Hindawi
Journal of Advanced Transportation
Volume 2019, Article ID 8908935, 12 pages
https://doi.org/10.1155/2019/8908935

Research Article

An Extended Boarding Strategy Accounting for the Luggage Quantity and Group Behavior

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Received 15 November 2018; Accepted 16 January 2019; Published 3 February 2019

Academic Editor: Zhi-Chun Li

The reasonable boarding strategy can enhance the efficiency, so how to enhance the boarding efficiency has been a hot topic in the air transportation. In this paper, we incorporate the luggage quantity and the passenger's group behavior into the boarding model, and develop an extended strategy to explore each passenger's boarding behavior and the influences of the proposed strategy on the boarding efficiency. The numerical results indicate that the proposed strategy can relieve the congestions at the wicket and in the cabin, eliminate the seat conflicts, and reduce the time of handling luggage and the boarding time. This shows that the proposed strategy can enhance the boarding efficiency. The results can help administrators organize the boarding pattern to enhance the efficiency.

1. Introduction

Boarding strategy has great impacts on the efficiency, which has attracted researchers to study how to enhance the efficiency. Beuselinck [1] studied the boarding mechanisms and used numerical results to define some excellent boarding patterns. Landeghen and Beuselinck [1] developed a strategy to reduce the boarding time. Nagel and Ferrari [2] sorted the passengers into three groups and developed a boarding strategy (called the Wilma strategy in [3]), where the passengers with A and F seat are the first group, the ones with B and E seat are the second group, and the ones with C and D seat are the third group (note: in the Wilma strategy, the passenger's order in each group is randomly generated). Briel et al. (2005) proposed a strategy (called the reverse pyramid). Bazargan [4] used linear programming to develop a strategy. Bachmat and Elkin [5] explored the performance of the BF (back-to-front) strategy. Nyquist and McFadden [6] developed a most cost-effective way to board passengers. Steffen [7] used the Markov Chain Monte Carlo optimization algorithm to design an optimal strategy (called the Steffen strategy), which was validated by some experimental data [3]. Soolaki et al. [8] developed linear programming to reduce the boarding time and used a genetic algorithm to solve the linear programming, where the numerical results showed that the proposed strategy can reduce the number of seat conflicts. Milne and Kelly [9] adopted the seat assignment to design a strategy that can reduce the boarding time. Qiang et al. [10] applied the luggage quantity to assign the passenger's seat and design a boarding strategy. Milne and Salari [11] applied the luggage quantity to assign the seat No. and design an optimal strategy. Notomista [12] used the online seat assignment to develop a fast boarding strategy. Qiang et al. [13] proposed a CA (cellular automaton) model to study the boarding process. Schultz [14] used the real-time evaluation to design a strategy, which was testified by some field data during the boarding process [15]. Zeineddine [16] developed a dynamic optimal boarding strategy. Hutter et al. [17] used some empirical data at a large European airport to study the impacts of some special factors (e.g., the number of passengers, the capacity of the air- plane, and the quantity of baggage) on the boarding time. Ren and Xu [18] used an experiment to classify the seat conflicts and aisle conflicts during the boarding process. In addition, Schultz [19] implemented the boarding model [15] during the real boarding process.

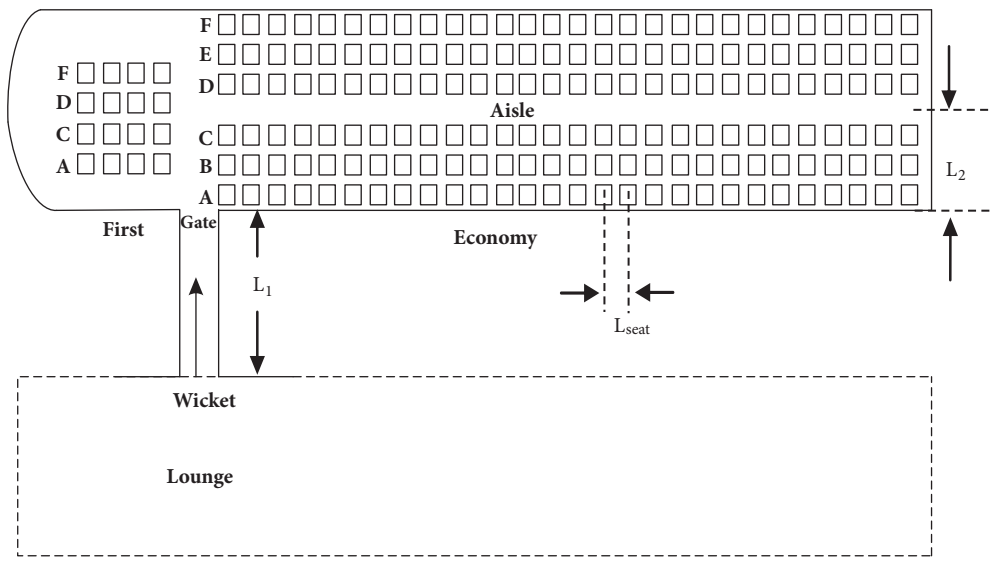

Figure 1: The scheme of an aircraft during the boarding process.

The above studies focused on exploring how to enhance the efficiency, so the impacts of strategies on each passenger's motion during the boarding process were not studied. To depict the passenger's motion, Tang et al. [20] proposed a pedestrian-following model to explore each passenger's boarding behavior; Tang et al. [21] introduced the passenger's individual property into the boarding model and proposed a model to study the impacts of the individual property on the passenger's motion behavior; Tang et al. [22] proposed a model to explore the effects of group behavior on the passenger's motion behavior and the boarding efficiency, and later they further studied the effects of the luggage quantity on the passenger's motion behavior and the boarding efficiency [23].

