Advancements in passenger processes at airports –

An aircraft perspective

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Abstract

This paper provides an overview about the research done in the field of aircraft boarding focusing on fast and reliable progress. Since future 4D aircraft trajectories demand the comprehensive consideration of environmental, economic, and operational constraints, a reliable prediction of all aircraft-related processes along the specific trajectories at both air and ground is essential for punctual operations. The ground processes (aircraft turnaround) are mainly controlled by ground handling, airport or airline staff, except the aircraft boarding, which is mainly driven by passengers' experience and willingness or ability to follow the proposed procedures. In this paper we provide a comparison of two model approaches to cover the individual behavior of passengers during the aircraft boarding. The implementation of two innovative infrastructural changes demonstrates the still unused potentials to further improve boarding progress. Furthermore, the need for adapted procedures, the capabilities of connected cabin, and first results of field trials focusing on a dynamic seat allocation are addressed.

Keywords: passenger boarding; infrastructural changes; Side-Slip Seat; cinema seat; aircraft turnaround

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1. Introduction

The aviation industry will be challenged by an annual 4.4-4.7 % growth in passenger traffic in the next 20 years (Airbus, 2017; Boeing 2017). It is imperative that advancements in process reliability and passenger comfort are developed to deal with increasing number of travelers at major hub airports to reach the ambitious Flightpath 2050 targets. Since the 1960's, the average number of installed seats per aircraft on short-haul segments has increased from 110 to 160 (Fuchte, 2014), caused by the trend towards denser aircraft cabins driven by both low cost carrier and larger aircraft types. The passenger aircraft boarding process has been an issue since the late 1970's as stated by Marelli et al. (1998). It is the last step of various landside handling processes (passenger trajectory), such as check-in and security check, which passenger have to follow in the airport terminal (Schultz and Fricke, 2011). From the airside perspective, the aircraft trajectory at the day of operations depends on efficient arrival/departure procedures and en-route performance, but also on a reliable and efficient turnaround. The turnaround consists of five major tasks: disembark, cater, clean, fuel, and boarding as well as the parallel loading/unloading. From the operator perspective all processes will follow defined procedures and mainly controlled by the ground handling, airport or airline staff. However, the boarding process is driven by passengers experience and willingness or ability to follow the proposed procedures (e.g. late arrivals, no shows, amount of hand luggage, status passengers, cf. Schultz et al. (2013)). Over the past decades, the average boarding velocity dropped from around 20 passengers per minute to nearly nine passengers per minute. This decline is a result from increased amount of hand luggage, different airline services (e.g. priority boarding) and passenger boarding schemes, as well as changing passenger demographics in terms of their composition and behavior. Other factors which influence the process are aircraft configuration, cabin layout, passenger anthropometrics and airport environment (e.g. gate or apron positions). The paper will focus on the evaluation of alternative boarding strategies to reliably increase the passenger boarding efficiency even under operational constraints. Airlines have applied various boarding strategies that call for a predefined sequence of passengers entering the cabin depending on their allocated seat (Schmidt et al., 2017a; Jaehn and Neumann, 2014). However, most of the strategies tested are not practical in regular flight operations. Novel approaches aim to reduce operational drawbacks and call for a parallelization of the boarding processes which showed a more efficient use of the aisle (Steffen, 2008; Milne and Kelly, 2014; Zeineddine, 2017). Since the stability and predictability of the boarding progress have to be focused to provide sustainable approaches for the aircraft boarding, we address innovative seat concepts with significant impact to current cabin infrastructure and passenger boarding time.

