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# Symmetrical design of strategy-pairs for enplaning and deplaning an airplane

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ABSTRACT

Enplaning and deplaning processes are two main activities that passengers experience in an airplane. They are also the main factors contributing to the airplane turn time. Thus, both processes need to be carefully considered when designing a new strategy. The main contribution of this paper is twofold. Firstly, we propose a symmetrical design of deplaning strategies to match three typical grouped enplaning strategies (back-to-front, windows-to-aisle and reverse pyramid), in which the groups are organized in a LIFO (Last In First Out) manner. Secondly, we present an integrated cellular automaton model to describe the dynamic characteristics of passengers in the enplaning and deplaning processes. Numerical evaluation results indicate that the proposed windows-to-aisle and reverse pyramid strategies perform better in the following aspects: (i) the total operation time decreases; (ii) the two strategies are less sensitive to the load condition, e.g., luggage distribution and cabin occupancy rate; (iii) passengers' satisfaction is enhanced since both individual waiting time and processing time lower down; (iv) the two strategies are fairer for the passengers since the difference among the groups remarkably shrinks.


## 1. Introduction

Due to the rapid civil aviation growth, the competition pressure increases among airlines. Therefore, airlines need to continually optimize their operations with the goal of maximizing their efficiency and profitability. One of the most promising ways is to reduce the airplane turn time, i.e., the time to unload an airplane after its arrival and to prepare it for departure again. A significant saving could be achieved by reducing the enplaning and deplaning time, since they are the main contributions to an airplane's turn time. A successfully designed strategy-pairs for enplaning and deplaning is expected to perform satisfactorily to meet the needs of the three principal users: the airlines, airport operators and the passengers.

Airlines make every effort to minimize the time that their flights stay on the ground. Nyquist and McFadden (2008) pointed out that for each minute an active airplane stays on the ground, the airline needs to spend US $30. Thus, each minute saved in the turn time of a flight can accumulate to produce considerable annual savings. Reduction of airplane turn time can also benefit the airport operators in three aspects: firstly, it could reduce the flight delays caused by imbalances between demand and capacity by scheduling more flights (Ball et al., 2010). Secondly, it improves the passengers' experience at airport terminals and consequently increases level of service of the airport; thirdly, it makes a more efficient utilization of the equipment on ground. For passengers, they are concerned about their own waiting time, and individual enplaning and deplaning time. Passengers generally prefer shorter enplaning and deplaning time. A reduction in total enplaning and deplaning time implies a reduction of the average individual enplaning and deplaning time for passengers.

Efforts have been made to reduce the enplaning time, and most of them are based on simulation works. Marelli et al. (1998) reported a discrete event simulation model and evaluated different enplaning scenarios and airplane interior configurations. Van Landeghem and Beuselinck (2002) discussed various enplaning strategies via computer simulation to study to what extent enplaning time can be reduced. Results have shown that the choice

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of enplaning strategies highly influences the enplaning time, both totally and individually. Ferrari and Nagel (2005) evaluated robustness of strategies with three disturbances: early or late enplaning of passengers, dimensions of airplane, and the occupancy level of the airplane. Steffen (2008, 2012) presented the most time-saving strategy by applying a Markov Chain Monte Carlo optimization algorithm. Tang et al. (2012) explored the dynamic properties of passengers' motions in enplaning process with consideration of passengers' individual properties. Milne and Kelly (2014) and Qiang et al. (2014) emphasized the importance of luggage storage space and passengers were assigned to seats based on the number of luggage they carried.

Apart from the simulation studies, new strategies are also proposed by using linear or nonlinear programming approaches, based on a basic assumption that a minimization of the number of interferences leads to a minimal enplaning time (Bazargan, 2007; Soolaki et al., 2012). Moreover, physicists have analyzed the impact of passenger sequential disorder on the scaling behavior of airplane enplaning time, in the context of a particle system with distinguishable particles on a substrate (Frette and Hemmer, 2012; Brics et al., 2013; Baek et al., 2013). Bachmat et al. (2009) used space-time geometry and random matrix theory to analyze the relation between the efficiency of various airline enplaning strategies and interior airplane design parameters.

Comparing with enplaning studies, the topic of deplaning is relatively new. To our knowledge, there are only a few papers discussing this process. For instance, Yuan et al. (2007) proposed a deplaning model and developed a new inside-out deplaning strategy for midsize and large airplanes. Wald et al. (2014) studied how to minimize the deplaning time by using deplaning group assignments. Unique features of deplaning process have been taken into account, e.g., the retrieving of carry-on bags and the interferences of passengers.