However, Tang et al. [23] did not introduce the luggage quantity and group behavior into the strategy. In fact, the two factors may be considered when the administrators organize the boarding process. Hence, how to optimize the two factors directly influence the boarding efficiency. In this paper, we propose an extended strategy accounting for the luggage quantity and group behavior to study each passenger's motion behavior and the effects of the proposed strategy on the efficiency. The boarding model [23] considered the quantity of luggage and the group behavior, but it did not design a boarding strategy according to the two factors, so Tang et al. [23] did not validate whether the two factors optimize the boarding strategy. The proposed strategy considers the two factors, and the numerical results show that the efficiency under the proposed strategy is prominently greater than the one under the model [23], so the proposed strategy is reasonable. Comparing with the strategies, the proposed strategy can reproduce the effects of the quantity of luggage and the group behavior on the efficiency since other strategies did not consider the two factors. The rest of this paper is organized as follows: the boarding strategies and models are introduced in Section 2; some numerical tests are conducted to study each passenger's motion behavior under the proposed strategy and the effects of the proposed strategy on each passenger's motion behavior and the boarding efficiency in Section 3; and some conclusions are summarized in Section 4.

2. Strategy and Model

In this section, we design an optimal strategy with the quantity of luggage and the group behavior to study each passenger's boarding behavior and the efficiency. Before designing the strategy, we should first give the following assumptions:

(i) The aircraft has 150 seats, a gate, and an aisle; the seat Nos. are, respectively, 1A-1F, ..., 25A-25F; the distance between two rows of seats is L_{seat}; the distance between the gate and the wicket is L_1; the distance between the gate and the aisle is L_2 (see Figure 1).

(ii) We only explore the passengers' boarding behavior in the economic cabin, where the 150 passengers' Nos. are, respectively, 1, 2, ..., 150; the 150 passengers immediately queue at the wicket when they hear the boarding information; each passenger's initial headway and the initial distance between the first passenger and the wicket are 0.2m; each passenger's seat No. is defined based on the boarding strategy.

(iii) Each passenger's behavior can include six steps, i.e., (1) queuing, (2) checking-in, (3) moving in the channel between the gate and the wicket, (4) moving in the cabin, (5) handling the luggage, and (6) seating.

(iv) Each passenger has 0-2 pieces of luggage, where $\rho_0, \rho_1, \rho_2 (\rho_0 + \rho_1 + \rho_2 = 1)$ are, respectively, the corresponding proportions. Milne and Kelly [9] gave 10 cases (see Table 1), but Qiang et al. [13] validated that that Case 6 is more accordant with the reality, so we use Case 6 in this paper.

In order to highlight the merit of the proposed strategy, we should introduce the random strategy, BF strategy, Wilma

Table 1: The distributions of the quantity of luggage.

	ρ_0	ρ_1	ρ_2
Case 1	100%	0%	0%
Case 2	70%	30%	0%
Case 3	60%	30%	10%
Case 4	50%	40%	10%
Case 5	30%	50%	20%
Case 6	20%	60%	20%
Case 7	10%	60%	30%
Case 8	10%	40%	50%
Case 9	10%	20%	70%
Case 10	0%	0%	100%

Table 2: The scheme of the BF strategy [5].

			Front			
25	25	25		25	25	25
24	24	24		24	24	24
23	24	23		23	23	25
	...		Aisle		...	
3	3	3		3	3	3
2	2	2		2	2	2
1	1	1		1	1	1

Table 3: The scheme of the Wilma strategy [2].

			Front			
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1
	...		Aisle		...	
1	2	3		3	2	1
1	2	3		3	2	1
1	2	3		3	2	1

strategy, and Steffen strategy, which can be expressed as follows:

(1) Random: Each passenger's seat No. is randomly assigned; i.e., the 150 passengers are randomly seated at 1A-1F, 2A-2F, ..., 25A-25F.

(2) BF strategy: The boarding order is defined in Table 2, where i denotes the *i*th row seat from back to front, the passengers' Nos. in the *i*th row are (i-1)∗6+1, (i-1)∗6+2, ..., (i-1)∗6+6, and the passenger's No. in each row is randomly distributed.

(3) Wilma strategy: The 150 passengers are divided into three groups (see Table 3). In this strategy, i denotes the ith group of passengers, where the passengers' Nos. in the *i*th group are, respectively, (i-1)∗50+1, (i-1)∗50+2, ..., (i-1)∗50+50, and the passenger's No. in each group is randomly distributed.

(4) Steffen strategy: The 150 passengers are divided into six groups, where the boarding order is shown in Table 4.

The above strategies focused on reducing the boarding time, so they did not explore the effects of strategy on each passenger's motion during the boarding process. Each passenger's motion during the boarding process may include six steps and the quantity of luggage and the group behavior may have impacts on each passenger's motion at each step. Therefore, how to incorporate the quantity of luggage and the group behavior into the strategy and optimize the strategy may have significant impacts on each passenger's motion and the boarding efficiency. Before proposing the optimal strategy, we should divide the impacts of the quantity of luggage and the group behavior into two situations as follows:

(1) The quantity of luggage and the group behavior have impacts on the passengers' queue structure at the wicket and each passenger's boarding behavior (including the velocity and the check-in efficiency). Therefore, the efficiency can be enhanced if we reasonably arrange each passenger's No. according to the quantity of luggage and the group behavior. At this time, the passengers' queue structure in the lounge is an important factor that has significant impacts on the boarding efficiency. Hence, we should reasonably arrange the passengers' queue structure. As for the passengers whose

Table 4: The scheme of the Steffen strategy [7].

