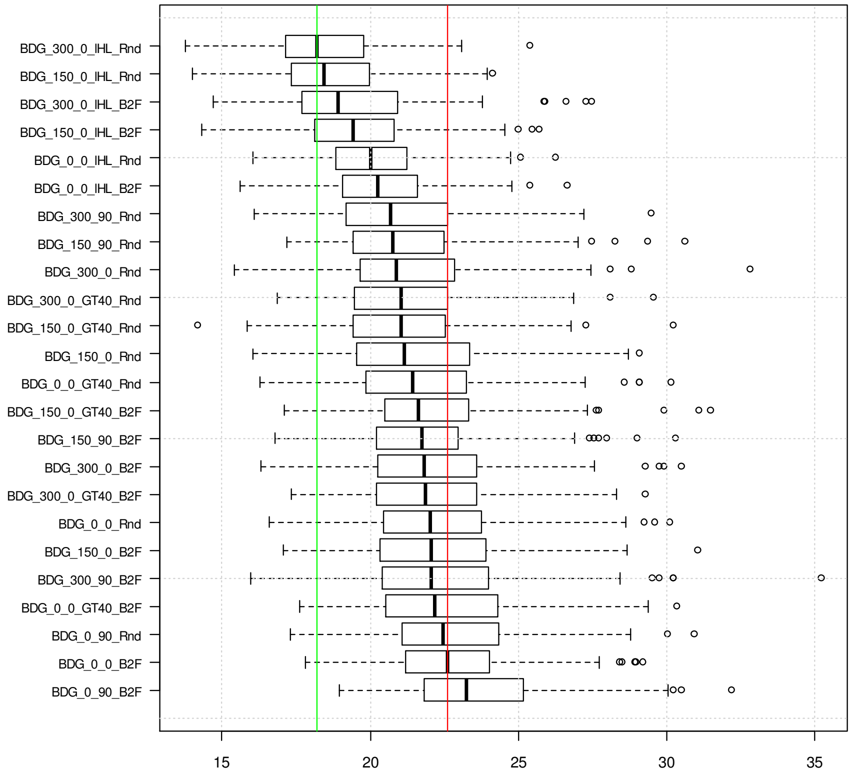

Speeding up the airplane boarding process by using pre-boarding areas

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Abstract

One major business of civil aviation is to carry passengers between airports while providing good customer services at low costs. The turn time of an airplane, i.e. broadly speaking, the time that an airplane is on ground, is crucial for its utilisation and thus for the airline's profitability. From this it follows, that the turn time needs to be as short as possible.

In this paper we analyse various actions (inside and outside the airplane) to reduce the boarding time and hence the turn time. These actions were investigated with a specifically developed simulation tool (the Airplane Boarding Simulator (ABS)), and cover the whole process from (and including) the gate until the passengers arrive at their seats.

The simulation model was calibrated by using video data from observations of eight boardings at Zurich airport. The primary goal was to determine the impact of the following factors on the boarding time: (i) number of pieces of hand luggage, (ii) pre-boarding area (and timing), (iii) boarding (seating) strategy inside the airplane, (iv) procedures at the gate desk (power-boarding, additional staff).

Based on the experiences on-site and the results of the simulations we found, that with a reduced number of pieces of hand luggage, the use of a pre-boarding area and an appropriate boarding (seating) strategy, a reduction of the boarding time of around four minutes for airplanes of similar size than the Airbus A321 is possible. Moreover, we outline feasible actions that could lead to further improvements. In any case, a good coordination of the actions taken is of crucial importance, together with an appropriate training of the staff (airplane crew and ground) and a clear and easy to understand information of the passengers.

Keywords

Airplane boarding – Pre-boarding areas – Turn time – Aviation – Simulation – Modelling

1. Introduction

The increasing cost pressure forces airlines to continually adopt and optimize their processes with the goal of maximizing their efficiency and profitability. At the same time, a specified level in customer satisfaction needs to be achieved as well. Usually these goals are contrary to each other. Based on its business model and strategy, every airline tries to reach the individual goals by optimally coping with its market environment. Detailed information on airline management and related topics can be found in O'Connor (2000) or Wensveen (2007).

Regarding the costs and revenues of an airline, the utilization of its fleet is very important. There are many parties involved and the processes that determine the utilisation are very interdependent and complex (e.g., Mirza (2008)). For scheduled flights, the utilisation depends for example on: (i) the airlines's fleet planning (e.g., type and number of airplanes), (ii) schedules planning (e.g., flight, crew), (iii) passenger reservations (e.g., booking system), (iv) flight operations (e.g., reaction of pilots on weather situation), (v) ground operations (e.g., taxi-in/taxi-out, luggage handling, refuelling, jetway handling, deplaning, boarding, etc.), (vi) airplane maintenance systems (e.g., time, staff and equipment required for safety checks), (vii) air traffic controllers (e.g., effectivity in handling airborne delays) and (viii) airport authorities (e.g., by defining regulations). It is obvious, that only a limited number of these tasks can be controlled by an airline itself.

As this paper mainly deals with the investigation of the airplane turn time[1], or, to be more specific, with the time required for passengers to board an airplane, we restrict ourselves to the ground operations, as they determine to a large extent the airplane boarding time. However, where required, we discuss other aspects as well. A simplified overview regarding the overall process and the part covered by the research presented in this paper, is shown in Figure 1.

The boarding process (including the processes at the gate, in the pre-boarding area (if available), in the jetway, and in the cabin) plays an important role with respect to the turn time, only if the boarding process is part of the "critical path", i.e., if the parallel processes (according to Figure 1, below), are completed before the boarding. In this case, a substantial reduction of the boarding time (e.g., by three minutes or more), can reduce the turn time by approximately the same amount. However, time savings due to improved boardings are usually

[1] According to Marelli et al. (1998), a rough definition of the airplane turn time is as follows: The time required to unload an airplane after its arrival at the gate and to prepare it for departure again. A more specific definition is provided by Delliehausen (2009): The turn time is the time from "Chocks on" (t_1) (at the airplane's arrival) until "Clearance to roll" (t_2) or "Doors closed" (t_2-3 min.) (at the airplane's departure).

quite difficult to realise as they depend on various aspects, or, to be more specific, on: (i) the airport infrastructure (type of boarding (through jetway or by bus gate), gate design, availability and size of pre-boarding areas, etc.), (ii) the airline (boarding strategy, hand luggage policy, customer service, etc.), and (iii) on the airplane type (number of seats, number of aisles, etc.).

In general, a reduction of the boarding time might either lower the turn time or, if existing, reduce departure delays. With respect to the costs, this is an important distinction, as the costs caused by an airplane on ground (i.e. the costs of the turn time) count rather on a strategic level (e.g., in future flight plans), whereas the latter have an effect at a tactical/operational[2] level. In any case, a lower boarding time is beneficial for an airline. In this paper, we do not investigate in detail the financial effects caused by an improved boarding process on a strategical and/or tactical/operational level, but provide some rather general information on possible effects at both levels in the following.

From an airline's perspective, one goal at a strategical level is to achieve a minimum turn time, as with this, the number of flights and thus the turnover can be increased. However, the practical realisation of these benefits is usually quite difficult, as in many cases[3] only a substantial reduction of the turn time allows to insert additional flights (e.g., a reduction of the turn time from 35 to 30 minutes), see for example Mirza (2008).

The estimation of the costs of delays is quite complex, as there are many parties involved, the cost structures are often not well defined and data are not or only partially available. We will not go into detail here, but refer to the very good introduction on this topic provided in Cook (2004, chapter 4) and the references therein. Additional information can also be found in Cook et al. (2009).

To give the reader an idea of possible costs savings due to a reduced turn time, we provide a simple but very realistic example according to Delliehausen (2009): Based on the current

[2] It shall be noted here, that we do not consider delay recovery, i.e. we assume that departure delay of an airplane is identical to the arrival delay. This is reasonable, as the average delays for arrival and departure in Europe differ usually only little (for details see EUROCONTROL (2009)).

