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Dynamic change of aircraft seat condition for fast boarding

Michael Schultz

German Aerospace Center (DLR), Institute of Flight Guidance, Lilienthalplatz 7, Braunschweig, Germany

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ABSTRACT

Aircraft boarding is a process mainly impacted by the boarding sequence, individual passenger behavior and the amount of hand luggage. Whereas these aspects are widely addressed in scientific research and considered in operational improvements, the influence of infrastructural changes is only focused upon in the context of future aircraft design. The paper provides a comprehensive analysis of the innovative approach of a Side-Slip Seat, which allows passengers to pass each other during boarding. The seat holds the potential to reduce the boarding time by approx. 20%, even considering operational constraints, such as passenger conformance to the proposed boarding strategy. A validated stochastic boarding model is extended to analyze the impact of the Side-Slip Seat. The implementation of such fundamental change inside the aircraft cabin demands for adapted boarding strategies, in order to cover all the benefits that accompany this new dynamic seating approach. To reasonably identify efficient strategies, an evolutionary algorithm is used to systematically optimize boarding sequences. As a result, the evolutionary algorithm depicts that operationally relevant boarding strategies implementing the Side-Slip Seat should differentiate between the left and the right side of the aisle, instead of the current operationally preferred boarding from the back to the front.

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 turnaround (critical path) and determines the estimated off block time of the aircraft (SESAR, 2014; Eurocontrol/IATA/ACI, 2014; IATA, 2016). Deviation in aircraft boarding (extension or reductions) 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. The following analysis of infrastructural changes provides a fundamental background for evaluating the boarding process in detail (Schultz et al., 2008, 2013) and provides an evaluation of the innovative Side-Slip Seat concept (Molon Labe Seating, 2017), which is expected to shorten the aircraft boarding time significantly.

1.1. Previous related work

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. Comparisons and reviews of different boarding approaches mainly focus on fast and reliable operational progress, but also address the economic impact (Nyquist and McFadden, 2008; Mirza, 2008).

A common goal of simulation-based approaches is to minimize the time that is required for passengers to board the aircraft.

E-mail address: michael.schultz@dlr.de.

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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-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 when boarding an aircraft forms the focus of a study by Bazargan (2007). The mathematical model's output aims to minimize the interferences by 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 aircraft/airline operational constraints of aircraft/airlines (e.g. seat load factor, arrival rates) is in 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. 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 closed 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.

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) focusses on the aircraft design and, in particular, the impact of aircraft cabin modifications with regard to the boarding efficiency whilst Schmidt et al. (2015, 2017) evaluate novel aircraft layout configurations and seating concepts for single and twin-aisle aircraft with 180–300 seats.

In the context of deboarding, the seat interference disappears and only the interference of passengers in the aisle is important for an efficient process. Wald et al. (2014) provide a study of deplaning strategies using stochastic optimization methods, Qiang et al. (2016) use a cellular automaton approach and Miura and Nishinari (2017) employ a model using an ex-Gaussian distribution.

New topics of boarding research are focusing on dynamic allocation and control aspects. Notomista et al. (2016) realize an efficient boarding procedure by allocating the seat numbers adaptively to passengers when they pass the boarding gate. Zeineddine (2017) emphasizes the importance of groups when traveling by aircraft and proposes a method whereby all group member should board together, assuming a minimum of individual interference ensured by the group itself.

The methods applied to boarding problems range from analytical approaches (e.g. Frette and Hemmer, 2012), mixed integer linear programs (e.g. Bazargan, 2007), polynuclear growth models (e.g. Bachmat et al., 2013), Markov Chain Monte Carlo model (Steffen, 2008a), statistical mechanics (Steffen, 2008b), stochastic cellular automaton approaches (e.g. Schultz et al., 2008) up to pedestrian-following models (Tang et al., 2012). If the research is aimed at finding an optimal solution for the boarding sequence, evolutionary/genetic algorithms are used to solve the complex problem (e.g. Li et al., 2007; Wang and Ma, 2009; Soolaki et al., 2012).

1.2. *Objectives and document structure*

This paper provides fundamental in-depth analysis of the Side-Slip Seat according its potential to reduce the aircraft boarding time under operational conditions (individual passenger behavior and operational constraints). After a brief introduction of the continuously developed stochastic boarding model (Schultz et al., 2008, 2013; Schultz, 2017) and a baseline simulation of a set of boarding strategies, the operational concept Side-Slip Seat (Molon Labe Seating, 2017) will be presented. The boarding model is extended according to the operational requirements and used to evaluate the effect of the Side-Slip Seat. Then these simulation results are compared against the baseline. Since the introduction of new infrastructures often demands adjusted operational procedures, in the second part of the paper, the approach of evolutionary algorithms will be used to derive appropriate boarding sequences. The idea behind evolutionary algorithms is biologically inspired: start with a set of possible solutions (random boarding sequences) and allow them to evolve over time using the processes of selection, heredity (cross-over and mutation) and replacement of least-fit solutions. Instead of the systematic testing of conceived boarding strategies (it is not possible to check all existing sequences in an appropriate amount of time), evolutionary algorithms explore the problem space in a more efficient way. The application of the developed