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An aircraft boarding model accounting for group behavior

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ABSTRACT

The rapid increase of civil aviation has posed a great challenge to air traffic (especially aircraft boarding). In this study, we propose a new aircraft boarding model to explore the impacts of group behavior on each passenger's motion, seat conflict, check-in time, time of handling luggage as well as boarding time during the boarding process. The numerical results show that the group behavior has some positive impacts on the boarding efficiency, and that the impacts become more prominent with an increasing number of groups. Hence, the group behavior should be encouraged to enhance the efficiency during the boarding process.

1. Introduction

Since 1950s, the demand of air transportation has grown rapidly. For instance, the number of air passengers in mainland China has increased to 200 million in 2010 from less than 10 million in 1950 (Zhang et al., 2010). The rapid increase of air passengers has produced many traffic problems (e.g., airline congestion, passenger-luggage congestion and mixed traffic congestion) (Clarke, 1995; Peterson et al., 1995; Brueckner, 2002a; 2002b, 2004; Janic, 2009; Skorupski and Stelmach, 2009).

To explore the aircraft boarding process, researchers have developed various models to study the boarding behavior. For example, Marelli et al. (1998) proposed a passenger enplane/deplane model to explore different boarding strategies and different configurations on a Boeing 757 airplane. Van Landeghem and Beuselinck (2002) studied different aircraft boarding patterns to investigate what extent boarding time can be reduced. Ferrari and Nagel (2005) investigated boarding time considering disturbances to the boarding sequence caused by early or late arrivals of passengers. Bazargan (2007) explored the interferences among passengers during the boarding process and developed a mixed integer linear program to minimize the interferences. Bachmat and Elkin (2008) provided bounds on the performance of back-to-front boarding strategies. Nyquist and McFadden (2008) concluded that strictly enforcing their carry-on standards of one personal item and using of the second aircraft door were two critical factors affecting average boarding time. Steffen (2008) used a Markov Chain Monte Carlo optimization algorithm to develop a boarding strategy assuming that the handling of the hand luggage is a major impact factor for the boarding time. Steiner and Philipp (2009) used simulations and video data to explore which factors affected boarding time and turn time. Tang et al. (2012a, 2012b) developed a pedestrian flow model to explore the boarding problem. Steffen and Hotchkiss (2012) designed an experimental test in a mock Boeing 757 fuselage to investigate the boarding process. Milne and Kelly (2014) proposed a method of assigning seat in order to minimize the boarding time, which was extended to assign passengers to a specific position in line that depends on their seat location (Milne and Salari, 2016). Qiang et al. (2014) proposed a boarding strategy that passengers with a high number of hand luggage items board onto the plane first. Using the online seat assignment based on passenger classification, Notomista et al. (2016) proposed a fast boarding strategy. Miura and Nishinari (2017) utilized an ex-Gaussian distribution to design a passenger distribution analysis model for the perceive time of boarding/deplaning. Schultz (2017a) used a microscopic simulation approach to model the passenger behavior to indicate the progress of the aircraft boarding. Schultz (2017b) provided a comprehensive analysis of the innovative approach of a Side-Slip Seat which allows passengers to pass each other during the boarding process. In addition, some pedestrian flow models can be applied to study the passenger's boarding behavior (Muramatsu and Nagatani, 2000; Nagatani, 2001, 2002; Tajima et al., 2001; Chen et al., 2013; Yang et al., 2015).However, the above models do not consider the impacts of group behavior on the boarding process. In fact, group behavior often exists during the boarding process and may affect the boarding behavior. van den Briel et al. (2003) presented results from a

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simulation model of the aircraft-boarding procedure for an Airbus 320 airplane that suggested that structured group boarding can result in boarding time reductions, and picking up the idea of block boarding, a study based on an analytical model showed significantly improved boarding times for block policies compared to the back-to-front policy (van den Briel et al., 2005). Qiang et al. (2016) proposed a symmetrical design of deplaning strategies to match three typical grouped enplaning strategies (back-to-front, windows-to-aisle and reverse pyramid). Zeineddine (2017) proposed a dynamically optimized aircraft boarding strategy to shorten the boarding time, reduce on-board interferences, and allow passengers' cliques to proceed together to their reserved seats.

In this paper, we propose a boarding model accounting for group behavior to study the boarding process. The remainder of this paper is organized as follows: a boarding model accounting for group behavior is developed in Section 2; some numerical tests are carried out to study the influences of group behavior on each passenger's trajectory, seat conflicts and boarding time in Section 3; and some conclusions are summarized in Section 4.

2. Model

The existing boarding models can be roughly divided into simulation models and ordinary differential equation (ODE) models. As for the ODE model, Tang et al. (2012a, 2012b) utilized the car-following model to explore each passenger's movements during the boarding process and proposed two boarding models, where the first model can be expressed as follows:

$$\begin{cases} \begin{cases} \frac{dv_n(t)}{dt} = \alpha(V(\Delta\bar{x}_1(t)) - v_1(t)), & \text{if } p_1(t)=0 \\ v_1(t)=0, & \text{if } p_1(t)=1 \end{cases}, & \text{if } \ n=1 \\ \begin{aligned} &\frac{dv_n(t)}{dt} = \alpha(V(\Delta x_n(t)) - v_n(t)) \\ &+\lambda_1(1-p_{n-1}(t))\Delta v_n(t) + \lambda_2 p_{n-1}(t)(-v_n(t)), \\ &\quad \text{if } N>n>1 \end{aligned} \\ \begin{cases} \frac{dv_N(t)}{dt} = \alpha(V(\Delta x_N(t)) - v_N(t)) \\ +\lambda_1(1-p_{N-1}(t))\Delta v_N(t) + \lambda_2 p_{N-1}(t)(-v_N(t)), \\ \text{if } p_N(t)=0 \\ v_N(t)=0, \quad \text{if } p_N(t)=1 \end{cases}, & \text{if } n=N \end{cases} \tag{1}$$