[3] This is of course a very general statement. The actual financial impact of a reduced turn time for an airline depends on several factors, e.g., fleet (types and number of airplanes per type), business strategy, flight plan (routes, leg sequences, airports), etc. From this we see, that the impact of a reduced boarding time on the turn-time and thus on the utilisation can be very different and as such no general rule can be applied.

situation at Zurich airport[4] and particularly the situation for SWISS International Air Lines (SWISS), we assume that for five flights per day at Zurich airport the minimum ground time (MGT) can be reduced by 5 minutes. The (ground) costs per minute are estimated to be around 70 Swiss Francs (according to SWISS) and thus the yearly savings are about 640’000 Swiss Francs (approx. 420’000 Euros), which is by far not negligible.

Nyquist and McFadden (2008) assume, that the boarding process is always part of the “critical path” and thus with every minute that the boarding process can be sped up, the airline saves money. This might hold for some airlines. However, we are less optimistic than Nyquist and McFadden (2008) regarding possible savings due to optimized boardings, as a significant number of longer turn times are caused not only by the boarding process, but by other factors as well (see EUROCONTROL (2009)). Moreover, not every reduction in boarding time leads automatically to a reduction in turn time. Only if the turn time can be lowered so that an earlier slot can be occupied, a reduced boarding time is actually a gain (part of flight planning; see also above). However, we fully agree that by intelligently combining feasible actions (e.g., introducing pre-boarding areas, reducing the maximum number of pieces of hand-luggage; see sections 6 and 7 for details), the savings for an airline can be significant. This is also corroborated by the simple calculation above.

From the above explanations we see, that reducing the boarding time and thus the airplane turn time can indeed lead to substantial savings for an airline. This potential has motivated airlines, airplane manufacturers (e.g., Boeing) and researchers in the past decade to analyse the involved processes, to determine the bottlenecks, i.e. the factors that cause delays and disturbances, and to find solutions, to speed up these steps. In previous research, the focus was mainly on the investigation and optimisation of the following aspects: (i) the processes inside the airplane, i.e. finding optimal seating strategies by minimising the number of interferences in the aisles and in the seat rows, (ii) the influence of the number of pieces of hand luggage (mainly relevant inside the airplane, since it takes more time to stow the baggage, but as well at the gate, if hand-luggage needs to be additionally labelled), (iii) number of ticket agents, and (iv) number of airplane doors used for boarding. The approaches that tackled one or more of the above mentioned aspects in recent research were based on either simulation (e.g., Marelli et al. (1998), van Landeghem and Beuselinck (2002), Ferrari and Nagel (2004), Pan (2004)) and/or approaches from operations research (e.g., van den Briel et al. (2003), Bazargan (2007), van den Briel et al. (2005)). A good summary of the major findings from previous research can be found in Nyquist and McFadden (2008).

[4] For general information on traffic development, airplane movements, punctuality, etc. at Zurich airport in 2008 see Unique (2009).

In previous research, a variety of very sophisticated and fast boarding strategies were developed. Unfortunately, many of them are not applicable in practice, mainly due to organisational restrictions: too complex processes, too much ground staff required, not reasonable for passengers, etc. Various papers suggested that a reduced number of pieces of hand luggage can reduce the boarding time significantly. This is a very important aspect, indeed. However, some airlines argue, that with this action, the perceived service quality might be below the passenger's expectations. Furthermore, for some airplane types (e.g., with more than 200 seats) it was suggested, that using two doors instead of one might speed up the boarding as well. This is considered to be a very good idea as the gains are significant (see Nyquist and McFadden (2008) for details), but, at least for boardings through jetways, this approach is currently possible only for a limited number of airports, as the infrastructure (jetways) is often not available. Nonetheless, as a mid- to long-term action this should be taken into account.

The research presented in this paper is also based on a simulation approach (discrete event simulation; for details we refer to section 3 below). We intend thereby to quantify the impact on the overall boarding time (i) by using pre-boarding areas, but also consider (ii) different boarding strategies ('Back-To-Front' and 'Random'), (iii) by the number of pieces of hand-luggage, and (iv) the timing during the so-called power-boarding[5].

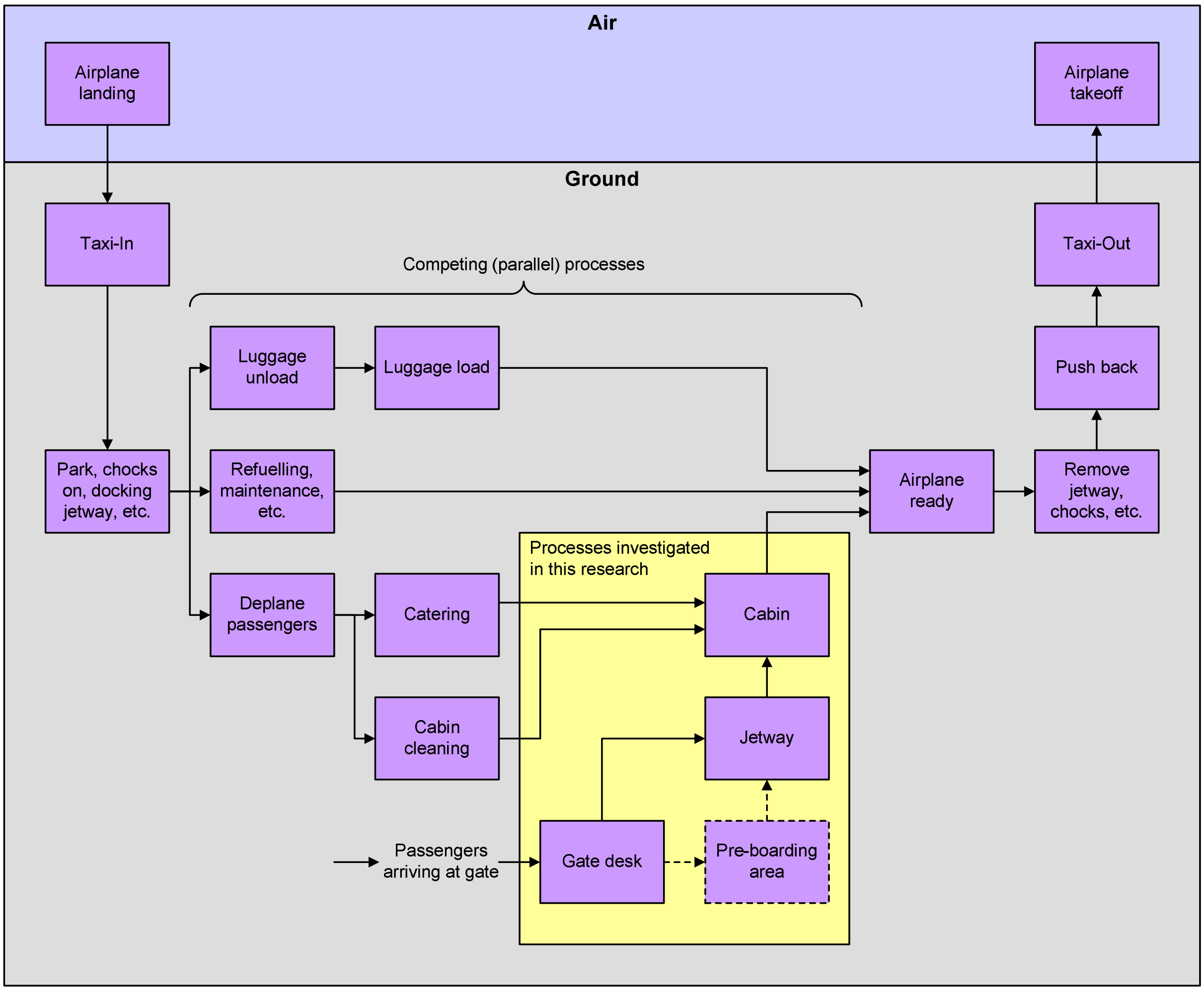
The rest of the document is organised as follows: In section 2 we provide an overview of the main processes that are relevant for the turn time and which of these steps are investigated here. In section 3 we present a short outline of the so-called Airplane Boarding Simulator (ABS), which forms the basis for the simulations carried out. To calibrate the model, we collected and analysed data from digital video-cams for eight flights at Zurich airport. These steps are documented in section 4. Section 5 describes the investigated simulation scenarios and in section 6 we present the results together with some recommendations for field implementations. Finally, in section 7, we draw some conclusions and give an outlook on possible future research. In Appendix A, the reader finds some detailed information on statistical hypothesis tests (comparing the median of the boarding times for the different scenarios). Furthermore, some plots of the Inter-Passenger Times (IPT) extracted from the video data are shown in Appendix B.