1.1. Status quo

In the following section, a short overview concerning scientific research on aircraft boarding is given. Relevant studies concerning aircraft boarding strategies include but are not limited to the following examples. A more comprehensive overview is provided by Jaehn and Neumann (2015) and Schmidt (2017a). A common goal of simulation-based evaluations is to minimize the time that is required for passenger boarding. Taking into account different boarding patterns, a study by Van Landeghem and Beuselinck (2002) investigates into the potential of optimized boarding strategies. A similar approach is used by Ferrari and Nagel (2005), particularly focused on disturbances on the boarding sequence caused by early or late arrivals of passengers. The results show improved values for the typical back-to-front boarding in the case of passengers not boarding in their previously assigned boarding groups. In contrast, Bachmat and Elkin (2008) support the back-to-front policy in comparison to random boarding strategy. The stochastic approach to cover both individual passenger behavior and aircraft/airline operational constraints by Schultz et al. (2008) exhibits that the efficiency of the back-to-front policy depends on the size of the boarding blocks (seat rows are aggregated to a boarding block). On the basis of an individual boarding strategy proposed by Steffen (2008), which considers the time a passenger needs to store baggage, the model developed by Milne and Kelly (2014) assigns passengers to seats so that their hand luggage is distributed evenly throughout the plane. Since individually boarding strategies often split passenger travelling together, Zeineddine (2017) proposed a dynamically optimized boarding strategy where passengers are sequenced in a boarding queue based on their seats' positions, associated groups, and the possibility of interferences, immediately after the last check-in. Chung (2012) addresses the aircraft seating layout and indicates that alternative designs could significantly reduce the boarding time. A link between the efficiency of an airline's boarding policies and the aircraft design parameters, such as distance between the rows, is given in a study by Bachmat et al. (2009). In this study, results show a higher attractiveness of random boarding among row-based policies. Focusing on the simulation of different deplaning strategies, several types are tested in a study by Wald et al. (2012). Picking up the idea of boarding groups, a study based on an analytical model by van

den Briel et al. (2005) shows a significantly improved boarding time by group boarding policies over the back-to-front policy. Based on a mathematical model that is related to the 1+1 polynuclear growth model with concave boundary conditions, Bachmat et al. (2013) study all aircraft configurations and boarding group sizes. Results show that the effectiveness of back-to-front boarding can be increased compared to random boarding but drops when having more than two boarding groups. Assessing the effectiveness of boarding strategies is also a core part of a study by Soolaki et al. (2012). Based on an integer linear programming approach together with a genetic algorithm, they analyze different boarding strategies to assess the effectiveness of their model. The interference of passengers when boarding an aircraft is in the focus of a study by Bazargan (2007). The mathematical model's output aims to minimize the interferences and to speed up the boarding time as interferences may lead to delays, especially in single-aisle aircraft. The interactions of passengers during the boarding process (e.g. occupied aisle) are also in the focus of a study by Frette and Hemmer (2012), Tang et al. (2012), and Schultz (2013). Frette and Hemmer calculate the average boarding time with a dynamical model, assuming that all permutations of the amount of passengers have the same weight. Tang et al. concentrate on the passenger's individual properties and apply this knowledge to their numerical model in order to evaluate the benefit of different boarding strategies. Schultz extends the stochastic boarding model to analyze twin-aisle configurations. An experiment was performed by Steffen and Hotchkiss in a mock Boeing 757 (2012). They tested different boarding methods and described the potential savings for airline companies through reduced boarding times. Fuchte (2014) focusses on the aircraft design and, in particular, the impact of aircraft cabin modifications with regard to the boarding efficiency. Schmidt et al. (2017) and Schmidt and Heinemann (2017) evaluate novel aircraft layout configurations and seating concepts for regional, single- and twin-aisle aircraft with 50-300 seats.

1.2. Document structure

In this paper we provide a comparison of two approaches to cover the individual behavior of passengers during the aircraft boarding. After a brief introduction of the different models, the impact of the number of hand luggage pieces to the boarding time is investigated. The implementation of two innovative infrastructural changes (Side-Slip Seat and cinema seat) demonstrates the still unused potentials to further improve the boarding progress. Following this, a brief discussion emphasize the need for adapted procedures, scaling effects, a complexity metric to enable a real-time prediction of the boarding time, potentials of a future connected cabin, and field trial results of a dynamic seat allocation.

2. Boarding Models

Two models are used for the evaluation of boarding strategies. Both models are based on a microscopic, individual approach to cover both the individual passenger behavior and the operational constraints.