			Front			
26	76	126		113	63	13
50	100	150		138	88	38
25	75	125		112	62	12
	...		Aisle		...	
15	65	115		102	52	2
39	89	139		127	77	27
14	64	114		101	51	1

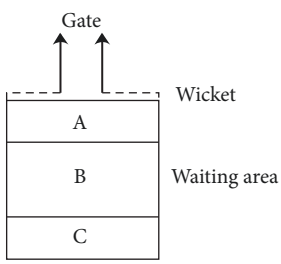

Figure 2: The three areas in front of the wicket.

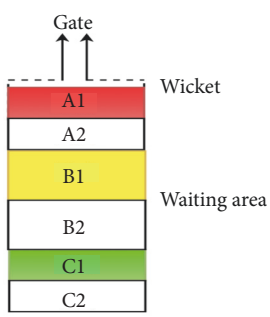

Figure 3: The subareas in front of the wicket.

speeds are slow, their trajectories should be short; otherwise, their travel time is long. Each passenger has 0-2 pieces of luggage and the quantity of luggage has impacts on each passenger's speed [13, 23]. First, we can sort the passengers into three groups, where the passengers with 2 pieces of luggage are arranged in the A area, the ones with 1 piece of luggage are arranged in the B area, and the ones without luggage are arranged in the C area (see Figure 2). The group behavior has effects on each passenger's motion [22, 23], so each area should further be sorted into two subareas, i.e., A1, A2, B1, B2, C1, and C2, where the passengers in A1, B1, and C1 have group behavior and those in A2, B2, and C2 have no group behavior (see Figure 3).

(2) The group behavior has impacts on the seat assignment [22, 23], which may have effects on each passenger's motion in the cabin since unreasonable seat assignment produces some seat conflicts [21]. Likely, the group behavior and the quantity of luggage have effects on each passenger's motion in the cabin. Hence, the efficiency can be enhanced if we reasonably assign each passenger's seat based on the quantity of luggage and the group behavior. Here, we divide the cabin into six areas, where I-VI correspond to A1, A2, B1, B2, C1, and C2, respectively (see Figure 4). Each passenger's seat in I, III, and V is assigned based on the rules defined by Tang et al. [22, 23], and each passenger's seat in III, V, and VI is assigned based on the rules defined by Tang et al. [21]. The detailed rules are shown in Figure 4.

Finally, we introduce the boarding model. Tang et al. [20–23] pointed out that the pedestrian-following model can be used to study each passenger's motion during boarding process. For simplicity, we in this paper use the boarding model [21] to depict each passenger's motion during the boarding process, i.e.,

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

where $v_n, \Delta x_n, \Delta v_n$ are, respectively, the nth passenger's speed, headway, and relative speed (note: $\Delta\overline{x}_1$ is the distance between the first passenger and his/her destination); $\alpha_n, \lambda_{1,n}, \lambda_{2,n}$ are three reaction coefficients related to the nth passenger's individual features; p_n is the probability that the nth passenger is interrupted; and V is the optimal velocity without the quantity of luggage. Tang et al. [21] defined p_n as follows:

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

F	49	47	45	43	41	39	37	35	33	31	29	27	25	23	21	19	17	15	13	11	9	7	5	3	1
E	99	97	95	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	61	59	57	55	53	51
D	149	147	145	143	141	139	137	135	133	131	129	127	125	123	121	119	117	115	113	111	109	107	105	103	101
	VI		V			IV						III									II		I		
C	150	148	146	144	142	140	138	136	134	132	130	128	126	124	122	120	118	116	114	112	110	108	106	104	102
B	100	98	96	94	92	90	88	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56	54	52
A	50	48	46	44	42	40	38	36	34	32	30	28	26	24	22	20	18	16	14	12	10	8	6	4	2

Figure 4: The seat assignment rules in the cabin.

where t_n^1 is the time when the nth passenger arrives at the wicket; T_n^1 is the nth passenger's delay time at the wicket; t_n^2 is the time when the nth passenger gets to his/her seat; and T_n^2 is the nth passenger's delay time at his/her seat.

$V(\Delta x_n)$ can be defined as follows [21]:

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

where v_{max} is the maximum speed and h_c is the safety distance.

Tang et al. [23] pointed out that the quantity of luggage and the group behavior have great effects on each passenger's boarding behavior and that the passengers in a group would reassign their luggage. Hence, Tang et al. [23] defined the nth passenger's virtual quantity of luggage as follows:

$$l_n^v = \begin{cases} l_n, & \text{if the passenger has no group behavior} \\ \dfrac{\sum l_i}{k}, & \text{if the passenger in the group and } \dfrac{\sum l_i}{k} = 0, 1, 2 \\ \left[\dfrac{\sum l_i}{k_i}\right] + 1, & \text{otherwise,} \end{cases} \quad (4)$$

where l_n^v is the nth passenger's virtual quantity of luggage; l_n is the nth passenger's initial quantity of luggage; and k is the group size.

Van Landeghem and Beuselinck [1] sorted T_n^1 into the nth passenger's passing time and delay time at the wicket. Tang et al. [23] pointed out that the quantity of luggage and the group behavior have effects on each passenger's motion at the wicket, so they defined T_n^1 as follows:

$$T_n^1 = \begin{cases} T_n^{check} + T_n^{pass} + T^{gap} \cdot l_n^v, & \text{if the passenger has no group behavior} \\ T_n^{check} + T_n^{pass} + T^{gap} \cdot l_n^v, & \text{if the passenger is the first one in a group} \\ T_n^{pass} + T^{gap} \cdot l_n^v, & \text{otherwise,} \end{cases} \quad (5)$$

where T_n^{check} is the nth passenger's check-in time; T_n^{pass} is the minimum time at which the nth passenger runs across the wicket; and T^{gap} is one parameter related to the quantity of luggage.