[5] If more than one gate agent (usually two) is serving the passengers at the ticket station (controlling the passport and the boarding card), this is called power-boarding.

2. The overall process

To get a better understanding of the overall process that determines the turn time (where the passenger boarding is part of), we depict the (simplified) sub-processes and their interactions in Figure 1. Based on the definition of the turn time on page 3 (bottom), we see that this is actually the time period between the blocks “Park, chocks on, etc.” and “Push back”. Once the airplane’s chocks are on, there are several parallel processes: (i) handling the luggage, (ii) refuelling, maintenance, etc., and (iii) deplaning, cabin cleaning/catering, and boarding. The part covered by the research presented in this paper is highlighted by the yellow box. We see that it includes all steps from the arrival of the passengers at the gate until the closure of the airplane’s doors.

Figure 1 Overview of the processes that determine the airplane turn time.



Basic idea according to Nyquist and McFadden (2008) and Marelli et al. (1998), with some extensions and modifications.

3. The Airplane Boarding Simulator

To allow the investigation of the sub-processes highlighted in Figure 1 (within the yellow box), we have developed a simulation environment in MATLAB™, the Airplane Boarding Simulator (ABS). The tool allows for the simulation of the four coupled sub-processes: (i) gate desk handling, (ii) pre-boarding, (iii) jetway, and (iv) airplane cabin. The underlying framework is a discrete event (DE) simulation model (an introduction to DE simulation can be found, e.g. in Banks et al. (2009)). All actions and movements of ground staff and passengers depend on booked events (e.g., ground staff allows passengers to leave pre-boarding area towards jetway and airplane) and conditional events (e.g., a passenger moves forward). The simulator determines the system's state after every event and creates new conditional events, if required, according to a list of conditions. When all events are executed, the simulation is completed. Movements of passengers are indicated on a grid to allow for interactions with other passengers. The main components of the model are described in Table 1.

Table 1 Model components of the airplane boarding simulator (ABS) together with a short description (geometry, behaviour rules, etc.).

Model component	Description
Gate desk	▪ The gate desk is modelled as a queueing system with two gate agents serving the passengers that are waiting in a queue.
Pre-boarding area	▪ The pre-boarding area is modelled as an area with a maximum size of 100 passengers. ▪ The distance to walk through is five meters. ▪ The time that passengers need to cross the pre-boarding area depends on their walking speed (more information on this can be found in section 4.2, 'Walking Speed'). ▪ As long as the boarding is not officially announced, passengers are kept inside. This time can be modified as a model parameter.
Jetway	▪ The jetway is modelled as a grid with a dimension of 2 x 61 cells. ▪ The cells size is 0.815 x 0.44 meters. ▪ The resulting walking distance for passengers is 50 meters. ▪ The grid structure allows to handle a queue in front of the airplane door if the entrance to the airplane is blocked. ▪ The width of two cells allows passengers to overtake others. ▪ Passengers travelling in groups will not overtake each other, due to their equal walking speed.

Airplane	▪ Inside the airplane one aisle provides a way for the passengers to their seat row. ▪ Once a passenger reaches her/his seat row, the time on how long the aisle is blocked for other passengers is estimated with the model described in section 4.2. ▪ Subsequent passengers can only overtake another passenger in front if the preceding passenger has the property to let others pass (see section 4.2 for details). ▪ The dimension of the airplane is: 33 rows with 6 seats, resulting in a total of 198 seats (similar to an Airbus A321). ▪ Seats for business class and cabin crew were not specifically considered.

As mentioned in section 1, a huge variety of different boarding strategies exists, with respect to the sequence in which the passengers enter the airplane, and finally find their seats. The time required for the different strategies varies largely. However, many of these strategies are not applicable due to reasons discussed above.

We decided to investigate the impact of only two different boarding strategies (see Table 2). The selection was mainly based on practical reasons. The “Back-To-Front boarding” is widely applied (e.g., by SWISS, American Airlines) and the “Random boarding” does not require additional organisational efforts by the ground staff (currently applied by Northwest Airlines; see Nyquist and McFadden (2008)). In most cases, “Random boarding” outperforms “Back-To-Front boarding”[6]. However, it is often argued that random boarding is not very customer friendly, as there are more interactions (aisle, rows). A detailed summary of the boarding strategies applied by major US airlines can be found in Nyquist and McFadden (2008). From this we also see, that so-called non-traditional methods like, e.g. the “Reverse-pyramid boarding” (which evidentially leads to reduced boarding times) are already applied in practice. To ease future investigations, sophisticated strategies (e.g., “Outside-In boarding”, “Reverse-pyramid boarding”) are already implemented in the ABS.

[6] This argumentation appears confusing at a first sight. However, at the beginning of the procedure with the “Random boarding”, the aisle is, on average, blocked less often by passengers compared to the “Back-To-Front boarding”. In addition, at the beginning of the boarding the chance for a passenger to sit in a front row, where she/he is not disturbed in taking her/his seat, is higher (on average).

Table 2 Applied boarding strategies in the ABS.

Boarding strategy	Description
Random Boarding	The easiest boarding strategy is random boarding. Passengers have assigned seats, but do enter the airplane in random order.
Back-To-Front	A very common boarding strategy in aviation is “Back-To-Front”, where passengers sitting in the tail rows of the airplane are boarded before the remaining passengers follow. SWISS applies this strategy and calls at first passengers with a seat row starting from row 22. We assume here, that 10% of the passengers do not follow this rule, on average.

4. Data collection and analysis

4.1 Data collection

In order to calibrate the boarding simulator explained in section 3, i.e. to estimate the model parameters, we filmed eight boardings at Zurich airport. While observing, we could additionally learn how specific tasks (such as a passenger taking a seat) were performed, to implement them correspondingly in the computer model. The recordings were taken with three camcorders at different viewpoints, according to the observations listed in Table 3 (in total 18).

Table 3 Recorded boarding situations and camera perspectives. Inside the airplane, the cameras were either placed in the front part (FV = front view) or in the rear part (RV = rear view) of the cabin.

Flight	Camera 1	Camera 2	Camera 3
LX1952	Gate	-	Jetway
LX634	Inside airplane (FV)	Gate	Inside airplane (RV)
LX1830	Gate	-	Inside airplane (RV)
LX1954	Inside airplane (FV)	Gate	Inside airplane (RV)
LX1838	-	Gate	Inside airplane (RV)
LX1254	-	Jetway	Gate
LX560	-	Jetway	Inside airplane (FV)
LX1272	-	Gate	Inside airplane (FV)

At the different camera positions, specific information was extracted from the video data. At the gate, we determined the time difference between passengers served at the ticket station (also known as gate desk). Thus, both the time that a ticket agent needs to serve a passenger and the delay of late arriving passengers are covered by this value. In the jetway, we could best observe the passenger’s walking speed and inside the airplane we tried to identify the time it takes a passenger to take a seat after stowing her/his hand luggage into the overhead bins. Additionally we extracted important information about:

- the amount of hand luggage that passengers are carrying 0, 1, 2 or more
- the occurring of interferences in front of the seat yes/no
- passengers waiting in a queue to pass another passenger yes/no
- the fact that passengers let subsequent passengers pass yes/no

The first three points of the list define all kinds of states a passenger can experience when arriving at the seat row. The last one is used as additional information in the model.

The observations took place on the 28th of May 2009, a warm spring day[7]. The observed flights together with some associated figures are listed in Table 4.

Table 4 Observed boarding scenarios. The capacity per airplane type can vary slightly for a given airplane type and does not include the seats of the cabin crew. Thus, the number of passengers on board can be higher than the denoted capacity. All flights were operated by SWISS.

