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An aircraft boarding model with the group behavior and the quantity of luggage

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ABSTRACT

A reasonable boarding model can effectively improve the boarding efficiency. Therefore, developing boarding models/strategies to improve the boarding efficiency has been an interesting topic in the air transportation. In this paper, we incorporate the group behavior and the quantity of luggage into the boarding process, and then develop an extended boarding model to investigate the effects of the two factors on the delay time and boarding time. The numerical results show that the quantity of luggage may make each passenger's boarding behavior more complex, while the group behavior can shorten some passengers' delay time and the total boarding time. The results can help administrators organize the boarding process and enhance the boarding efficiency.

1. Introduction

To date, the quantity of air passengers rapidly increases (Zhang et al., 2010), which has caused many great challenges to air traffic management. For example, airline congestion, passenger-luggage congestion and mixed traffic congestion widely occur in the civil aviation system (Clarke, 1995; Peterson et al., 1995, Brueckner, 2002a, 2002b, 2004; Steffen, 2008; Janic, 2009; Skorupski and Stelmach, 2009). Hence, researchers developed models to explore the formation mechanisms of the above traffic problems, and then designed strategies to solve/relieve the above traffic problems (Marelli et al., 1998; Van Landeghem and Beuselinck, 2002; Ferrari and Nagel, 2005; Van den Briel et al., 2005).

However, the above studies focused on exploring how to improve the operational efficiency of airline or reducing the operational cost, but they cannot be used to study the aircraft boarding problem since they were not developed from the boarding process. As for the operational cost, Steffen (2008) used experimental data to testify that it should take 30 dollars for an aircraft to stay at an airport for a minute. This shows that reducing the boarding time can save the operational cost. To reduce the boarding time, researchers developed many models or strategies to enhance the boarding efficiency. For example, Marelli et al. (1998) first developed a passenger enplane/deplane simulation model to investigate the impacts of strategies and configurations on the boarding efficiency on one Boeing 757 airplane. Beuselinck (2002) proposed a strategy to reduce the passenger's boarding time. Van Landeghem and Beuselinck (2002) designed different boarding patterns and explored the boarding behavior under each pattern. Van den Briel et al. (2003, 2005) proposed an integer programming and nonlinear assignment model to study the boarding process, and used observed

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data to further testify the numerical results. Ferrari and Nagel (2005) proposed different indexes to evaluate the existing strategies, and then design a new strategy with a small number of boarding groups to explore the boarding behavior. Yasuda and Fujitaka (2005) explored the necessity of boarding control for international flights, and proposed a framework for controlling the cosmic radiation exposure of aircraft crew. Bazargan (2007) explored the passenger interference that causes delay, and then proposed an integer programming model to reduce the number of interferences. Bachmat and Elkin (2008) discussed the performance of the back-to-front strategy and further explored the bound. Nyquist and McFadden (2008) used the most cost-effective way to study the boarding activities and strategies. Steffen (2008) introduced the Markov Chain Monte Carlo optimization algorithm into the boarding process, and then defined a boarding ordering to reduce the boarding time. Steiner and Philipp (2009) investigated special actions (including the ones inside and outside the airplane) which can reduce the boarding/turn time, then proposed a simulation model, and finally applied the video data collected at the Zurich airport to calibrate the parameters of the proposed model. Steffen and Hotchkiss (2012) used one experimental test to testify the proposed method during a real boarding process. Tang et al. (2012a) developed a pedestrian-following model to study the boarding process. Based on the passenger's individual features, Tang et al. (2012b) proposed a boarding strategy and a pedestrian-following model to explore the boarding process and the effects of the passenger's individual features on the boarding efficiency. Milne (2014) used the passenger's seat assign to optimize the boarding total time. Milne (2016) studied the importance of luggage storage space, and developed a strategy to assign the luggage storage space to the specific position that depends on the passenger's seat. Qiang et al. (2014) proposed a cellular automaton (CA) model to describe each passenger's motion during the boarding process. Qiang et al. (2016a) proposed some boarding parameters (e.g., the passengers' movement, the relationship between the average boarding time and check-in time, etc.) to evaluate the boarding efficiency. Qiang et al. (2016b) designed a strategy with group behavior to study the boarding and deplaning behaviors. Zhao et al. (2015) simulated the impacts of luggage on each passenger's motion during an aircraft evacuation, and used experimental data to calibrate the quantitative effects of the quantity of luggage on the passenger's velocity during the boarding process. Based on the online seat assignment and the passenger classification, Notomista et al. (2016) designed a fast boarding strategy to study the boarding behavior. Miura and Nishinari (2017) used the ex-Gaussian distribution to construct a distribution analysis model for the perceived boarding/deplaning time. Schultz (2017a) used the potential seat interference to study the boarding process and evaluate the boarding efficiency. Schultz (2017b) applied the real-time information of the seat's status to depict the boarding process. Schultz (2017c) defined a metric for the real-time evaluation of the boarding progress and studied the impacts of the real-time information on the boarding efficiency. Zeineddine (2017) proposed a dynamical optimal strategy to study the boarding efficiency.

