

Experimental Study on Luggage-Laden Pedestrian Movement in a Narrow Seat Aisle

Shenshi Huang, Ruichao Wei, Siuming Lo, Shouxiang Lu

Abstract—The experiment of one-dimensional luggage-laden pedestrian movement in a narrow seat aisle was performed in this study, to investigate the hindrance effect of seat configuration on pedestrian flow. In a seat arrangement similar to a vehicle carriage, experiments of individual walking and single-file pedestrian flow were carried out, respectively. The result shows that carrying luggage has little effect on pedestrian walking ability. However, carrying large luggage such as trolley case can significantly increase the distance headway of pedestrians. It is also found that, although the pedestrian dynamic pattern in narrow seat aisle was similar to that in open environment, the randomness of the narrow seat aisle environment shows obviously greater.

Keywords—Luggage, pedestrian, seat aisle, walking.

I. INTRODUCTION

THE topic of the safe evacuation of a high-speed train car has received widespread attention. As for the passenger evacuation progress inside the car, luggage-laden passengers and narrow seat aisle are the two important obstructive factors. Previous studies [1], [2] had pointed out that pedestrians with luggage tend to walk slower and occupy a larger space when boarding and alighting, and this impact will be more serious when passengers pass through the narrow seat aisle.

Present studies on pedestrian evacuation of a seating area mostly focused on the evacuation time, egress rate, and occupant density. The pedestrian dynamic is rarely of concern. In the past years, researches on pedestrian dynamics focused on concern related to pedestrian walking ability [3], [4] and the interaction between individual pedestrians [5], [6]. It is pointed out that the pedestrian individual walking speed can be affected by many factors such as particularity of individuals, and environment. Also, when there are pedestrians walking, they will usually keep a certain distance between each other, meanwhile the movement speed will be affected by that of others. In order to better understand pedestrian evacuation of a seat area, it is necessary to analyze the pedestrian dynamic parameters in such an environment.

This study focuses on the movement of the luggage-laden

Shenshi Huang (PhD Candidate) is with the State Key Laboratory of Fire Science, University of Science and Technology of China. 230026, Hefei, China (corresponding author, phone: +86-18019934220; e-mail: kermi@mail.ustc.edu.cn).

Ruichao Wei (PhD Candidate) is with the State Key Laboratory of Fire Science, University of Science and Technology of China. 230026, Hefei, China (e-mail: rwei@mail.ustc.edu.cn).

Siuming Lo (Professor) is with the Department of Architecture and Civil Engineering, City University of Hong Kong. 999077, Kowloon, Hong Kong (e-mail: bcsml@cityu.edu.hk).

Shouxiang Lu (Professor) is with the State Key Laboratory of Fire Science, University of Science and Technology of China. 230026, Hefei, China.

pedestrian. Experiments of individual walking and single-file pedestrian flow are carried out in the narrow seat aisle, and the pedestrian walking speed and distance headway are analyzed. Based on the discussion of luggage impacts on pedestrian movement in the narrow seat aisle, this study will give the useful benchmark for evacuation simulation of similar scenarios as well as provide reference to safety design of new train cars.

II. EXPERIMENTAL CONDITIONS

The experimental set-up was similar to our previous studies [7], [8]. The impact of luggage on pedestrian movement was investigated by rearrange the seat and luggage configurations. Experiment was carried out in the multi-function room, and the aisle was set up using six seat rows with spacing of 1.0 m. The aisle width was fixed as 0.5 m, which is the most common width in vehicle cars. Pedestrians were asked to walk through this 5-meter-long seat aisle, carrying different kinds of luggage. All the trolley cases weight no more than 10 kg and all the bags weight no more than 5 kg. Normal walking and fast walking conditions were designed, to simulate

Cameras were set up to record the whole experiment process. By using the *PeTrack* [9], [10] software, the position of each pedestrian and the trajectories could be extracted, as illustrated in Fig. 1. Based on the measured position, the pedestrian walking speed, distance headway, and other parameters can be obtained.

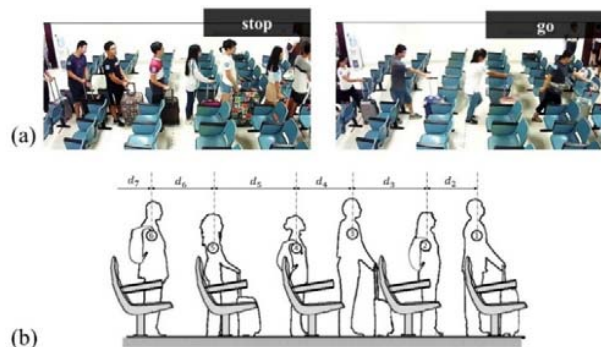


Fig. 1 (a) Images of the luggage-laden pedestrian movement in this experiment; (b) Illustration of the pedestrian motion in seat aisle and distance headway

This experiment includes two parts: individual pedestrian walking and single-file pedestrian movement. In the individual walking part, the pedestrian individual walking behaviors were measured. In the single-file pedestrian movement part, a “stop”

instruction and a “go” instruction were designed, and the interaction between luggage-laden pedestrians was observed. The detail of experimental conditions is listed in Table I. Moreover, two repetitions of each test case were performed, in order to reduce the randomness of results.

