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Implementation and application of a stochastic aircraft boarding model

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ABSTRACT

The aircraft turnaround processes is mainly controlled by the ground handling, airport or airline staff, except the aircraft boarding, which is driven by the passengers' experience and willingness or ability to follow the proposed boarding procedures. The paper uses a prior developed, calibrated, stochastic aircraft boarding model, which is applied to different boarding strategies (chronological order of passenger arrival, hand luggage handling), group constellations and innovative infrastructural changes (Flying Carpet, Side-Slip Seat, Foldable Passenger Seat). In this context, passenger boarding is assumed to be a stochastic, agent-based, forward-directed, one-dimensional and discrete process. The stochastic model covers individual passenger behavior as well as operational constraints and deviations. A comprehensive assessment using one model allows for efficient comparison of current research approaches and innovative operational solutions for efficient passenger boarding.

1. Introduction

Aircraft boarding holds the potential to significantly influence the entire aircraft trajectory over the day of operations, since it is the last process of the aircraft turnaround and determines the estimated off block time of the aircraft (SESAR, 2014, Eurocontrol/IATA/ACI, 2014, IATA, 2016). Deviations in aircraft boarding times could directly result in additional delays or compensation of inbound delays. In particular, short-range flights require a reliable turnaround and boarding to prevent the accumulation of delays during the aircraft rotation over the day. To allow for a reliable evaluation of the passenger boarding process, a stochastic boarding model was developed (Schultz et al., 2008, 2013) and calibrated with measurements from field trials (Schultz, 2017a, 2018a). The stochastic boarding model is implemented in a simulation environment and used to provide a comprehensive and comparative assessment of boarding strategies and infrastructural changes, which aim to shorten boarding time significantly.

1.1. Status quo

In the following section, a short overview concerning scientific research on aircraft boarding problems is given. Relevant studies concerning aircraft boarding strategies include, but are not limited to, the following examples. More comprehensive overviews are provided by Jaehn and Neumann (2015) for boarding and by Schmidt (2017) for the aircraft turnaround.

A common goal of simulation-based approaches is to minimize the time that is required for passengers to board the aircraft. Taking into account specific boarding patterns, a study by Van Landeghem and Beuselinck (2002) investigates the efficiency of different boarding strategies. A similar approach is used by Ferrari and Nagel (2005), particularly focused on disturbances to the boarding sequence caused by early or late arrivals of passengers. The results show faster boarding times for the commonly used *back-*

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to-front boarding in the case of passengers not boarding in their previously assigned boarding block. This fact indicates that a *back-to-front* policy is not an optimal solution for the boarding problem. Picking up the idea of block boarding, a study based on an analytical model by van den Briel et al. (2005) shows significantly improved boarding times for block policies compared to the *back-to-front* policy. In contrast, Bachmat and Elkin (2008) support the *back-to-front* policy in comparison to the *random* boarding strategy. Schultz et al. (2008) demonstrate with a stochastic cellular automaton model that *back-to-front* boarding is most efficient if two boarding blocks are used, which is confirmed by Bachmat et al. (2013) using a 1 + 1 polynuclear growth model with concave boundary conditions.

The interference of passengers during the seating process is focused upon in a study by Bazargan (2007) using a mixed integer linear program for optimization. A stochastic approach to covering both the individual passenger behavior (e.g. passenger conformance to the proposed boarding strategy, individual hand luggage amount and distribution) and the operational constraints of aircraft/airlines (e.g. seat load factor, arrival rates) forms the focus of the research of Schultz et al. (2008). Using a Markov Chain Monte Carlo optimization algorithm, Steffen (2008a) develops a boarding strategy assuming that the handling of the hand luggage is a major impact factor for the boarding time and provides a model based on fundamental statistical mechanics (Steffen 2008b). Frette and Hemmer (2012) identify a power law rule, where the boarding time scales with the number of passengers to board, which allows the prediction of the results of the *back-to-front* boarding strategy, and Bernstein (2012) extends this approach to large numbers of passengers.

Tang et al. (2012) develop a boarding model considering passengers' individual physique (maximum speed), quantity of hand luggage, and individually preferred distance. Based on a boarding strategy from Steffen (2008a), Milne and Kelly (2014) develop a method which assigns passengers to seats so that their luggage is distributed evenly throughout the cabin, assuming a less time-consuming process for finding available storage in the overhead bins. Audenaert et al. (2009) and Qiang et al. (2014) propose a boarding strategy which prioritizes passengers with a high number of hand luggage items to board first. Milne and Salari (2016) assign passengers to seats according to the number of hand luggage items and propose that passengers with few pieces should be seated close to the entry. Kierzkowski and Kisiel (2017) provide an analysis covering the time needed to place items in the overhead bins depending on the availability of seats and occupancy of the aircraft. Zeineddine (2017) emphasizes the importance of groups when traveling by aircraft and proposes a method whereby all group members should board together, assuming a minimum of individual interference ensured by the group itself.

Bachmat et al. (2009) demonstrate with an analytical approach that the efficiency of boarding strategies is linked to the aircraft interior design (seat pitch and passengers per row). Chung (2012) and Schultz et al. (2013) address the aircraft seating layout and indicate that alternative designs could significantly reduce the boarding time for both single and twin-aisle configuration. Fuchte (2014) focuses on the aircraft design and, in particular, the impact of aircraft cabin modifications with regard to the boarding efficiency while Schmidt et al. (2015, 2017) evaluate novel aircraft layout configurations and seating concepts for single and twin-aisle aircraft with 180–300 seats. An innovative approach to dynamically changing the cabin infrastructure through a Side-Slip Seat was evaluated by Schultz (2017d, 2017e).

1.2. Objectives and document structure

This paper provides a comprehensive and comparative assessment of the impact of different boarding strategies (passenger sequences), passenger group constellations, amount of hand luggage items and infrastructural changes. To evaluate potential passenger boarding improvements the paper introduces a calibrated, agent-based, stochastic boarding model. The model is extended to cover the requirements of new infrastructure (e.g. innovative seat configurations). Five different approaches impacting the aircraft boarding process are evaluated and compared against a reference scenario: boarding sequences (chronological order of passengers), hand luggage items (amount and distribution), passenger group constellations (from 2 to 12 passengers), the Flying Carpet concept (Wallace, 2013), and two dynamic seat configurations (Side-Slip Seat (Molon Labe Seating, 2017), Foldable Passenger Seat (SII Group, 2017)). Finally, the conclusion provides an overview of the achieved results and an outlook on future research activities.

2. Boarding model

To reflect operational conditions of aircraft and airlines (e.g. seat load factor, conformance to the boarding procedure) as well as the non-deterministic nature of the underlying processes (e.g. amount and distribution of hand luggage) a stochastic model was developed (Schultz et al., 2008, 2013) and calibrated (Schultz, 2017a, 2018a). This section provides a brief overview about the model and parameter, which allows to reproduce both the model and the results achieved during the simulation trials in the following sections.

2.1. Stochastic, individual-based approach

The dynamic model for the boarding simulation is based on an asymmetric simple exclusion process (ASEP). The ASEP was successfully validated and adapted to model the dynamic passenger behavior in the airport terminal environment (Schultz, 2010, 2014; Schultz et al., 2010; Schultz and Fricke, 2011). In this context, passenger boarding is 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 A320, 29 rows, 174 seats (Airbus, 2017)). This regular grid consists of equal cells with a size of