Nevertheless, we would like to point out that present studies investigated enplaning and deplaning separately. Therefore, potential optimization might be achieved by considering the enplaning and deplaning processes integratedly. Moreover, in present studies, little attention has been paid to the individual experience of passengers. Motivated by the above facts, this paper proposes a cellular automaton model to study the enplaning and deplaning processes in an integrated way. A symmetrical design of deplaning strategies to match three typical enplaning strategies has been presented. In particular, the individual experience of passengers has been evaluated.

The remainder of the paper consists of four sections. Section 2 surveys the common practically used enplaning strategies, and proposes the matched deplaning strategies for each of enplaning strategies. Section 3 presents a cellular automaton model integrating both enplaning and deplaning processes. Section 4 performs extensive evaluation of the proposed strategies from the perspective of airlines and passengers. Finally, section 5 summarizes the research findings and makes outlooks for future research.

## 2. Strategies

Fig. 1 illustrates the four typical enplaning maps, including the random, back-to-front (BF), windows-to-aisle (WA) and reverse pyramid (RP). These strategies are employed by major airlines and their rules are summarized as follows.

(1) Random: Each passenger has an assigned seat, and enters into the airplane in an unstructured manner (see Fig. 1a). Examples of usage are American Airlines and US Airways.
(2) Back-to-Front: Passengers are divided into several groups and enplane in a back to front order, and passengers are essentially random in each group (see Fig. 1b). This strategy is widely used in, e.g., Delta, American Airlines, Spirit Airlines and Frontier Airlines.
(3) Windows-to-Aisle: United Airlines lets passengers enplane in an order of windows first, followed by the middle and aisle seats enplaning last. Within each group the passengers are essentially random (see Fig. 1c).
(4) Reverse Pyramid: US Airways (America West) used a hybrid method between the traditional back-to-front and outside-in enplaning strategies. Passengers enplane in a V-like manner with back windows and middle boarding first, followed by back aisle and front aisle (see Fig. 1d).

Since no airline adopts a deplaning strategy, passengers leave the airplane without any organization. Therefore, passengers with rear seats will wait for a long time to deplane. It will be unfair for them if they have suffered a long waiting time when enplaning. An ideal order should be that passengers are organized as enplaning first and deplaning later. Furthermore, it has been proved by Wald et al. (2014) that a structured deplaning strategy may reduce the deplaning time. Based on these facts, we proposed a series of matching structured deplaning strategies by considering their enplaning strategies. Passengers are divided into groups according to their enplaning orders and deplane with a basic principle that the first enplaning group will be the last to leave, much like a “stack” system. The rules are summarized respectively as follows.

(1) Front-to-Back: Passengers are divided into several groups and deplane in a front to back order.
(2) Aisle-to-Windows: Passengers with aisle seats deplane first; once those ones have fully deplaned, passengers with middle seats deplane, followed by passengers with window seats.
(3) Pyramid: Passengers deplane in a pyramid manner with front aisle and back aisle first, followed by middle and back windows.

The proposed strategies are listed by comparing with the originals, see Table 1.

## 3. Integrated simulation framework

This section develops an integrated simulation framework which captures inherent benefits of strategies without complicating the model with unsubstantiated assumptions. The airplane model is simple, describing a typical narrow body, single aisle airplane with 150 seats, divided into 25 rows and 6 seats per row, just like airplanes of the Airbus 320 family or the Boeing 737. For simplicity, we assume that passengers do not know each other, thus they enplane and deplane individually. We further assume that passengers do not try to overtake other passengers, which is reasonable in a narrow cabin aisle.

The cabin is represented by a rectangular array comprised of a set of cells, see Fig. 2. Each cell represents a space, either seat or aisle, which can be occupied by only one passenger at a time. The size of the cell is 0.8 m in length (0.4 m of the length of seat and 0.4 m of leg room in the front of seat) and 0.4 m in width. The seats are indicated by letters from A to F and the rows are numbered from 1 in the front to 25 in the rear of airplane.

### 3.1. Passenger enplaning model

Enplaning starts when the first passenger starts to check his ticket and ends when the last passenger is seated. Activities that influence passengers' experiences in enplaning include lining up in front of the gate, ticket validation, walking in the cabin, stowing of