Using the same method (Qiang et al., 2016a; [23]), $T_n^{check}, T_n^{pass}, T^{gap}$ can be defined as follows:

$$\begin{aligned} T_n^{check} &= 2\text{s}, \\ T_n^{pass} &= 2.4\text{s}, \\ T^{gap} &= 0.6\text{s}. \end{aligned} \quad (6)$$

Zhao et al. (2015) used experimental data to testify that the quantity of luggage has great impacts on each passenger's speed; i.e., the speed of the passenger with one piece of luggage approximately drops by 1/4 and that of the passenger with two pieces of luggage approximately drops by 1/2. Thus, $V_n(\Delta x_n)$ can be defined as follows:

$$V_{n,l}(\Delta x_n) = \begin{cases} V(\Delta x_n), & \text{if } l_n^v = 0 \\ \dfrac{3}{4}V(\Delta x_n), & \text{if } l_n^v = 1 \\ \dfrac{1}{2}V(\Delta x_n), & \text{if } l_n^v = 2, \end{cases} \quad (7)$$

where $V_{n,l}(\Delta x_n)$ is the nth passenger's optimal speed with the quantity of luggage.

As for the passengers with group behavior, their optimal speeds are often determined by the slowest passenger in the group. Thus, Tang et al. [23] assumed that each passenger in a group has the same optimal speed; i.e.,

$$V_{l,g} = \min\{V_{n,l}(\Delta x_n)\}, \quad (8)$$

where the nth passenger has group behavior.

Thus, we can simply define the nth passenger's real optimal speed as follows:

$$V_{\mathrm{n,r}}(\cdot) = \begin{cases} V_{\mathrm{n,l}}(\cdot), & \text{if the nth passenger has no group behavior} \\ V_{l,g}(\cdot), & \text{if the nth passenger has group behavior.} \end{cases} \quad (9)$$

Tang et al. [20–23] pointed out that T_{n}^{2} includes two parts; i.e.,

$$T_{\mathrm{n}}^{2} = T_{\mathrm{n}}^{\mathrm{store}} + T_{\mathrm{n}}^{\mathrm{seat}}, \quad (10)$$

where $T_{\mathrm{n}}^{\mathrm{seat}}$ is the nth passenger's delay time caused by the seat conflict and $T_{\mathrm{n}}^{\mathrm{store}}$ is the time of the nth passenger's handling luggage, which is defined as follows [23]:

$$T_{\mathrm{n}}^{\mathrm{store}} = \begin{cases} a_0 + \dfrac{a_1 l_{\mathrm{n}}}{[(a_2+1)-(l_{\mathrm{e}}+l_{\mathrm{n}})]}, & \text{under } \mathrm{CI_n} \\ \displaystyle\sum_{\mathrm{i}=1}^{\mathrm{k_i}} \left(\left(a_0 + \dfrac{a_1 l_{\mathrm{i}}}{[(a_2+1)-(l_{\mathrm{e}}+l_i)]} \right) - a_0 (\mathrm{k_i}-1) \right), & \text{under } \mathrm{CII_n} \\ 0, & \text{under } \mathrm{CIII_n}, \end{cases} \quad (11)$$

where a_0 is the minimum time of handling luggage; a_1 is a coefficient that is related to the luggage; a_2 is the rack capacity; l_{e} is the quantity of luggage stored in the rack; $\mathrm{k_i}$ is the ith group's size; $\mathrm{CI_n}$ indicates that the nth passenger has no group behavior and $l_{\mathrm{n}} > 0$; $\mathrm{CII_n}$ indicates that the nth passenger is the last one in a group and the total quantity of luggage in the group is larger than 0; and $\mathrm{CIII_n}$ denotes other cases. Note: $0 \le l_{\mathrm{e}} + l_{\mathrm{n}} \le a_2$.

Some seat conflicts occur during the boarding process and the seat conflicts cause delay time [2, 20–23]. Based on the above discussions, $T_{\mathrm{n}}^{\mathrm{seat}}$ can be defined as follows [13]:

$$T_{\mathrm{n}}^{\mathrm{seat}} = \begin{cases} T_{\mathrm{c}} + 2T_{\mathrm{c}} y_{\mathrm{n}}, & \text{if the nth passenger has no group behavior} \\ 0, & \text{if the nth passenger has group behavior,} \end{cases} \quad (12)$$

where T_{c} is the minimum delay time that is caused by a seat conflict and y_{n} is the number of seat conflicts.

Finally, other parameters are defined as follows [23]:

$$\begin{aligned} \alpha_{\mathrm{n}} &= 1, \\ \lambda_{1,\mathrm{n}} &= 0.5, \\ \lambda_{2,\mathrm{n}} &= 0.2, \\ v_{\max} &= 0.5\mathrm{m/s}, \\ h_{\mathrm{c}} &= 0.5\mathrm{m}, \\ L_1 &= 100\mathrm{m}, \\ L_2 &= 1.5\mathrm{m}, \\ L_{\mathrm{seat}} &= 0.8\mathrm{m}, \\ a_0 &= 2, \\ a_1 &= 11, \\ a_2 &= 6, \\ T_{\mathrm{C}} &= 2s. \end{aligned} \quad (13)$$

3. Numerical Tests

In this section, we simulate each passenger's boarding behavior and the influences of the proposed strategy on the efficiency. Before conducting the numerical tests, we should give the discretization scheme of (1). It is difficult to obtain the analytical solution of (1), so we should use numerical scheme to discretize (1). (1) are many numerical schemes, but the schemes have no qualitative impacts on the numerical results and the quantitative impacts are beyond the scope of this paper, so we use the Euler difference to discretize (1); i.e.,

$$v_{\mathrm{n}}(t+\Delta t) = v_{\mathrm{n}}(t) + \Delta t \cdot \frac{\mathrm{d}v_{\mathrm{n}}(t)}{\mathrm{d}t}, \quad (14a)$$

$$x_{\mathrm{n}}(t+\Delta t) = x_{\mathrm{n}}(t) + v_{\mathrm{n}}(t) \cdot \Delta t + \frac{1}{2}\frac{\mathrm{d}v_{\mathrm{n}}(t)}{\mathrm{d}t} \cdot (\Delta t)^2, \quad (14b)$$

where Δt is the time-step length and $x_{\mathrm{n}}(t)$ is the nth passenger's position at t. Note: the last passenger's initial position is the origin of x-axis in this paper.