Observation	Flight	Destination	Airplane	Capacity	Passengers on board	Boarding time [min.]	Gate time [min.]
1	LX1952	BCN	A321	200	194	22	18
2	LX634	GDC	A319	138	139	17	11
3	LX1830	ATH	A321	200	193	21	14
4	LX1954	BCN	A321	200	192	25	19
5	LX1838	ATH	A321	200	198	28	18
6	LX1254	ARN	A320	162	160	23	19
7	LX560	NCE	A321	195	184	26	20
8	LX1272	CPH	A321	195	197[8]	26	20

As not all flights were booked by the same amount of passengers and airplanes with different capacities were investigated, not all boarding times can be compared directly. Similar ones are observations 1, 3, 4 and 5 with a mean boarding time of around 24 minutes, a mean gate time of 17.25 minutes, a mean passenger load factor of 0.97, and a mean number of passengers on board of about 194. These values are used to calibrate (number of passengers on board) and (roughly) verify (durations) the results of the computer simulations, respectively.

Since most information extracted from the movies was used as input for the computer simulations, we briefly discuss the measurement, the extracted data and the way of using these values in the computer simulation, in the following section.

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[7] This information is crucial as the amout of hand luggage of passenger depends on the weather, e.g., on cold winter days, passengers carry winter jackets and coats, which requires additional space inside the airplane.

[8] Two passengers were assigned to seats reserved for cabin crew.

4.2 Data analysis and modelling

Inter passenger time (IPT) at the gate

The inter passenger time (IPT) denotes the time between two served passengers at the ticket station, who are about to board the airplane. Within this time, the ticket agent is either:

- verifying the flight ticket together with the passport
- checking-in hand luggage, which is too large for the cabin LH
- exchanging incorrect tickets TH
- announcing the boarding GA
- communicating with the cabin crew BY
- waiting for delayed passenger(s) NP
- providing any other service to the customers CS
- or solving any other problem (not identifiable from video data) UP

We extracted the durations from the recorded videos at the gate desk for every single ticket station (occupied by an agent). Values higher than 40 seconds were identified as very long IPT's. Additionally, we obtained the time lag between the first served passengers at all stations. This is crucial as power boarding (all stations are served) should be executed right from the beginning of the boarding procedure. The observed time differences and the number of very high values are listed in Table 5.

Table 5 Passenger gate time observations and reasons for circumstances with values taking more than 40 seconds (for abbreviations check list above).

Flight	Time lag [sec.]	Number of extreme observations (IPT > 40 sec.) and causes	
LX1952	117	3	BY, GA, LH
LX1954	242	4	NP, LH, NP / NP
LX1830	56	4	CS, NP / NP, NP
LX1838	109	7	LH, GA, TH, LH / TH, TH, NP
LX1254	12	8	LH, LH, TH / TH, TH, LH, TH, UP
LX1272	17	9	LH, LH, LH, LH, LH / TH, LH, TH, TH
LX634	6	4	TH, TH / NP, NP

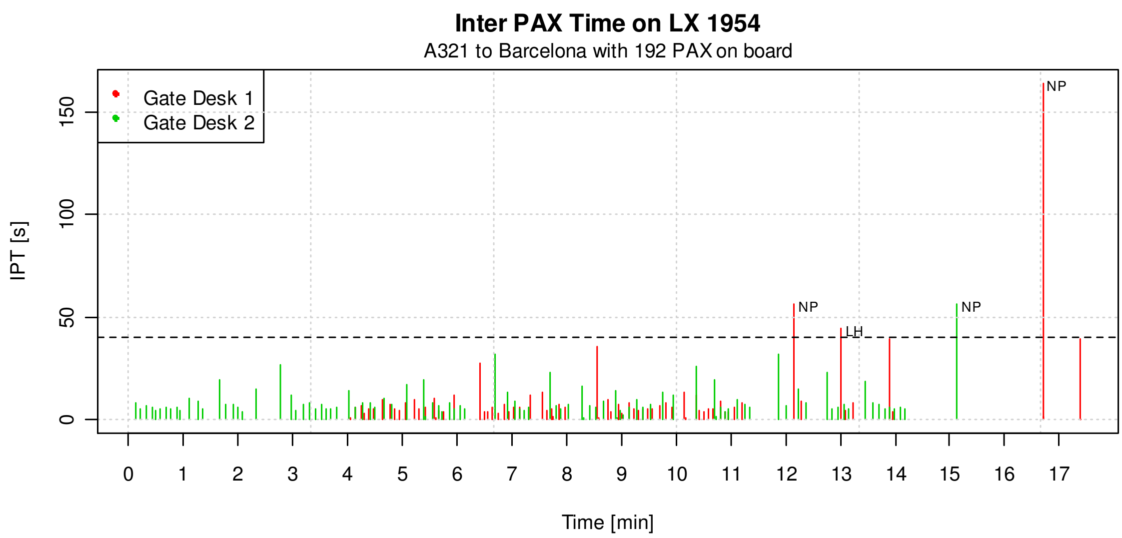
Figure 2 depicts the IPT of both ticket stations for flight LX1954. Further examples of extracted IPT can be found in appendix B.

Toward the end of the boarding procedure longer IPT tend to occur more often. This is also considered in the computer simulation. The progress is determined through the cumulating load factor of the airplane. The computer simulator handles this part of the boarding process by sampling from the observed times (i) > 40 sec. or (ii) ≤ 40 sec., according to the probabilities listed in Table 6.

Table 6 Probabilities for inter passenger time (IPT) ≤ 40 seconds in the course of the gate process.

Processed passengers	Probability for IPT ≤ 40 sec.
0 - 20 %	0.984
20 - 40 %	0.984
40 - 60 %	0.975
60 - 80 %	0.967
80 - 100 %	0.929

Figure 2 Inter passenger times on flight LX1954. The higher the value, the longer the time gap between two passengers at the gate desk. Gate desk 1 was opened four minutes later than gate desk 2. The dashed horizontal line denotes the limit to consider an IPT as very high. Gate desk 2 closes after 15 minutes, whereas at gate desk 2 the last passenger was processed after 17.5 minutes.



Walking speed

The walking speed of passengers determines the time a passenger needs to move from one cell to the next in the computer simulation. This is of interest only when the cell ahead of a passenger is empty, i.e. she/he can walk with her/his desired speed. Otherwise the passengers walking speed will be reduced automatically. We assume a lower walking speed inside the airplane as the aisle is more narrow than the jetway.

From the recordings we could extract the walking speed only very roughly (time for passengers to walk five meters in the jetway and time to pass one seat row inside the airplane). However, it is well known from empirical investigations (e.g., Buchmüller and Weidmann (2006), Daamen (2004) or Weidmann (1993)), that the pedestrian free speed can be described approximately by a normal distribution. In accordance with the literature, we assumed a normally distributed walking speed in the jetway with a mean of 1.23 m/s and standard deviation of 0.18 m/s and a normally distributed cabin (aisle) walking speed with a mean of 0.59 m/s and standard deviation of 0.15 m/s. These parameters were estimated based on a very limited sample extracted from the video sequences.

Cabin time

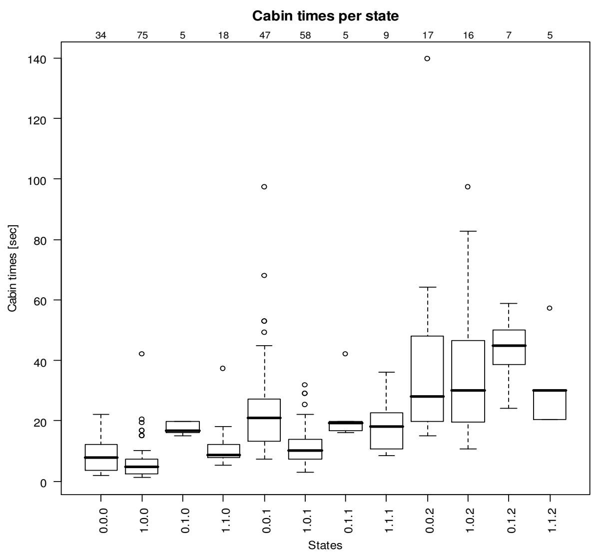
The cabin time is a very crucial and critical part of the boarding process as one passenger slowly stowing her/his luggage or taking a seat, can slow down the boarding process for seconds or even minutes. The most important factors determining the so-called cabin time of a passenger are listed in Table 7.

Table 7 Crucial factors determining the cabin time of a passenger.

