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Reducing airplane boarding time by accounting for passengers' individual properties: A simulation based on cellular automaton

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ABSTRACT

The increase of air travel puts tremendous burden on airline companies. A time saving boarding strategy is required to improve the utilization of airplane boarding time and explore flexible time management strategies. Firstly, an improved boarding strategy is introduced by assigning individual passengers to seats based on the number of luggage they carry. Passengers with the most luggage board onto the plane first. To test the behavior of boarding strategies under different conditions, a sophisticated simulation environment based on cellular automata model is designed. Simulation results indicate that the improved boarding strategy shows an excellent efficiency and robustness comparing with other strategies.

1. Introduction

In recent years, the rapid development of the aviation industry especially civil aviation puts more and more loads on airport management. Reducing costs and improving efficiency are of utmost priority for airlines. A commonly used metric to measure the efficiency of commercial airlines' operations is airplane turn time (Marelli et al., 1998; Van Landeghem and Beuselinck, 2002; Ferrari and Nagel, 2005; Van den Briel et al., 2005). Usually, it constitutes the time from the arrival of the airplane to its next departure. Nyquist and McFadden (2008) found that the average cost to an airline company for each minute spent at the terminal is roughly $30. Thus, each minute saved in the turn time of a flight has the potential to generate considerable annual savings. Reducing idle time on the ground will lead to improved airplane utilization and a more flexible time management.

Factors that determine turn time include passenger boarding and deplaning, airplane fueling, cargo un-loading and loading, cabin cleaning and galley servicing. While improving any of these factors can decrease the turn time, a particularly critical factor is the boarding time, since it is one of the lengthiest parts of an airplane's turn time; its reduction could contribute a significant savings to airline companies.

Some previous works have been done to study the airplane boarding process and optimize the airplane boarding strategies. Marelli et al. (1998) of Boeing Corporation proposed a discrete event simulation model to test different boarding strategies under various configurations and made a series of validations. Van Landeghem and Beuselinck (2002) explored various boarding patterns with computer simulation to detect to what extent boarding time can be reduced. Ferrari and Nagel (2005) used a simulation model to evaluate robustness of various airplane boarding strategies under the effect of three recognizable disturbances: early and/or late passengers, airplane dimensions, and the occupancy level of the plane. Nyquist and McFadden (2008) used the most cost-effective way to study the airplane boarding activities and strategies while maintaining quality and customer satisfaction. Steffen (2008) and Steffen and Hotchkiss (2012) applied the Markov Chain Monte Carlo optimization algorithm and computer simulation to study the passenger boarding process and a boarding strategy that minimized airplane boarding time was found. Some researchers provided efficient mechanisms for constructing the new strategies. Briel et al. (2005) applied a nonlinear assignment method to minimize expected boarding interferences to reduce boarding time. Bazargan (2007) examined the interferences among the passengers that cause delays in boarding times for a single aisle airplane and offered a new mixed integer linear program to minimize these interferences. Soolaki et al. (2012) offered a new integer linear programming approach to reduce the passenger boarding time and a genetic algorithm was used to solve this problem. All of the methods above are based on an assumption that there is a correspondence between minimizing the expected number of interferences and minimizing the boarding time. One exception is a study by Bachmat et al. (2006, 2009). In their work, the airplane

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boarding was analyzed via space-time geometry and random matrix theory, their analysis reveals a clear link between the efficiency of various airline boarding policies and a congestion parameter which is related to interior airplane design parameters.

However, the models mentioned above can't completely describe the airplane boarding behavior since many airplane boarding factors are not explicitly considered. In order to explore the dynamic properties of passengers' motions in airplane boarding, Tang et al. (2012a,b) proposed a new airplane boarding model with consideration of passengers' individual properties. Recently, Milne and Kelly (2014) proposed a new method based upon Steffen by assigning individual passengers to seats based on the amount of luggage they carry. They assign passengers to seats so that their luggage is distributed evenly throughout the plane.

In order to decrease the airplane boarding time, in this paper, a more efficient boarding strategy is proposed in consideration of passengers' individual properties. Furthermore, we test this strategy by numerical simulation. The basic difficulty of airplane boarding simulation is in establishing a reasonable passenger behavior model. Considering the previous simulators mentioned above have limitations in dynamics describing the passenger's individual behaviors, an improved cellular automaton model is introduced in this paper. Cellular automaton has been widely used in traffic flow theory since it provides a good approximation of complex flow patterns (Maerivoet and Moor, 2005). Even though the motion characters of passengers in airplane boarding processes are more complex than vehicular flows, there are many similarities to the traffic following model under the assumption that no overtaking behavior happens and each passenger advances with his/her expect velocity. So, a realistic cellular automaton model is proposed based on commonly used NaSch (Nagel and Schreckenberg, 1992) model while taking into consideration seat and aisle interferences.