where v_n, V are respectively the nth passenger's speed and optimal speed; Δx_n (n>1) is the distance between the nth passenger and the (n-1)th passenger; $\Delta\bar{x}_1$ is the distance between the first passenger and his destination; Δv_n (n>1) is the speed difference between the nth passenger and the (n-1)th passenger; p_{n-1} is the probability that the (n-1)th passenger is interrupted during the boarding process; α, λ_1, λ_2 are three parameters. Since Tang et al. (2012a) did not take into account the passenger's individual properties, p_n, V can be simplified as follows:

$$p_n(t) = \begin{cases} 1, & \text{if } t_n^1 \le t \le t_n^1 + T_1 \\ 1, & \text{if } t_n^2 \le t \le t_n^2 + T_2, \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

$$V(\Delta x_n) = \frac{v_{max}}{2}(\tanh(\Delta x_n - h_c) + \tanh(h_c)), \tag{3}$$

where t_n^1 is the time when the nth passenger arrives at the wicket; T_1 is the time that the teller checks the nth passenger's ticket; t_n^2 is the time when the nth passenger reaches his/her seat; T_2 includes the time that it takes the nth passenger to place his/her carried luggage at his/her seat and the delay time produced by the seat conflicts; and h_c, v_{max} are respectively the safety distance and the maximum speed. T_1, T_2 are set as follows (Tang et al., 2012a):

$$T_1 = T_{10},\ T_2 = T_{lugg} + T_{seat}^{conflict}, \tag{4}$$

where T_{lugg} is the time of each passenger's handling luggage when he/she arrives at his/her seat; $T_{seat}^{conflict}$ is the delay time caused by the seat conflict. Tang et al. (2012a.b) divided T_{lugg} into two parts, i.e.,

$$T_{lugg} = T_2^{min} + T_2^{stochastic}, \tag{5}$$

where T_2^{min}, $T_2^{stochastic}$ are respectively the minimum time and the stochastic time that the passengers handle their luggage. Tang et al. (2012a) defined T_2^{min}, $T_2^{stochastic}$ as follows:

$$T_2^{min} = T_{20},\ T_2^{stochastic} = \text{randperm}(0, T_{20}), \tag{6}$$

where randperm$(0, T_{20})$ generates a random integer in the interval $[0, T_{20}]$. Note: T_{10}, T_{20} are here two integers that are beforehand defined.

Tang et al. (2012a) found that Eq. (1) can reproduce each passenger's boarding behavior, but it cannot be used to describe the influences of the passenger's individual properties on each passenger's motion. Hence, Tang et al. (2012b) developed a boarding model with the passenger's individual properties, i.e.,

$$\begin{cases} \begin{cases} \frac{dv_n(t)}{dt} = \alpha_1(V_1(\bullet) - v_1(t)), & \text{if } p_1(t)=0 \\ v_1(t)=0, & \text{if } p_1(t)=1 \end{cases}, & \text{if } \ n=1 \\ \begin{aligned} &\frac{dv_n(t)}{dt} = \alpha_n(V_n(\bullet) - v_n(t)) \\ &+\lambda_{1,n}(1-p_{n-1}(t))\Delta v_n(t) + \lambda_{2,n} p_{n-1}(t)(-v_n(t)), \\ &\quad \text{if } N>n>1 \end{aligned} \\ \begin{cases} \frac{dv_N(t)}{dt} = \alpha_N(V_N(\bullet) - v_N(t)) \\ +\lambda_{1,N}(1-p_{N-1}(t))\Delta v_N(t) + \lambda_{2,N} p_{N-1}(t)(-v_N(t)), \\ \text{if } p_N(t)=0 \\ v_N(t)=0, \quad \text{if } p_N(t)=1 \end{cases}, & \text{if } n=N \end{cases} \tag{7}$$

where α_n, $\lambda_{1,n}$, $\lambda_{2,n}$ are three parameters determined by the nth passenger's individual properties; V_n is the nth passenger's optimal speed. As for the exact definitions of α_n, $\lambda_{1,n}$, $\lambda_{2,n}$, V_n, please refer to the literature (Tang et al., 2012b).

The boarding models (Tang et al., 2012a, 2012b) cannot describe the impacts of group behavior on the boarding problem since this factor is not considered. In fact, group behavior (e.g., family boarding together in cliques) often exists during the boarding process, so each boarding model should consider this factor. Next, we propose a boarding model accounting for group behavior. Before proposing the model, we should give the following assumptions:

(1) The scenario of the boarding is shown in Fig. 1, where L_1 is the distance between the wicket and the gate of aircraft; L_{seat} is the distance between two rows of seats; L_2 is the distance between the seat D and the gate of aircraft.
(2) We only study the passenger's motion in the economy cabin; the aircraft's capacity is 150; the 150 passengers are homogeneous, i.e., each passenger's related parameter can be defined as a constant; the passengers cannot run abreast during the boarding process.
(3) Some passengers have group behavior while other passengers do not have group behavior. The passengers with group behavior are divided into a number of groups, where each group includes 2–6 passengers. The passengers without group behavior are looked on as separate individuals. Each group of passengers is randomly distributed in the 150 passengers.
(4) As for the passengers with group behavior, the first passenger in each group shows their tickets at the barrier and the last passenger in each group handles their luggage at their seats; their seats lie in the same row, where the No. is defined based on the size of each group, i.e.,
    (a) If the size is 2, the seat Nos. are AB, BC, CD, ED or FE.