Variable	Description	State	Effect on cabin time
Luggage	The number of pieces of hand luggage that is stowed in the overhead bins.	1, 2 or more	increase
Interferences	The fact that another person is already sitting between the aisle and the arriving passenger's seat.	yes, no	increase
Queue	The fact that a queue of waiting passengers forces a passenger to hurry.	yes, no	decrease

The combination of the variables leads to 12 characteristic states that a passenger can be in, when arriving at her/his seat row. The boxplots of the observed cabin times per state are shown in Figure 3. The variability differs for the various states. Nonetheless, an increase of the cabin time is observed when the number of pieces of hand luggage is greater than zero, and a decrease can be found, when a queue is building up (i.e., the variable 'Queue' for this passenger is in state 'yes'). However, the small number of observations (listed above the top axis of the plot for all states) is in fact a problem for optimally determining the cabin times required by the computer model.

Figure 3 Observed cabin times per state combination. The states are labelled in the form of *x.y.z* where *x* denotes the queue (0 = no, 1 = yes), *y* denotes the interferences (0 = no, 1 = yes) and *z* denotes the luggage (0 = 0, 1 = 1, 2 = 2 or more pieces).



We defined the following linear regression model to predict a passenger's cabin time, given the state at the point in time when the passenger arrives at her/his seat row.

$$\log(Y) \approx Luggage + Interferences + Queue$$

This leads to the linear equation with only factorized exogenous variables

$$\log(Y_i) = a + b_{L_1} L_{1,i} + b_{L_2} L_{2,i} + b_I I_i + b_Q Q_i + e_i$$

where

$$L_{1,i} = \begin{cases} 1 & \text{if number of pieces of hand luggage is 1} \\ 0 & \text{otherwise} \end{cases}$$

$$L_{2,i} = \begin{cases} 1 & \text{if number of pieces of hand luggage is} \geq 2 \\ 0 & \text{otherwise} \end{cases}$$

$$I_i = \begin{cases} 1 & \text{if number of interferences is more than 0} \\ 0 & \text{otherwise} \end{cases}$$

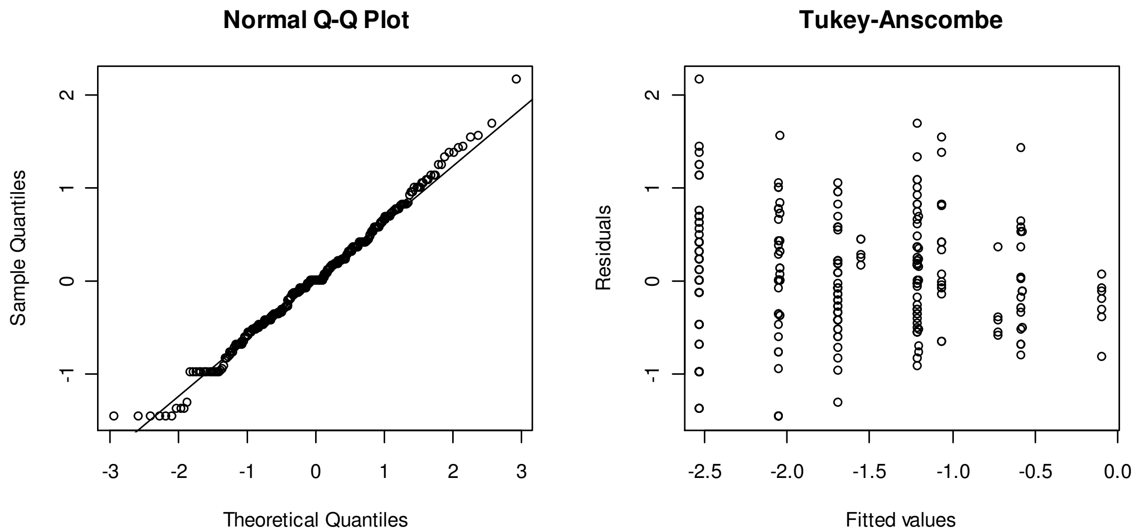
$$Q_i = \begin{cases} 1 & \text{if a passenger is waiting behind to pass} \\ 0 & \text{otherwise} \end{cases}$$

The (robustly) estimated parameters of the equation are

$$a = -2.0438084$$
$$b_{L_1} = +0.8376487$$
$$b_{L_2} = +1.4642483$$
$$b_I = +0.4912027$$
$$b_Q = -0.4821557$$

The analysis of residuals (see Figure 4) did not unambiguously show evidence for normally distributed errors. Therefore, in the computer simulation the residuals were randomly sampled from the data and added to the estimated value $\log(\hat{y}_i)$.

Figure 4 Residual analysis of a linear regression model for the cabin time. The Q-Q-plot (left) shows small deviations from the normal distribution. The Tukey-Anscombe plot (right) shows the small number of observations within several states, but the overall variances appears to be similar after the log transformation of Y.



Hand luggage distribution

The relevant number of pieces of hand luggage, which was stowed in the overhead bins, was also captured when examining the recordings. 45% of passengers did not carry hand luggage or stowed it under their front seat, which does not lead to additional cabin time, 40% stowed one piece and 15% stowed two or more pieces of hand luggage into the overhead bins.

Passenger travel groups

Passengers often travel in groups (e.g., families, couples or business partners). This leads to a lower cabin time for the whole group, due to the fact, that they enter the airplane successively and in right order as well as they help each other (i) when looking for their seat row or (ii) when stowing their luggage. The behaviour of travel groups is completely implemented in the computer simulation. Considering the observations, 7% of the passengers travel in groups of three persons, 38% of the passengers travel in groups of two persons and 55% of the passengers travel alone[9].

Pass Rate

The rate of passengers that allow passengers behind them to pass is around 10%. To simplify things, we assume a reaction time of 0.5 seconds. In the computer simulation, a passenger with the property to let other passengers pass, will allow others to pass as soon as one of two cells behind her/him is occupied.

[9] The case of passengers travelling in groups but not sitting together was not considered as it does not affect the cabin times.

5. Simulation scenarios

The simulated scenarios are listed in Table 8. Each scenario was simulated 200 times for the boarding strategies “Random boarding” (Rnd) and “Back-To-Front boarding” (B2F) to get statistical accuracy. Thus, a total of 24 scenarios was investigated.

Table 8 Description of the simulation scenarios.

Code	Pre-boarding area	Start pre-boarding (time before gate announcement) [sec.]	Begin of power boarding [sec.] (GA1, GA2)	Inter passenger time [sec.]	Hand luggage distribution [%] (0, 1, ≥ 2)
BDG_0_0	no	0	[0, 0]	not restricted	[45 40 15]
BDG_0_90	no	0	[0, 90]	not restricted	[45 40 15]
BDG_150_0	yes	-150	[0, 0]	not restricted	[45 40 15]
BDG_150_90	yes	-150	[0, 90]	not restricted	[45 40 15]
BDG_300_0	yes	-300	[0, 0]	not restricted	[45 40 15]
BDG_300_90	yes	-300	[0, 90]	not restricted	[45 40 15]
BDG_0_0_GT40	no	0	[0, 0]	< 40	[45 40 15]
BDG_150_0_GT40	yes	-150	[0, 0]	< 40	[45 40 15]
BDG_300_0_GT40	yes	-300	[0, 0]	< 40	[45 40 15]
BDG_0_0_LHL	no	0	[0, 0]	not restricted	[50 45 5]
BDG_150_0_LHL	yes	-150	[0, 0]	not restricted	[50 45 5]
BDG_300_0_LHL	yes	-300	[0, 0]	not restricted	[50 45 5]