The above models can describe the boarding/deplaning process, but they did not simultaneously consider the quantity of luggage or the group behavior, so they cannot be used to explore the impacts of the two factors on the boarding efficiency. In fact, the quantity of luggage and the group behavior are two important fundamental factors that directly influence the boarding efficiency. In this paper, we incorporate the group behavior and the quantity of luggage into the boarding process (Tang et al., 2012b), and construct a boarding model to study the effects of the two factors on each passenger's boarding behavior and the efficiency. This paper is organized as follows: the boarding model is proposed in Section 2, some numerical tests are conducted to study the two factors on the boarding efficiency in Section 3, and conclusions are summarized in Section 4.

2. Model

In this section, we propose a boarding model to study the influences of the luggage's attribution and the passenger's individual features on the boarding efficiency. There are many models that can be used to study the boarding process, but the pedestrian-following model easily describe the dynamic features of each passenger's movement (including the effects of some factors (e.g., checking ticket, handling carried luggage, etc.) on the dynamic features), so we in this paper use the pedestrian-following model to study each passenger's following behavior during the boarding process. As for this topic, Tang et al. (2012b) applied the pedestrian flow theory to propose a boarding model, which can be formulated as follows:

$$\begin{cases} \begin{cases} \frac{dv_n(t)}{dt} = \alpha_1(V(\Delta\bar{x}_1(t)) - v_1(t)), & \text{if } p_1(t) = 0 \\ v_1(t) = 0, & \text{if } p_1(t) = 1 \end{cases}, & \text{if n=1} \\ \frac{dv_n(t)}{dt} = \alpha_n(V(\Delta x_n(t)) - v_n(t)) + \lambda_{1,n}(1 - p_{n-1}(t))\Delta v_n(t) + \lambda_{2,n}p_{n-1}(t)(-v_n(t)), & \text{if N> n> 1}, \\ \begin{cases} \frac{dv_N(t)}{dt} = \alpha(V(\Delta x_N(t)) - v_N(t)) + \lambda_{1,N}(1 - p_{N-1}(t))\Delta v_N(t) + \lambda_{2,N}p_{N-1}(t)(-v_N(t)), & \text{if } p_N(t) = 0 \\ v_N(t) = 0, & \text{if } p_N(t) = 1 \end{cases}, & \text{if n = N} \end{cases} \tag{1}$$

where N is the number of passengers, v_n, V_n are respectively the nth passenger's speed and optimal speed; α_n, $\lambda_{1,n}$, $\lambda_{2,n}$ are the nth passenger's reaction coefficients relevant to his individual features; 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 is the probability that the nth passenger is interrupted during the boarding process and can be defined as follow:

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