2.1. Stochastic approach - paxSim

The proposed dynamic model for the boarding simulation is based on an asymmetric simple exclusion process (ASEP, cf. Schultz, 2014). The ASEP was successfully adapted to model the dynamic passenger behavior in the airport terminal environment (Schultz et al., 2008; Schultz and Fricke, 2011). In this context, passenger boarding is assumed to be a stochastic, forward-directed, one-dimensional and discrete (time and space) process. To provide both an appropriate set of input data and an efficient simulation environment, the aircraft seat layout is transferred into a regular grid with aircraft entries, the aisle(s) and the passenger seats as shown in Fig. 1 (reference: Airbus 320, 29 rows, 174 seats). This regular grid consists of equal cells with a size of 0.4 x 0.4 m, whereas a cell can either be empty or contain exactly one passenger. The boarding progress consists of a simple set of rules for the passenger movement: a) enter the aircraft at the assigned door (based on the current boarding scenario), b) move forward from cell to cell along the aisle until reaching the assigned seat row, and c) store the baggage (aisle is blocked for other passengers) and take the seat. The passenger movement only depends on the state of the next cell (empty or occupied). The storage of the baggage is a stochastic process and depends on the individual amount of hand luggage. The seating process is stochastically modelled as well, whereas the time to take the seat depends on the already used seats in the corresponding row. The stochastic nature of the boarding process requires a minimum of simulation runs for each selected scenario in order to derive reliable simulation results. In this context, a simulation scenario is mainly defined by the underlying seat layout, the number of passengers to board (seat load factor, default: 85%), the arrival frequency of the passengers at the aircraft (default: 14 passengers per minute), the number of available doors (default 1 door), the specific boarding

strategy (default: random) and the conformance of passengers in following the current strategy (default: 85%). Further details regarding passenger model, simulation environment, and calibration/validation are provided by Schultz et al. (2008, 2013) and Schultz (2017a).
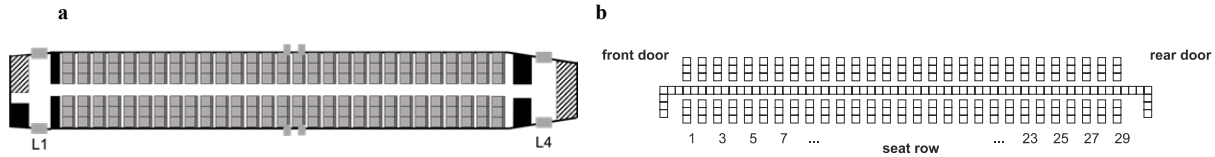

Fig. 1 (a) A320 reference cabin layout (L1 front door, L4 rear door); (b) corresponding regular grid structure of A320 model

2.2. PAXelerate

The passenger flow simulation framework PAXelerate (Schmidt et al., 2016a, 2017b) is based on a microscopic approach applying agent-based modeling techniques. Each passenger is represented as an agent with individual properties such as body dimensions, walking speed, target seat or type of carry-on luggage. This allows agent interactions to be modeled to capture the resulting complex system behavior. Virtual passengers are generated, taking into account their anthropometrics and assigned seats. The anthropometric properties of waist width, body depth and walking speed are determined using a normal distribution between minimum and maximum values. Based on the passenger's age, the appropriate walking speed is derived. Diverse behavior patterns mainly influence the simulation process in terms of agents' overtaking behavior. Optional carried hand luggage has an impact on the walking speed and requires the additional stowing task to be performed before seating. This enables dynamic reactions to be modelled based on the mood and environment and various passenger's patterns to be defined, such as business or leisure travelers. The boarding sequence can be set using predefined boarding strategies. Agents use an A-Star pathfinding algorithm to search for the shortest and most cost efficient path to their assigned seat. The simulation foundation is based on a grid enabling the agent to move in eight directions. Each node on the grid possesses properties such as location, neighbors and occupation status, as well as, distance and cost which are important during the pathfinding. A gradient-based potential is defined around the cabin monuments and agents permitting the agents to walk directly next to the obstacles. The agent follows the calculated path and reacts to obstacles occurring on the way to the assigned seat. The agent is able to turn in 45-degree steps allowing for a step sideways.

3. Operational and Procedural Improvements

To improve the aircraft boarding process, several approaches are developed. In this section we will focus on the hand luggage (number of items and distribution in the cabin), infrastructural changes (Side-Slip Seat, cinema seat), and the impact of groups (two members and two rows with 6 members). To cover the impact to the passenger boarding, three different boarding strategies are used as a reference: random, block, and outside-in boarding. The random boarding is defined by no specific chronological order of the passengers arriving at boarding gate. For the block boarding, the aircraft is divided into six blocks, where each block contains of five seat rows (last block has four rows), and these blocks are boarded form the back of the aircraft to the front. The outside-in boarding is defined by three boarding groups: the first group contains all passengers seated on the window, followed by a group with all passengers seated on the middle seat, and the last group contains all aisle seated passengers. This boarding strategy is also named as "WilMA" (window, middle, aisle). In the evaluation, the different strategies are used as follows: random boarding as baseline, block boarding as commonly used strategy, and outside-in as reference for a fast boarding strategy.