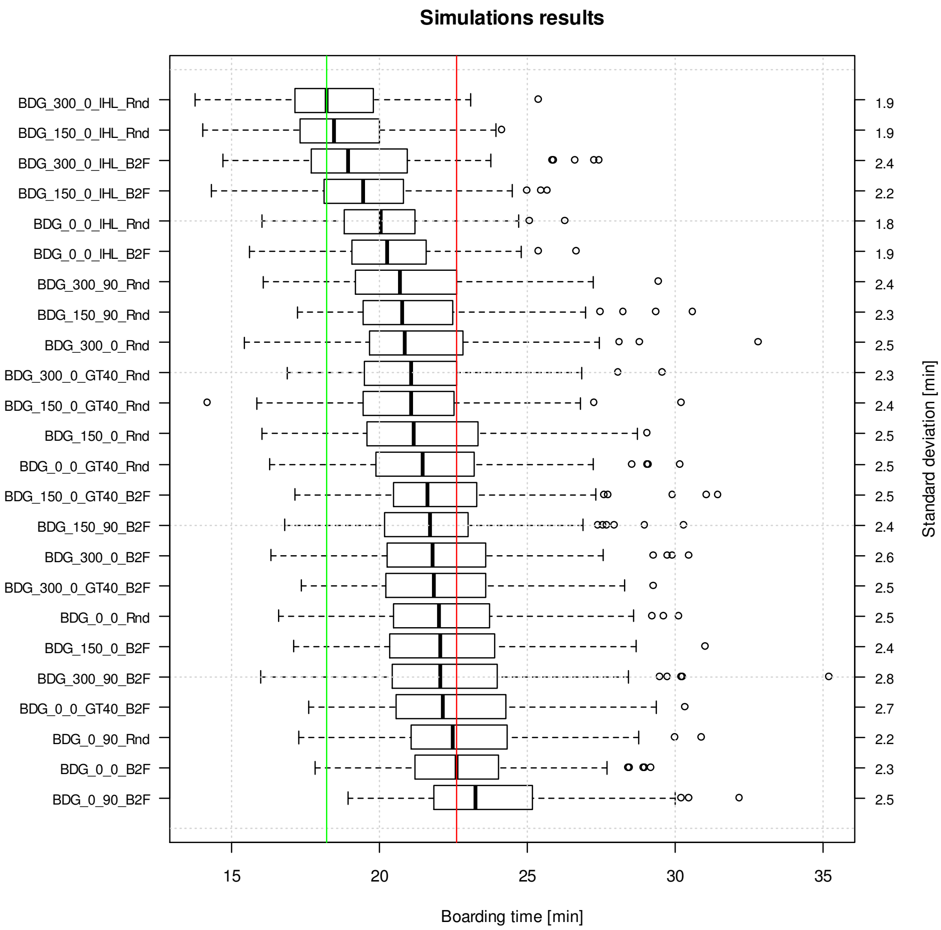
As the observations were carried out mainly for flights on airplanes of type Airbus A321, all simulations performed are based on the same airplane type (see also settings defined in Table 1).

6. Results and recommendations

6.1 Simulation results

Figure 5 contains boxplots of the simulated boarding times for the 24 scenarios investigated. As one can see, the most efficient strategies are those where pre-boarding is applied and passengers are carrying less hand-luggage.

Figure 5 Comparison of the simulation results. The red line refers to the strategy currently applied by SWISS ("Back-To-Front"), without a pre-boarding area and with power boarding from the absolute beginning of the boarding. The green line indicates the most efficient boarding strategy among the simulated scenarios. The time difference between these two scenarios is around 4:20 minutes (-19%).



We do not discuss the simulation results in detail here but refer instead to (i) concrete recommendations based on the findings from the simulations in the next section, (ii) the summary (section 7) and (iii) further information provided in appendix A.

6.2 Recommendations

From the simulation results presented in section 6.1 and the experiences on-site during observing various boardings, we derived the recommendations for possible field implementation (for airplanes similar to the Airbus A321) listed in Table 9.

Table 9 Recommendations and potential time savings for different actions.

Action	Description	Potential savings
Pre-boarding area	Using a pre-boarding area can speed up the boarding time by up to one minute, on average.	< 1 min.
Power boarding	Power boarding right from the beginning of the boarding is an effective way, when no pre-boarding area exists. On the other hand, power boarding does not lead to much improvement if using pre-boarding.	≈ 0.5 min.
Less hand luggage in cabin	A very effective action is reducing the number of pieces of hand luggage inside the cabin. Between two and for minutes can be saved when passengers do not carry too many pieces (luggage, bags, jackets) that need to be put into the overhead bins. It is important to note, that a further reduction of the number of hand luggage could lead to even higher savings (see also Nyquist and McFadden (2008) but also comments on that in section 7 below).	≈ 2-4 min.
Separate gate agent dealing with problems	An additional gate agent who deals specifically with problems that appear at the gate desk to lower the IPT, could improve the boarding time by about 30 seconds on average. When pre-boarding areas are used, this action is less effective and thus not meaningful.	≈ 0.5 min.
"Random boarding" vs. "Back-To-Front boarding"	In all cases "Random boarding" outperforms "Back-To-Front boarding". This is not surprising. Having a detailed look at the "Back-To-Front boarding" (in both, the video recordings and the simulations), in this scenario, the airplane aisle does quickly fill with passengers waiting for their seat in the tail region of the airplane. On the other hand, the probability of passengers having a seat in a front row during the first minutes of the boarding is much higher with "Random boarding". Those can take their seat earlier and release space to following passengers.	< 1 min.

To summarise the recommendations in Table 9, substantial gains would result when (i) applying pre-boarding areas with starting the pre-boarding (silent boarding) at around 2.5 minutes before the official boarding announcement, (ii) limiting the number of hand luggage per person[10] and (iii) applying the “Random boarding” strategy (or other efficient and feasible strategies). Boarding through a further jetway may additionally reduce the boarding time[11]. Less effective is the use of power boarding if pre-boarding is applied. However, during that period, the second gate agent could serve passengers by checking-in some hand luggage (those exceeding the allowed number).

It is important to mention here, that the above recommendations hold specifically for airplanes of type Airbus A321 (size, number of doors), as observations and simulations were carried out only for this airplane type. However, we would assume, that for larger airplanes (more passengers; more doors available for boardings is assumed), the impact of pre-boarding areas would be even higher than in the case of an A321. This estimate is based on the assumption, that due to the higher number of doors used, more passengers can be served during pre-boarding until the observed congestion in front of the airplane door(s) sets in. The higher number of “pre-boarded” passengers thus could reduce the time required for serving the remaining passengers. However, detailed investigations (observations *and* simulations) are indispensible to better understand the dynamics and the impact of the involved process steps and thus to allow for appropriate recommendations (see also section 7, future research).

[10] Here we would like to recall the importance of a more detailed investigation on the cabin time model (see ‘cabin time’ in section 4.2).

[11] However, to implement this in the field, appropriate infrastructure is required (e.g., prevent jetways from ranging over the airplane’s wings, to ensure passenger safety (fuel in wings)).

7. Conclusions and future research

In this paper we presented the setup and results of investigations to reduce the airplane boarding time. The impact of various factors was examined by using a simulation-based tool, the Airplane Boarding Simulator, which was developed specifically for this project. In particular we wanted know, what actions are appropriate to reduce the boarding time while being practically applicable. We restricted ourselves to the case of boarding via jetway, a load factor of 100%, airplanes similar to the Airbus type A321 (one aisle) and on using one door only. The simulation model was calibrated based on real video data and time measurements. The results indicate clearly, that there is a considerable potential to speed up the boarding process and thus to reduce the turn time.

Regarding the processes inside the airplane, we found the following: (i) compared to the observed number of hand luggage, reducing the fraction of passengers with two or more pieces of hand luggage from 15% to 5% can reduce the boarding time by two to four minutes; (ii) applying “Random boarding” (i.e., passengers enter the airplane in no predefined order) instead of “Back-To-Front boarding” can save another minute on average. This is both in accordance with findings in earlier research. However, both actions have a direct influence on the customer satisfaction, as they either restrict her/his freedom of action (reduced number of hand luggage) or increase the number of interferences (for “Random boarding”). Nonetheless, due to the potential time savings, it might be worth to consider the application of these actions. In addition, besides the two investigated boarding strategies, more sophisticated seating strategies could be considered in the future as well. However, to achieve these savings, this requires in any case a good instruction of the staff (ground, crew) as well as of the passengers.

With respect to the passenger processes outside the airplane, i.e. from (and including) the gate until the jetway, simulations have shown, that additional time savings are possible. The major findings are: (i) By using pre-boarding areas, one can improve the boarding process by around one minute. One of the most important aspects with the pre-boarding is, that with this the first few minutes after the boarding announcement can be used to bring the first passengers earlier to the airplane. Besides this benefit, late passengers can be detected earlier and hence unloading of luggage can start earlier, which prevents potential delays; (ii) At the gate desk, the process can be sped up by using additional staff to care for special cases (i.e. those leading to IPT’s above 40 sec.) and by forceful applying power-boarding, i.e. right from the beginning of the boarding. However, simulations have shown, that applying additional actions at the gate desk lead to further improvements only in the case with no pre-boarding area. In any case, as for improved seating strategies, a careful instruction of the staff is required.