First, we study each passenger's trajectory in the cabin during the boarding process (see Figure 5). From Figure 5, we have the following:

(1) Under the random strategy, each passenger randomly gets to his/her seat and is seated (see Figure 5(a)).

(2) Each passenger reaches his/her seat and is seated based on the given order under the BF/Wilma strategy (see Figures 5(b) and 5(c)).

(3) The passengers are sorted into two groups in the cabin, and each group of passengers arrive at their seats and are seated according to the given order under the Steffen strategy (see Figure 5(d)).

(4) The passengers are sorted into three groups in the cabin and each group is sorted into two subgroups; the passengers in each subgroup reach their seats and are seated based on the given order under the proposed strategy (see Figure 5(e)).

(5) Comparing with the random strategy, no congestion occurs in the cabin under other 4 strategies, which shows that other 4 strategies can eliminate the congestion in the cabin.

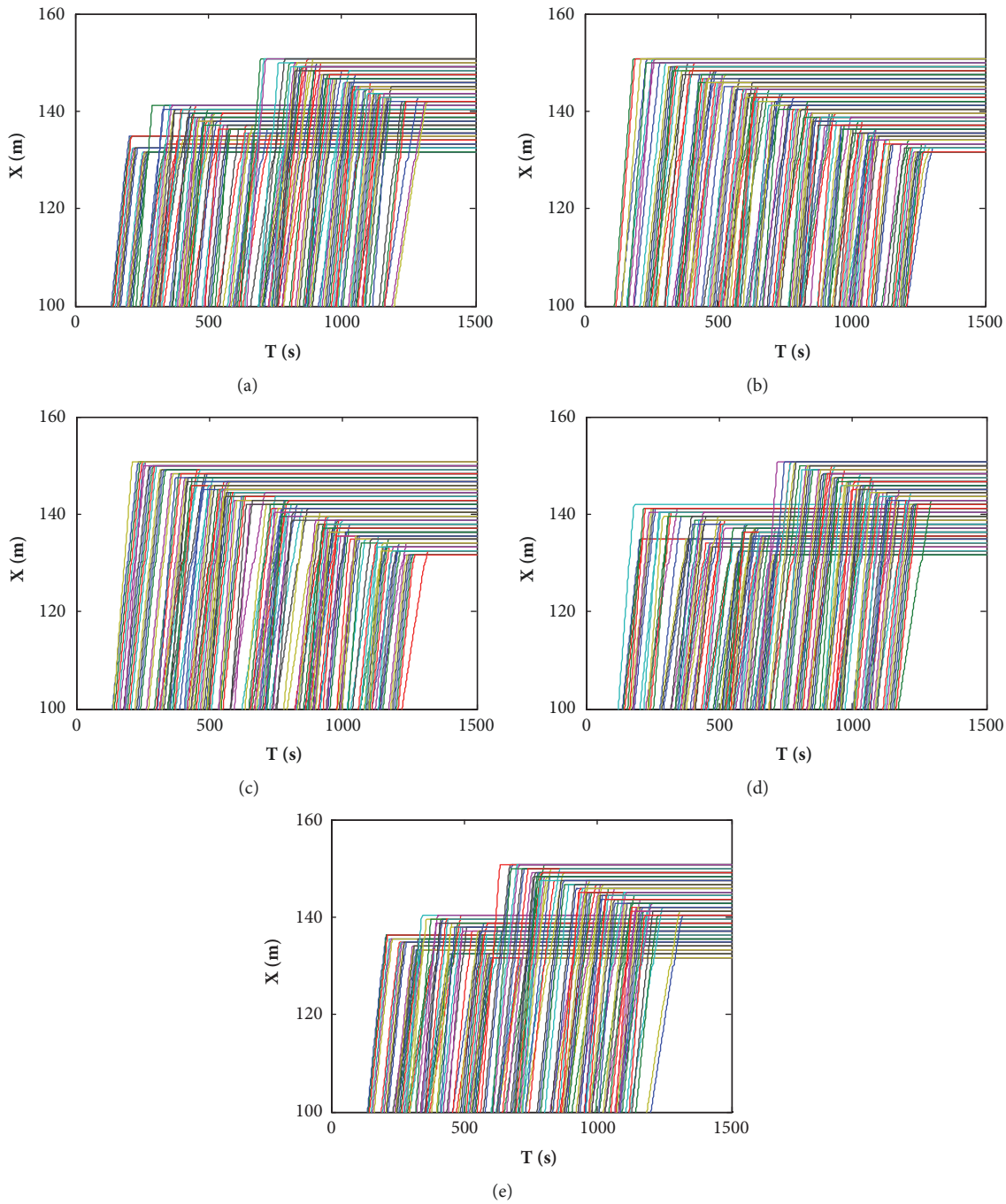

Figure 5: Each passenger's trajectory during the boarding process, where (a)-(e) are, respectively, the random strategy, BF strategy, Wilma strategy, Steffen strategy, and proposed strategy.

As for Figure 5(d), we here give the following note: group behavior destroys the distribution of the passengers' seat Nos. under the Steffen strategy and the passengers' seats in each group should be in the same row. It is the group behavior that sorts the passengers' trajectories in the cabin into two groups; i.e., one group corresponds to the trajectories of the passengers without group behavior and the other group corresponds to that of the passengers with group behavior.