3.1. Number of hand luggage items

Two frequently statements with regard to the hand luggage items are: a) if passengers have no hand luggage, the boarding will be immediately faster, and b) a large amount of hand luggage leads to blocked overhead compartments and results in counterflow conditions in the aircraft aisle, when passengers are looking for empty compartments. In the prior analysis, the focus was more set on the boarding sequence optimization to prevent unfavorable seat row states (see Schultz, 2008, 2013), where the amount of hand luggage was taken as an external, unchanged parameter. Besides the expected positive effects on the boarding time, passengers could perceive a reduced amount of hand luggage items as a degrade level of service caused by additional baggage

drop and pickup processes in the (congested) check-in and baggage claim areas in the airport terminal. These processes will results in additional waiting times for the individual passenger. In Fig. 2 the characteristics of the boarding time is shown in relation to the number of hand luggage items. The application of both the stochastic paxSim and PAXelerate results in a decreasing boarding time, when the number of items is reduced. PAXelerate calculates are higher degree of dependency between the number of items and the boarding time: -75% boarding time for random boarding in contrast to -34% boarding time using paxSim. On the other hand, paxSim indicates a higher performance of the block boarding, if the number of items are smaller than 0.45 items per passenger at average. In a two-door configuration, the block and the random boarding demonstrate a comparable behavior.
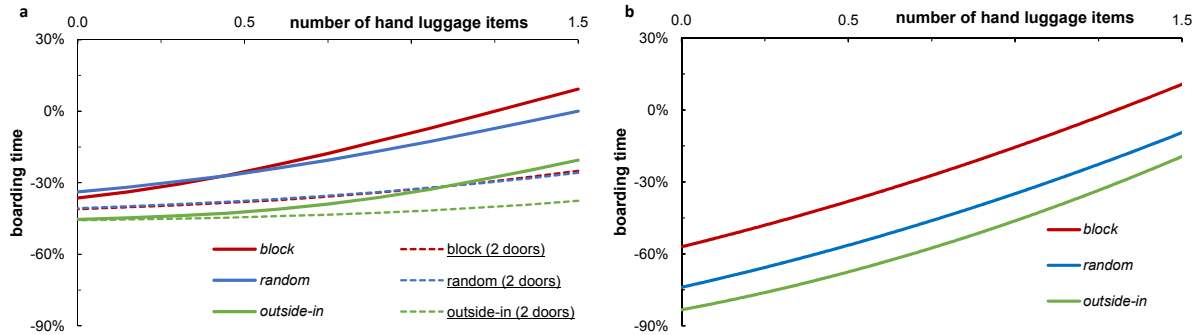

Fig. 2 Boarding time reduction accompanied with a decreasing number of hand luggage items. (a) paxSim: the boarding time continuously decreases for both one-door and two-doors configuration; (b) PAXelerate confirm this trend but on a higher level

3.2. Distribution of hand luggage in the cabin

As the prior analysis clearly show, the reduction of hand luggage items is a good candidate to reduce the boarding time. Another approach aims the distribution of the hand luggage in the aircraft cabin (see Milne and Kelly (2014), Qiang et al. (2014), and Milne and Salari (2016)). In this paper, two strategies are evaluated: board high number of items first (bags first rule) and board passengers with a high number of hand luggage items in the rear of the aircraft (bags rear rule), despite any load/trim requirements. In Fig. 3, the results of the evaluation are shown. Whereas PAXelerate indicates only a minor benefit/effort (±2%), paxSim demonstrates a significant benefit particularly for the bags-rear rule.
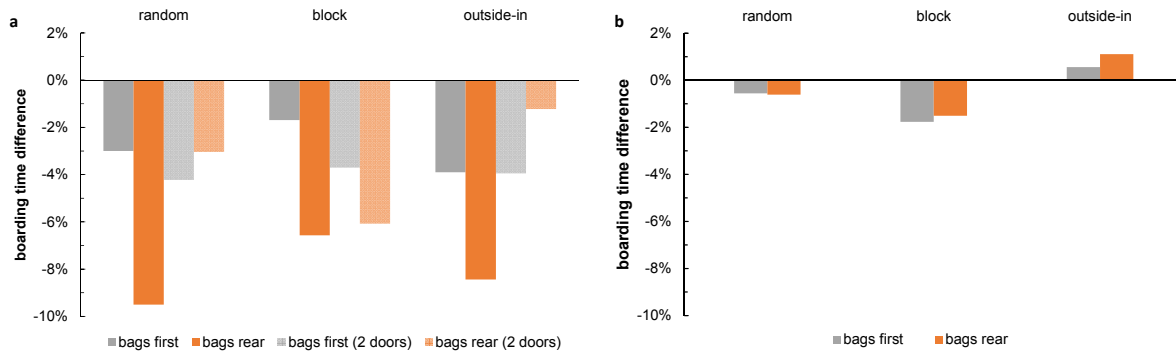