To summarise, the investigations performed so far, have shown various ways to substantially reduce the boarding time, inside and outside the airplane. In any case, actions to reduce the boarding time (and with this the turn time) should always take into account also overall costs (e.g., additional staff required) and the customer satisfaction. The weighting of these factors (costs of turn time, costs for staff, customer satisfaction) of course is strongly determined by an airline's general policy.

As we have seen, there are different ways to improve the boarding process by actions outside and inside the airplane. To further investigate ways to reduce the boarding time, we see the following starting points for future research[12]: (i) To better quantify and understand the variability of boarding times, additional video sequences should be captured. A better understanding of the actual processes inside the airplane is important not only to better match simulations with real observations but also to reduce the variability of the boarding times. This would allow for a better planning at an operational level; (ii) The investigation of other gate configurations would allow for the identification of additional opportunities, as from our point of view, there is still some room for improvement; (iii) Investigation of scenarios based on using two doors. This depends of course on the available infrastructure setup, but especially for large airplanes (using ≥ 2 doors), this might be very beneficial; (iv) Investigation of additional (and feasible) seating strategies (e.g., "Reverse-pyramid"); (v) Analysing seating strategies that allow older passengers and families to board first in the rear part of the airplane, so they have more time to install themselves; (vi) Investigations (observations and simulations) for airplanes of types other than Airbus A321. Especially for larger airplanes the potential savings of the different actions considered could differ substantially from those for the A321. However, without further investigations it is rather difficult to assess the potential gains; (vii) Investigation of possible incentives (usually more customer friendly than penalties) and their impact on reducing the number of pieces of hand luggage, e.g., one way could be to let passengers with less hand luggage board first.

To conclude, we think, that there is a considerable potential to further improve the airplane boarding process, both outside and inside the airplane. Simulations (calibrated and validated based on on-site observations) can help to better identify and quantify these improvements. However, a close cooperation of simulation specialists and aviation experts is indispensable to get feasible and time saving solutions.

Furthermore, a good coordination of the actions taken is of crucial importance, together with an appropriate training of the staff (airplane crew and ground) and a clear and easy to understand information of the passengers.

[12] The order of the list is chosen arbitrarily and does not prejudge any recommendation or selection.

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Appendix

A. Statistical tests

Table 10 Time differences and Wilcoxon p-values between boarding scenarios.

	BDG_0_0_Rnd	BDG_0_0_B2F	BDG_0_0_GT40_Rnd	BDG_0_0_GT40_B2F	BDG_0_0_IHL_Rnd	BDG_0_0_IHL_B2F	BDG_0_90_Rnd	BDG_0_90_B2F	BDG_150_0_Rnd	BDG_150_0_B2F	BDG_150_0_GT40_Rnd	BDG_150_0_GT40_B2F	BDG_150_0_IHL_Rnd	BDG_150_0_IHL_B2F	BDG_150_90_Rnd	BDG_150_90_B2F	BDG_300_0_Rnd	BDG_300_0_B2F	BDG_300_0_GT40_Rnd	BDG_300_0_GT40_B2F	BDG_300_0_IHL_Rnd	BDG_300_0_IHL_B2F	BDG_300_90_Rnd	BDG_300_90_B2F
BDG_0_0_Rnd	-	0.00	0.03	0.11	0.00	0.00	0.00	0.00	0.00	0.73	0.00	0.62	0.00	0.00	0.00	0.16	0.00	0.35	0.00	0.69	0.00	0.00	0.00	0.69
BDG_0_0_B2F	0.60	-	0.00	0.04	0.00	0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDG_0_0_GT40_Rnd	-0.57	-1.18	-	0.00	0.00	0.00	0.00	0.00	0.11	0.03	0.00	0.12	0.00	0.00	0.00	0.57	0.07	0.25	0.01	0.09	0.00	0.00	0.00	0.01
BDG_0_0_GT40_B2F	0.15	-0.46	0.72	-	0.00	0.00	0.52	0.00	0.00	0.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.00	0.00	0.18
BDG_0_0_IHL_Rnd	-1.98	-2.59	-1.41	-2.13	-	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDG_0_0_IHL_B2F	-1.75	-2.36	-1.18	-1.90	0.23	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
BDG_0_90_Rnd	0.45	-0.15	1.03	0.31	2.44	2.21	-	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.11
BDG_0_90_B2F	1.22	0.62	1.80	1.08	3.21	2.98	0.77	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BDG_150_0_Rnd	-0.85	-1.45	-0.27	-0.99	1.14	0.91	-1.30	-2.07	-	0.00	0.08	0.00	0.00	0.00	0.07	0.06	0.39	0.01	0.42	0.01	0.00	0.00	0.00	0.00
BDG_150_0_B2F	0.04	-0.57	0.61	-0.11	2.02	1.79	-0.41	-1.18	0.88	-	0.00	0.17	0.00	0.00	0.00	0.06	0.00	0.19	0.00	0.43	0.00	0.00	0.00	0.75
BDG_150_0_GT40_Rnd	-0.96	-1.56	-0.39	-1.11	1.02	0.79	-1.41	-2.18	-0.11	-1.00	-	0.00	0.00	0.00	0.74	0.00	0.17	0.00	0.37	0.00	0.00	0.00	0.52	0.00
BDG_150_0_GT40_B2F	-0.37	-0.98	0.20	-0.52	1.61	1.38	-0.82	-1.59	0.47	-0.41	0.59	-	0.00	0.00	0.00	0.18	0.00	0.93	0.00	0.99	0.00	0.00	0.00	0.12
BDG_150_0_IHL_Rnd	-3.57	-4.17	-2.99	-3.71	-1.59	-1.82	-4.02	-4.79	-2.72	-3.61	-2.61	-3.20	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00
BDG_150_0_IHL_B2F	-2.58	-3.18	-2.00	-2.72	-0.59	-0.82	-3.03	-3.80	-1.73	-2.62	-1.62	-2.21	0.99	-	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00
BDG_150_90_Rnd	-1.25	-1.86	-0.68	-1.40	0.73	0.50	-1.70	-2.47	-0.41	-1.29	-0.29	-0.88	2.32	1.33	-	0.00	0.29	0.00	0.55	0.00	0.00	0.00	0.28	0.00
BDG_150_90_B2F	-0.28	-0.88	0.30	-0.42	1.71	1.48	-0.73	-1.50	0.57	-0.32	0.68	0.09	3.29	2.30	0.97	-	0.03	0.93	0.00	0.33	0.00	0.00	0.00	0.02
BDG_300_0_Rnd	-1.14	-1.75	-0.57	-1.29	0.84	0.61	-1.60	-2.37	-0.30	-1.18	-0.18	-0.77	2.43	1.43	0.11	-0.87	-	0.00	0.58	0.00	0.00	0.00	0.03	0.00
BDG_300_0_B2F	-0.21	-0.81	0.37	-0.35	1.78	1.55	-0.66	-1.43	0.64	-0.25	0.75	0.16	3.36	2.37	1.04	0.07	0.94	-	0.00	0.89	0.00	0.00	0.00	0.03
BDG_300_0_GT40_Rnd	-0.96	-1.57	-0.39	-1.11	1.02	0.79	-1.41	-2.18	-0.12	-1.00	0.00	-0.59	2.61	1.62	0.29	-0.68	0.18	-0.75	-	0.00	0.00	0.00	0.12	0.00
BDG_300_0_GT40_B2F	-0.16	-0.77	0.41	-0.31	1.82	1.59	-0.62	-1.39	0.68	-0.20	0.80	0.21	3.41	2.41	1.09	0.11	0.98	0.04	0.80	-	0.00	0.00	0.00	0.17
BDG_300_0_IHL_Rnd	-3.79	-4.39	-3.21	-3.93	-1.80	-2.03	-4.24	-5.01	-2.94	-3.83	-2.83	-3.41	-0.22	-1.21	-2.53	-3.51	-2.64	-3.58	-2.83	-3.62	-	0.00	0.00	0.00
BDG_300_0_IHL_B2F	-3.09	-3.69	-2.52	-3.24	-1.11	-1.34	-3.54	-4.31	-2.24	-3.13	-2.13	-2.72	0.48	-0.51	-1.84	-2.81	-1.95	-2.88	-2.13	-2.93	0.70	-	0.00	0.00
BDG_300_90_Rnd	-1.34	-1.95	-0.77	-1.49	0.64	0.41	-1.80	-2.56	-0.50	-1.38	-0.38	-0.97	2.23	1.24	-0.09	-1.07	-0.20	-1.14	-0.38	-1.18	2.44	1.75	-	0.00
BDG_300_90_B2F	0.05	-0.55	0.62	-0.10	2.03	1.80	-0.40	-1.17	0.90	0.01	1.01	0.42	3.62	2.63	1.30	0.33	1.19	0.26	1.01	0.21	3.84	3.14	1.39	-