Next, we study the number of seat conflicts occurring during the boarding process. Figure 6 displays the numbers of one seat conflict and two seat conflicts under each strategy. From this figure, we can conclude the following findings:

(1) Seat conflicts always occur under the random, BF, Wilma, and Steffen strategies (see Figure 6), while no seat conflict occurs under the proposed strategy (i.e., the numbers of two seat conflicts and one seat conflict are both zero). This shows that only the proposed strategy can completely

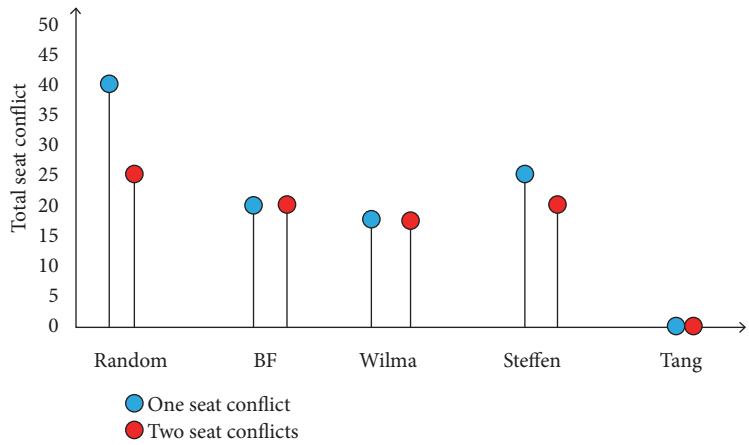

Figure 6: The number of seat conflicts under the random, BF, Wilma, Steffen, and proposed strategies.

eliminate the seat conflict, i.e., the proposed strategy can enhance the efficiency.

(2) The number of seat conflicts under the random strategy is largest, the number of seat conflicts under the Steffen strategy is slightly greater than the one under the BF strategy, and the number of seat conflicts under the Wilma strategy is slightly lower than the one under the BF strategy.

(3) The number of one seat conflict is prominently greater than that of two seat conflicts under the random strategy, the number of one seat conflict is slightly greater than that of two seat conflicts under the Steffen strategy, and the number of one seat conflict is approximately equal to that of two seat conflicts under the BF and Wilma strategies.

As for Figure 6, we should give the following notes:

(i) Group behavior exists and the passengers' seats must be in the same row, so the group behavior has changed the distribution of each passenger's seat No. (especially the passengers with group behavior) under the Wilma and Steffen strategies. If no group behavior occurs, no seat conflicts occur under the two strategies; but if group behavior occurs, some seat conflicts occur.

(ii) Group behavior widely exists. However, Figure 6 shows that only the proposed strategy can completely eliminate the seat conflicts, which further indicates that the proposed strategy is reasonable and can enhance the boarding efficiency.

Next, we define each passenger's total delay time during the boarding process; i.e.,

$$T_{\mathrm{n}}^{\mathrm{delay}} = T_{\mathrm{n}}^{1} + T_{\mathrm{n}}^{2}, \tag{15}$$

where $T_{\mathrm{n}}^{\mathrm{delay}}$ is the nth passenger's total delay time that occurs during the boarding process.

Thus, we can obtain $T_{\mathrm{n}}^{\mathrm{delay}}$ (see Figure 7). From Figure 7, we have the following:

(1) $T_{\mathrm{n}}^{\mathrm{delay}}$ causes oscillations under each strategy, but the amplitudes under the random, BF, and Steffen strategies are prominently larger than the ones under the Wilma and proposed strategies, which shows that the Wilma and proposed strategies have weaker negative effects on the efficiency than the other three strategies.

(2) The oscillation frequency under the proposed strategy is less than the ones in other strategies; the oscillation frequency under the Wilma strategy is less than the ones under other strategies; the oscillation frequencies under the BF and Steffen strategies have no prominent differences but are less than the one under the random strategy.

(3) If we calculate the 150 passengers' delay time, we can find that the proposed strategy can reduce the total delay time; i.e., the proposed strategy can enhance the efficiency.

The time of each passenger's motion during the boarding process is one important index used to evaluate the efficiency, so we should study this index under different strategy. For simplicity, we call the time of each passenger's motion 'the effective boarding time'. Before studying the effective boarding time, we first define each passenger's total boarding time; i.e.,

$$T_{\mathrm{n}}^{\mathrm{total}} = t_{\mathrm{n}}^{\mathrm{seated}} - t_{\mathrm{n},0}, \tag{16}$$

where $T_{\mathrm{n}}^{\mathrm{total}}$ is the nth passenger's time spent during the boarding process; $t_{\mathrm{n}}^{\mathrm{seated}}$ is the time at which the nth passenger is seated; and $t_{\mathrm{n},0}$ is the time at which the nth passenger starts to move.

Each passenger's effective boarding time can be defined as follows:

$$T_{\mathrm{n}}^{\mathrm{effective}} = T_{\mathrm{n}}^{\mathrm{total}} - T_{\mathrm{n}}^{\mathrm{delay}}, \tag{17}$$

where $T_{\mathrm{n}}^{\mathrm{effective}}$ is the nth passenger's effective boarding time.

Thus, we can simulate $T_{\mathrm{n}}^{\mathrm{effective}}$ under different strategies (see Figure 8). From Figure 8, we can conclude the following findings:

(1) Under each strategy, $T_{\mathrm{n}}^{\mathrm{effective}}$ increases with n and causes some slight oscillations that are caused by some stochastic factors.