The remaining parts of the paper are organized as follows. In Section 2, an improved airplane boarding strategy with consideration of passengers' individual properties is proposed. In Section 3, a cellular automata model is proposed to simulate the dynamic properties of passengers' motions in airplane boarding. In Section 4, numerical tests are carried out for different boarding strategies. In Section 5, conclusions and future research opportunities are given.

2. Boarding strategy by considering passengers' individual properties

The most prominent characteristic of our proposed method is that the seats of passengers are assigned considering the number of luggage they carry. The main reason for boarding time delay is interference. Two kinds of interferences happen in boarding process. One is aisle interference, it occurs when passengers stowing luggage block other passengers' access to their seats in cabin aisle. The other is the seat interference which occurs when passengers seated close to the aisle block other passengers to proceed to their seat in the same half-row. Note that a passenger in the last row of the plane blocks nobody when stowing luggage while a passenger in the front row blocks all other passengers behind if he/she takes too much time in stowing luggage. Besides, the configuration that allows the maximum number of passengers to load their luggage simultaneously will quicken the boarding process. Based on these insights, an improved strategy is developed to reduce boarding time by considering passengers' luggage properties. We modeled a “standard” airplane with 150 seats, divided into 25 rows and three on either side of the single aisle (20 m in length). Below is the procedure for how passengers should board an airplane.

a. Passengers board according to the Steffen sequence based on their assigned seats, Fig. 1a. All adjacent passengers are assigned seats that are separated by exactly one row; the passengers' seat serial numbers are divided into 1–13, 14–26, 27–38,…,139–150.
b. In each group, the seat serial number is given based on the number of pieces of luggage carried by the passenger, as the passenger who takes more luggage enters the plane first in each group.

Once the passengers have been assigned to specific seats, they board the airplane in the Steffen sequence. For the purpose of our discussion, the proposed strategy is compared with five other boarding strategies including random, back-to-front, outside-in, reverse pyramid and Steffen strategy. The rule of each strategy is described as follows and their configurations are exhibited respectively in Fig. 1:

(1) Steffen strategy: This method has the passengers lining up in a prescribed order that incorporates, in a specific way, boarding from the back to the front and from the windows to the aisle (see Fig. 1a).
(2) Random: This is the easiest boarding strategy. Passengers have assigned seats, but enter the airplane in no predefined order (see Fig. 1b).
(3) Outside-in (OI): Passengers are divided into three groups and boarded in an order of windows first, followed by the middle and aisle seats boarding last; within each group the passengers are essentially random (see Fig. 1c)
(4) Back-to-front (BF): This is the most widely used boarding strategy among airlines. Passengers are divided into several groups (three groups in this paper) and boarded in a back to front order; within passengers essentially random in each group (see Fig. 1d).
(5) Reverse Pyramid (RP): This strategy is a hybrid between the traditional back-to-front and outside-in boarding strategies. Passengers board the airplane in a V-like manner with back windows and middle boarding first, followed by back aisles and front aisle (see Fig. 1e).

3. Simulation model based on cellular automaton

We divided the cabin floor into square cells of equal size with 0.4 m in length. Seats are numbered by row and by one of the letters from A to F. Floor cells and seat cells are marked in white and blue respectively, see Fig. 2. The model only considers economy-class passengers and each flight is completely full. Passengers enter into the aisle in sequence with a constant rate. Each passenger occupies one cell in every time step and there must be at least one empty cell in front of him/her. For analytical tractability, passengers don't try to pass other passengers in the boarding process. Besides, this model does not include the clustering of passengers into companions or families and other effects of human nature.

Boarding time starts when the first passenger enters the plane and ends when the last passenger is seated. From time step $t \rightarrow t+1$, the parallel update rules of passenger boarding are described as follows. With T_{enter} time interval, a passenger will enter into the aisle. When a passenger has reached his/her assigned row, it will take him/her some time steps to deal with carry-on luggage. Once the luggage has been stored, he/she will deal with seat interference. The detailed rules will be introduced below.

3.1. Passenger movement model

The NaSch model is modified to describe passengers' movement behaviors. In the process of boarding, each cell may either be occupied by one passenger, or empty. Each passenger has an integer velocity with value between 0 and v_{max}. For an arbitrary configuration, one update of the system consists of the following four