Fig. 3 Boarding time differences applying bag-first and bags-rear rule on random, block, and outside-in boarding strategy for (a) paxSim and (b) PAXelerate

3.3. Infrastructural changes

Standard operational approaches to accelerating the boarding process mainly address the management of the passenger behavior by providing specific boarding sequences or the airline hand luggage regulation. A first infrastructural approach is to use the rear aircraft door, since this approach usually comes along with an apron position of the aircraft and a bus shuttle transfer (or walk boarding), which counteracts the idea of an optimized passenger sequencing. In fact, the use of the rear door results in substantially faster boarding times, even assume random boarding (Schultz et al., 2008, 2013). A significant change of the infrastructure has to overcome the negative impacts of a blocked aisle, caused by hand luggage storing or seat shuffling. With the innovative approach of foldable seats, the available infrastructure could be dynamically changed to support the boarding

process by providing an extra space to allow two passengers to pass each other in a convenient way (cf. Schultz (2017b) and Schmidt (2017a) for details). Two variants of sideways foldable seat concepts exist: one model where the aisle seat is sliding over the middle seat, as proposed by Molon Labe Seating (2017) and the other where the aisle seat sliding under the middle seat, as investigated by Isikveren et al. (2012). Fig. 4 demonstrates the Side-Slip Seat (S3) developed by Molon Labe Seating, where the aisle seat could be moved in the direction of the middle seat.
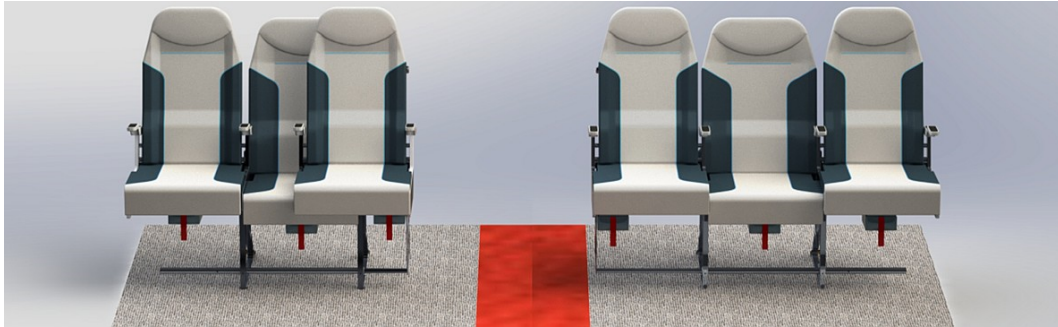

Fig. 4 Side-Slip Seat (Molon Labe Seating, 2017) provides a wider aisle for boarding: seat in initial, folded condition (left) and unfolded operational condition (right)

The most prominent effect on the boarding time is accompanied with a blocked aisle due to passengers storing baggage or entering their seat row. With the innovative technology of S3, the available infrastructure could be dynamically changed to support the boarding process by providing a wider aisle which allows two passengers to pass each other in a convenient way. Two additional benefits come with this new technology: the wider aisle allows airlines to offer full-size wheelchair access down the aisle (meeting the needs of disabled passengers, cf. Schultz (2017b)) and the middle seat is 2" wider than the aisle and window seats (aisle and window seats retain their standard width). The aisle seat will be in the initial position (folded) until one passenger wants to access the middle or aisle seat. The developed boarding models are adapted to allow the parallel movement of two passengers along the aisle. The dynamic status of the seat row (folded/unfolded) is implemented in both boarding models to enable/disable the parallel movement of passengers. If the seats on both sides of the row are in the initial condition, a second passenger can pass without reducing the walking speed. If only one side is unfolded, the speed is reduced by 50%. If both sides are used by passengers, the standard boarding is active, where only one passenger is allowed to move in the aisle.