(2) $T_{\mathrm{n}}^{\mathrm{effective}}$ under the proposed strategy is slightly less than those under other strategies. This indicates that the proposed strategy can reduce each passenger's effective boarding time, but the reduction is very limited. Hence, the effective method that enhances the efficiency is to reduce each passenger's delay time during the boarding process.

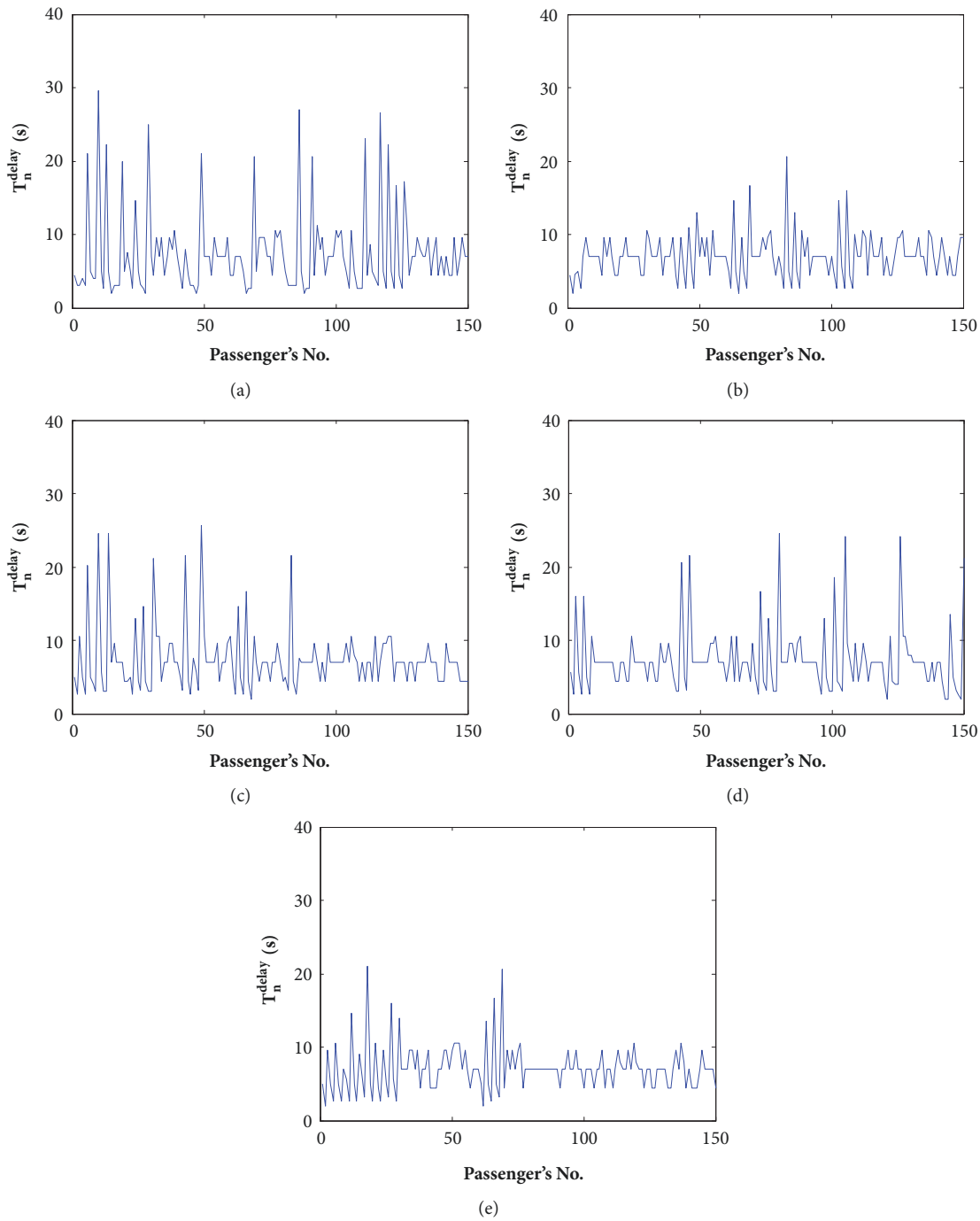

FIGURE 7: T_n^{delay} under different strategies during the boarding process, where (a)-(e) are, respectively, the random, BF, Wilma, Steffen, and proposed strategies.

Since the total boarding time is another index that can be used to evaluate the efficiency, we finally simulate this index under different strategies. To display the merits of the proposed strategy, we here give the following assumptions:

(1) The group size in the following numerical tests is 3 and the seat Nos. in each group are, respectively, A-C or D-F.

(2) The number of groups is defined as a parameter and we simulate the impacts of the parameter on the boarding time under different strategies.

Thus, we can obtain the relationships between the total boarding time and the number of groups under different strategies (see Figure 9). From Figure 9, we have the following:

(1) The total boarding time drops with the number of groups under each strategy; i.e., the group behavior has positive effects on the total boarding time under each strategy. Hence, the group behavior should be encouraged if each passenger can obey the boarding rules.