In Table 10, the values in the lower triangular matrix describe the time difference in decimal minutes between any two scenarios in the matrix. A value lower than zero indicates that the boarding scenario denoted by the code in the first column is faster than the corresponding boarding scenario denoted by the code in the first row. The green and red borders are in correspondence with the colours used in Figure 5 (green: fastest scenario, red: scenario applied today by SWISS).

In the upper triangular matrix, every combination of two boarding scenarios is regarded as a paired sample of simulations and can be tested on equality by the Wilcoxon signed-rank test. The null hypothesis tested is H0: The median of two compared simulations is equal to zero. A p-value lower than 0.05 rejects H0, while a value equal or greater than 0.05 cannot reject the null hypothesis (denoted by red font), thus the two samples are not proved to be statistically unequal.

B. Inter-Passenger times at the gate desks (service times)

Figure 6 Inter passenger times on flight LX634.

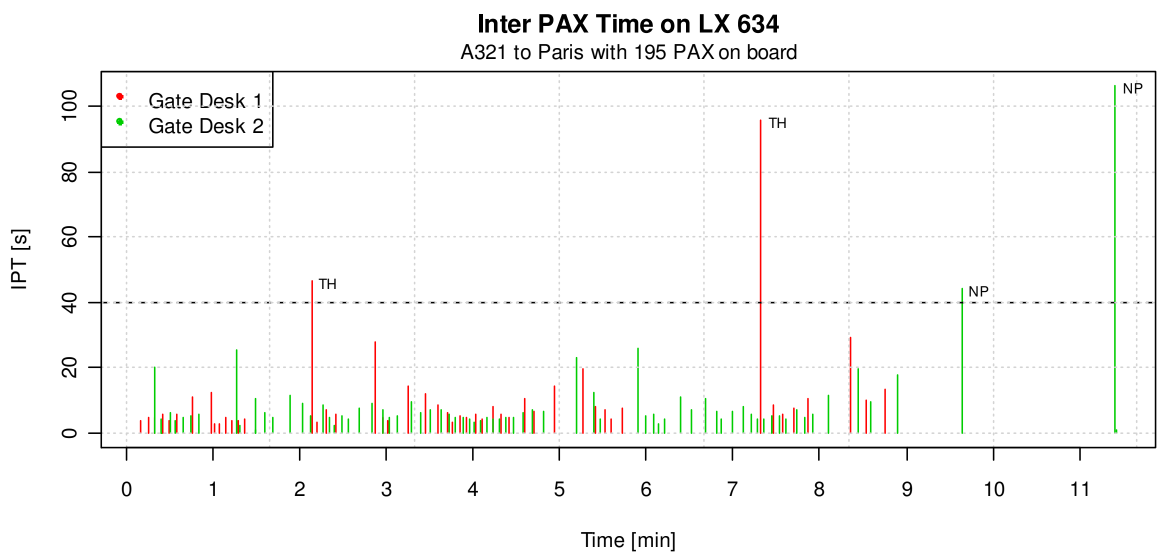

Figure 7 Inter passenger times on flight LX1272.

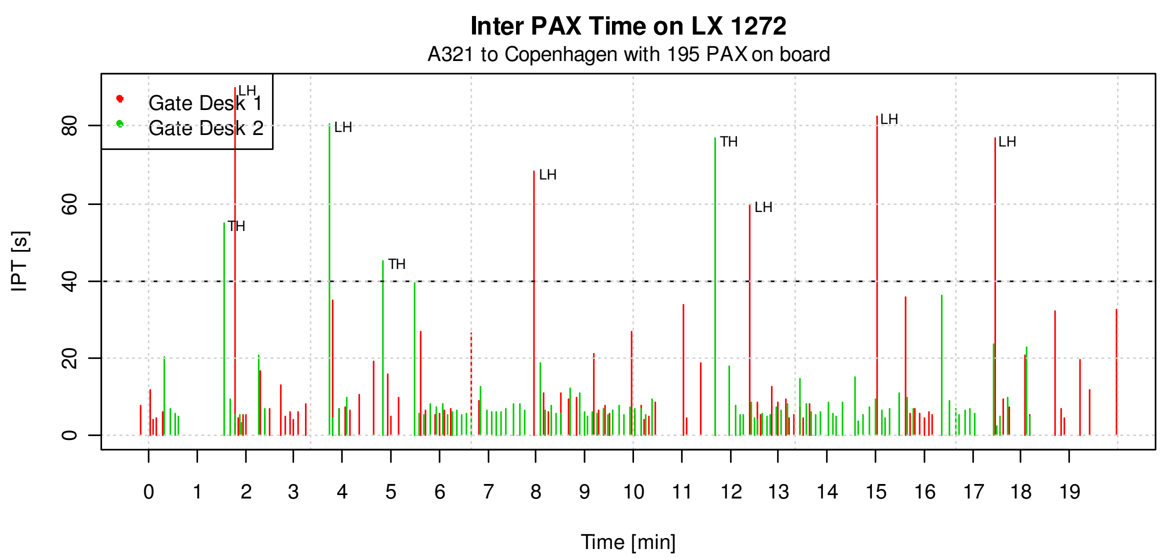

Figure 8 Inter passenger times on flight LX1830.

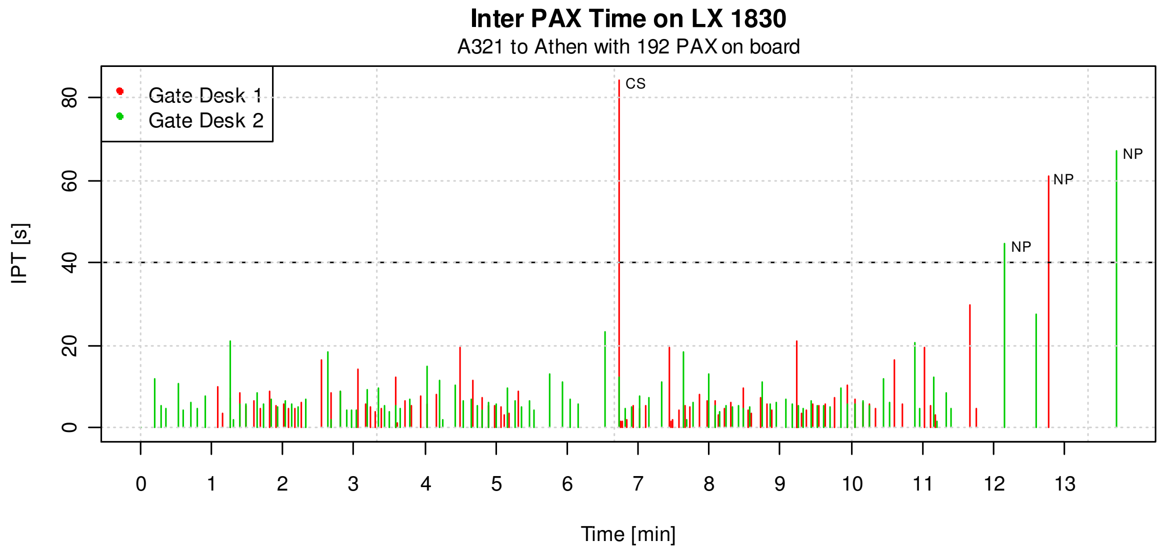

Figure 9 Inter passenger times on flight LX1838.