The concept of a cinema seat was introduced by AIDA Development (Sii Engineering, 2017). The aim of the seating concepts is to increase the moving space of passengers in the row and enhance their access to the overhead bins. For the cinema seat, the aisle width remains unchanged during boarding. It allows passengers to step into the row, if the aisle seat is not yet occupied, and to stow their hand luggage in the overhead bin without blocking the aisle. Passengers can stand up while remaining within the row in the case of row interferences when seated at the aisle reducing the duration of aisle interferences. When passengers seated at aisle seats, have reached their row, they unfold the seat (see Fig. 5).
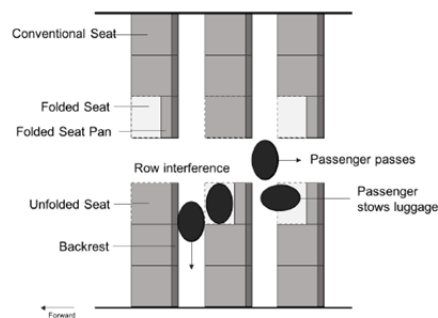

Fig. 5 Concept of the cinema seat, which could be folded to provide additional space to store luggage in the overhead compartment and to efficiently enter the seat row (Schmidt et al., 2016a)

Both seating concepts show improved boarding efficiency, as depicted in Fig. 6, while slight advantages for the S3 seat are present. The stochastic paxSim demonstrate a conservative improvement of the boarding all boarding strategies (10-20%), where PAXelerate demonstrate an optimistic evaluation of 30-60% faster boarding, if the new infrastructure is applied.
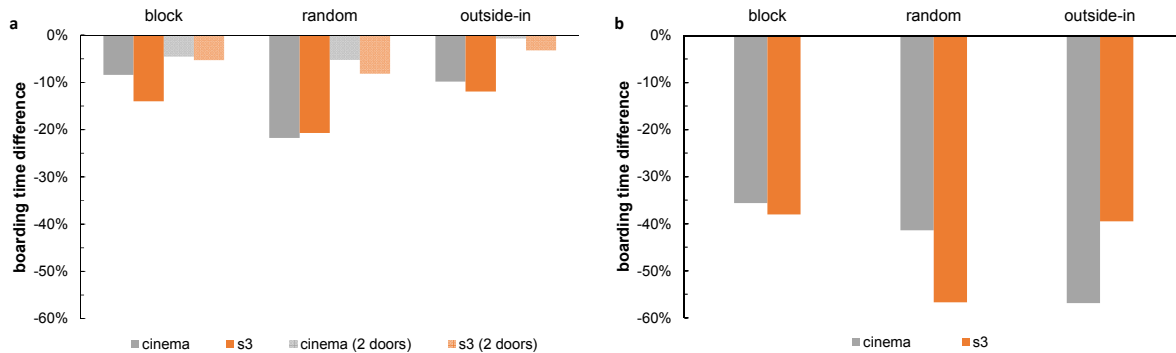

Fig. 6 Comparison of the impact of the Side-Slip Seat (S3) and the cinema seat: (a) paxSim; (b) PAXelerate

3.4. Group with two members

The number of passengers travelling in a group differs between business and tourist passengers. Whereas business passengers tend to travel alone (73% alone), the tourists are organized more in groups (19% alone) (Schultz and Fricke, 2011). To model the effect of grouped passengers, a group of two passengers is implemented in paxSim, assuming that the group members always will sit together. The benefit of the group boarding is caused by the fact that group members are boarded at the same time and reduce their interdependencies themselves. It is assumed that they choose the most convenient sequence to enter the seat row. The member sitting in the window (middle) seat will enter before the middle- (aisle-) seating member. This behavior generally mitigates unfavorable seat conditions and the negative impact on the subsequently following passengers. In Fig. 7, two exemplary group constellations are used in paxSim: a group with two members and a group with six members (sitting in two successive rows). While block and random strategy benefits from the increasing ratio of groups, the outside-in strategy are disturbed by group members.
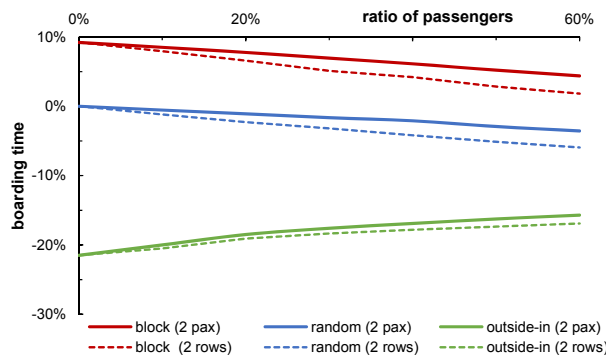