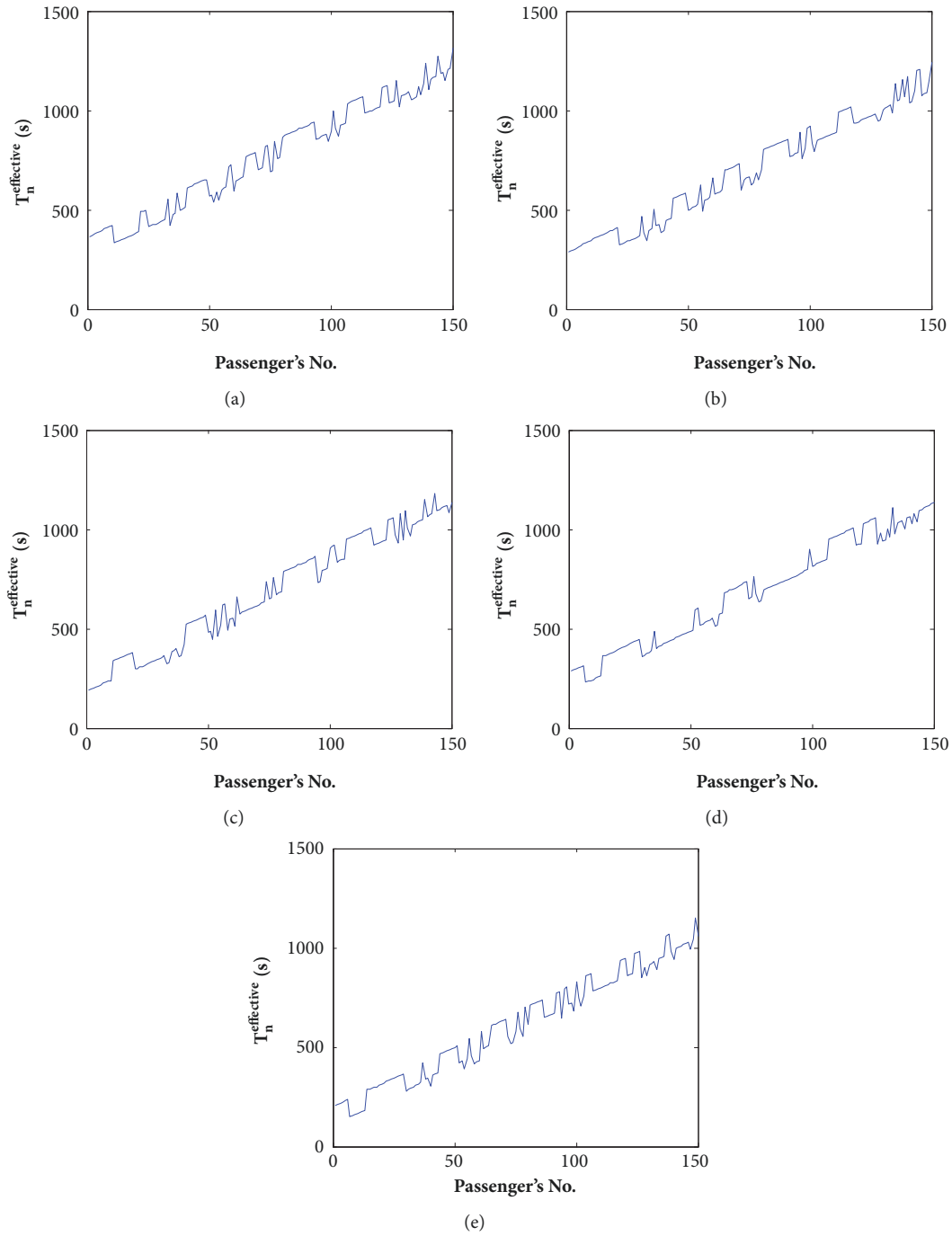

FIGURE 8: $T_n^{effective}$ under different strategies during the boarding process, where (a)-(e) are, respectively, the random, BF, Wilma, Steffen, and proposed strategies.

(2) The total boarding time under the proposed strategy is the smallest and the difference turns more prominent with the number of groups, which indicates that the proposed strategy is better than other strategies and can enhance the efficiency.

4. Conclusions

Although many models have been proposed to study the boarding problem, most of them focused on proposing strategies to enhance the boarding efficiency, so they did not study each passenger's motion. To describe each passenger's motion during the boarding process, Tang et al. [20, 21] proposed two boarding models, recently introduced the group behavior and the quantity of luggage into the boarding process, and proposed two boarding models [22, 23], but they did not study the impacts of the two factors on the boarding strategy. In this paper, we first study the effects of the group behavior and the quantity of luggage on each passenger's

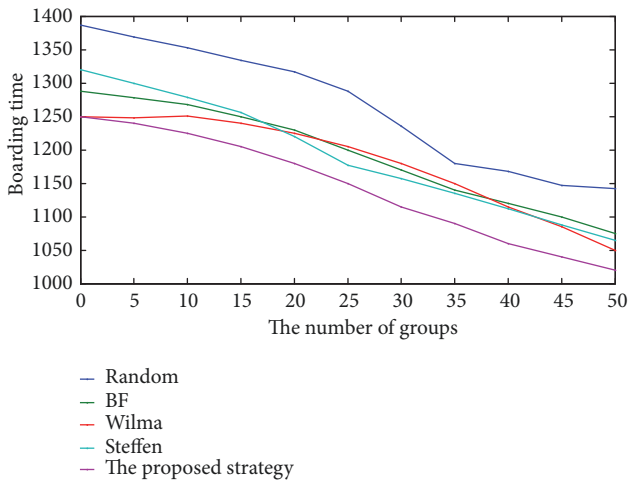

Figure 9: The total boarding time under the random, BF, Wilma, Steffen, and proposed strategies.

motion and then propose a strategy to study each passenger's boarding behavior. The numerical results illustrate that the proposed strategy can enhance the efficiency; i.e., the strategy can be encouraged if the administrator organizes the passengers to board based on the rules that we design in this paper.

However, the parameters and the numerical results are not calibrated by experimental or empirical data. In the future, we will use observed data to develop a more realistic model and strategy and explore the boarding process in which the group behavior exists. In addition, we will use the similar methods [24, 25] to study the boarding strategy and to propose some more realistic optimal boarding strategies.

Data Availability

The original codes of the numerical tests used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

This work was supported by the National Natural Science Foundation of China (71771005, 71422001, and 71271016).

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