Fig. 7 Impact to boarding time considering groups with two members and six members (two rows) using paxSim

4. Conclusion and Outlook

In our contribution, we provide a comparison of two model approaches, paxSim and PAXelerate, to reliably consider the individual behavior of passengers during the aircraft boarding. The application covers infrastructural changes and future technologies/procedures for aircraft boarding. The two model approaches show similar overall trends with deviations in the absolute benefit. A decreasing boarding time can be identified, when the number of hand luggage items is reduced as well as when passengers with larger bags are seated in the rear cabin. The two concepts of dynamic seats (Side-Slip Seat, cinema seat) result in a significantly faster boarding through providing extra space to allow two passengers to pass each other in a convenient way. Since the number of passengers travelling in a group differs, we tested the impact on several boarding strategies. While

the block and random strategy benefits from the increasing ratio of groups, the outside-in strategy is disturbed by group members.

There are many ideas to efficiently handle the future aircraft/passenger operations, to provide operational related design approaches, and to transfer the knowledge achieved with the A320 reference layout to twin-aisle or blended wing body configurations. The turnaround is the complex aircraft-airport-passenger interface and the key element for efficient operations. The airport facilities, such as check-in counters and boarding bridges, have to ensure a sufficient passenger flow to allow for a punctual completion of the boarding process. The predictability of the process time is challenging, due to the power of each individual passenger to influence the boarding process. The foldable seats provide a backwards compatible solution for current aircraft. The operational applicability of the foldable seat concepts relies on the certification and passenger acceptance in terms of manageability, integration of inflight amenities and seating comfort. The folding mechanism introduces more complexity, which leads to higher maintenance efforts. Here, it was assumed that a passenger, who unfolded a seat, was not blocking the aisle. The benefits will be radically reduced if this could not be guaranteed during operation. A removal of the metal strap prohibiting hand luggage to move around the cabin affects the stowage of luggage under the seat, which is a major drawback with current high amounts of hand luggage (Schmidt et al., 2016b, 2017). Furthermore, the seat belt requires a redesign to prevent getting blocked. The concepts are still under development and are partly certified, however they are currently not integrated in commercially used aircraft. The boarding process is not on the same level of criticality for most flights using a twin aisle aircraft, since delay can be compensated during a longer flight and scheduled ground time allowing transfer passenger to reach their connection. The twin-aisle cabin splits the passenger flow into two separate streams after the passengers have entered the aircraft. However, the queuing up of passengers up to the door due to aisle interferences in the first rows has a negative effect, since both aisles are blocked in this situation. Lower absolute boarding times can be accomplished when comparing with single-aisle cabins accommodating an equal amount of passengers. An adaption of seat-based boarding schemes becomes necessary, especially in the case of an uneven number of middle seats and modified door positions.

The new dynamic infrastructure approaches often comes with specific demands and appropriate changes in the procedural/operational design as well. In a first step, the boarding models have to be extended to cover the Side-Slip Seat and the cinema seat with their specific demand for a parallel movement in the aisle. In the prior evaluation only three boarding strategies are tested, but a deeper investigation into the S3 technology results in a new boarding strategy (Schultz, 2017b). While current boarding strategies differentiate between the rear and the front of the aircraft, the new strategy differentiates between the left and the right side of the cabin. In Fig. 8 the new left/right boarding strategy is shown: during the half of the boarding progress, passengers are able to pass each other, which results in a 20% faster boarding (same level as outside-in boarding).
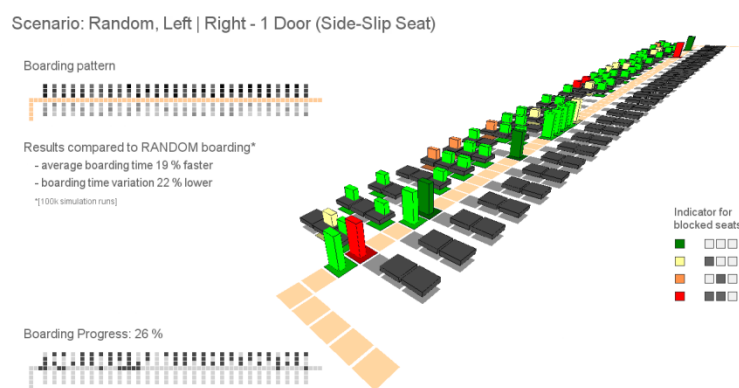

Fig. 8 paxSim implementation of Side-Slip Seat with appropriately adapted left/right boarding strategy (Schultz, 2017b)

The turnaround consists of five major tasks: deboarding, catering, cleaning, fueling and boarding as well as the parallel processes of unloading and loading. From the operator perspective, all these aircraft handling processes follow defined procedures and are mainly controlled by ground handling, airport or airline staff. As an exception, the boarding process is driven by the passengers' experience and willingness or ability to follow the proposed procedures (e.g. late arrivals, no-shows, amount of hand luggage, status passengers). To provide a reliable time

stamp for the target off block time, the critical path of the turnaround has to be under the control of the operational entities. Especially the stochastic and passenger-controlled progress of the aircraft boarding makes it difficult to reliably predict the turnaround time, even if the boarding is already in progress. Future cabin management systems will provide an enabling infrastructure to further improve the overall turnaround process and to allow for real-time prediction of specific handling processes (Schultz, 2017c). In this context, the aircraft seats are used as a sensor network with the capability to detect the status (free or occupied) of each seat. These individual seat statuses are used to derive an aggregated interference potential (measurement of complexity) of the current seating condition with regards to the passenger seating process. The interference potential is a major indicator for the expected aircraft boarding time. In combination with an integrated airline/airport information management (e.g. sequence of boarding passengers) the boarding progress will be transformed from a black box to a transparent progress with the operator's online ability to react to significant deviations from the planned progress. To allow for a real-time investigation of the boarding progress, a sensor environment was developed to detect the passenger movements in the aisle and the seat status (occupied/free). This environment consists of seat specific pressured sensors from the automotive industry coupled with a processing unit, which is connected to local WiFi network. Furthermore, the environment consists of a sensor floor, which provides the individual position of each passenger. The sensor floor is also coupled with a processing unit and part of the local WiFi network. In Fig. 9, a test setup in an Airbus A319 is shown. In close cooperation with Eurowings and Cologne Bonn Airport, this sensor environment was successfully used for boarding field test. The installed sensors in the cabin provide real-time information as an input for complexity evaluation (Schultz, 2017c), which enable a reliable prediction of current boarding time.

Fig. 9 Sensor environment in a field trial: sensor floor, seat sensors, central processing unit, seat processing unit (from left to right)

Beside new technologies and procedures for the passenger boarding, the key element is still unsolved: the boarding is controlled by the passenger. Each passenger is able to sustainably influence the whole boarding progress. Therefore the seatNow concept is developed, which enables a dynamic seat allocation and brings the control back to the aircraft operator. The passengers get their seats as recently as they scan their boarding passes (see Fig. 10). Depending on the specific passenger status and the current boarding progress (complexity measure using already boarded and seated passengers, information provided by a sensor network), an algorithm defines the most appropriate seat position in the airplane (cf. Notomista, 2016). During the field test with Eurowings at Cologne Bonn Airport seatNow was successfully tested against random and outside-in boarding, considering also operational disturbances (e.g. groups). The outside-in strategy was 13% faster and seatNow was 22% faster than the random boarding.
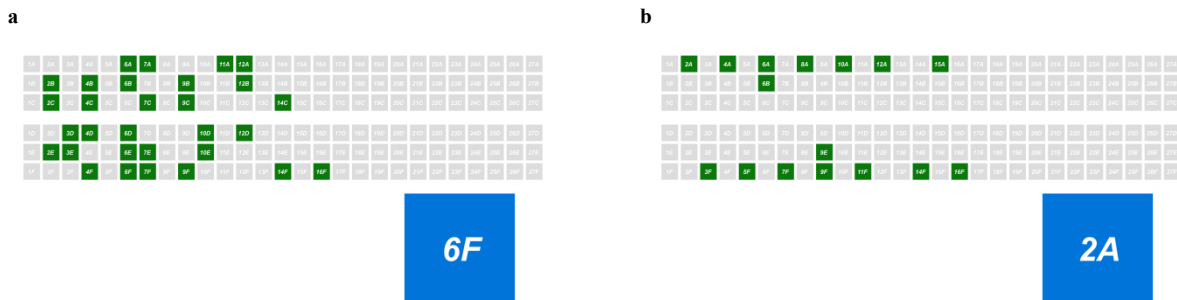

Fig 10 Exemplary seat allocation for (a) random boarding and (b) dynamically optimized boarding considering individual preferences, such as passenger groups

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