TABLE I
THE DETAIL OF EXPERIMENTAL CONDITIONS PEDESTRIAN MOVEMENT IN
NARROW SEAT AISLE

Case No.	Seat aisle width	Pedestrian type	Luggage
D1	0.50 m	individual	none
D2	0.50 m	individual	bag
D3	0.50 m	individual	trolley case
D4	0.50 m	single-file	none
D5	0.50 m	single-file	bag
D6	0.50 m	single-file	trolley case
D7	0.50 m	single-file	trolley case and bag
D8	0.50 m	single-file	G1 none + G2 bag
D9	0.50 m	single-file	G1 trolley case + G2 bag
D10	0.50 m	single-file	G1 trolley case + G2 none

G1: 50% of all participants, with the Pedestrian No. of 1, 3, 5, 7, 9, 12, 14, 16, 18, 20, 22, 24, 26;

G2: the other 50% of all participants, with Pedestrian No. of 2, 4, 6, 8, 10, 11, 13, 15, 17, 19, 21, 23, 25.

Similar to our previous studies, different methods were applied to the analysis of different pedestrian types. The individual walking parameters were measured as spatial mean values, representing the basic attributes of the pedestrians. On the other hand, the single-file walking parameters were described by instantaneous values, in order to present the whole

process of pedestrian movement under the action of instructions.

III. RESULTS AND DISCUSSIONS

A. Individual Pedestrian Movement

The average walking parameters of each individual in each test case is described in Fig. 2, where the mean values are shown as scatter points and the distributions are present by box chart.

It is clearly observed that, the bag has little impact on walking behaviors, no matter on walking speed, step size, and step frequency. Under normal walking condition, the pedestrians were able to walk at a speed of about 1.5 m/s on average, with about 0.7 m per step. Under fast walking condition, the pedestrian can walk at about 1.7 m/s, and the average step size increases to about 0.8 m. This result is not very different from that of open space [8]. However, in the case of the pedestrian carrying large luggage, the walking parameters would be much different. The statistical mean value of waking speed decreases and the variance increases significantly. Due to the obstructive effect of narrow aisle, pedestrians cannot easily carry the trolley case. The average walking speed was observed to be 1.2 m/s for normal walking and 1.6 m/s for fast walking cases. Besides, with carrying trolley case, the mean step size reduces to about 80% while the step frequency slightly increases. It indicates that carry large piece of luggage has a significant impact on pedestrian's walking ability.

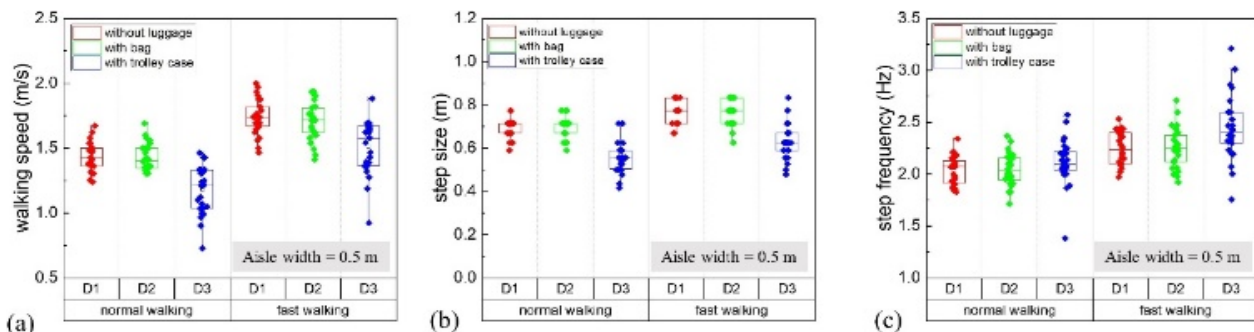


Fig. 2 Distribution of (a) average walking speed, (b) mean step size, and (c) step frequency of individual luggage-laden pedestrian walking through the seat aisle

B. Single-File Pedestrian Movement

The x-t curve of typical single-file pedestrian movement cases are shown in Fig. 3, where the instantaneous moving speed is represent by the slope and the distance headway of each pedestrian can be indicated by the difference in height of curve clusters. As seen from Fig. 3, the x-t curves are quite similar, which includes a three movement phase corresponding

to the designed instructions. In the first and the third phase, when the pedestrian queue was moving smoothly, the walking parameters such as maximum speed and distance headway were observed. In the second phase, when the pedestrians were lining up and waiting, the safety margin can be measured. Moreover, the propagation velocity of the action speed can also be calculated based on the curve offsets.

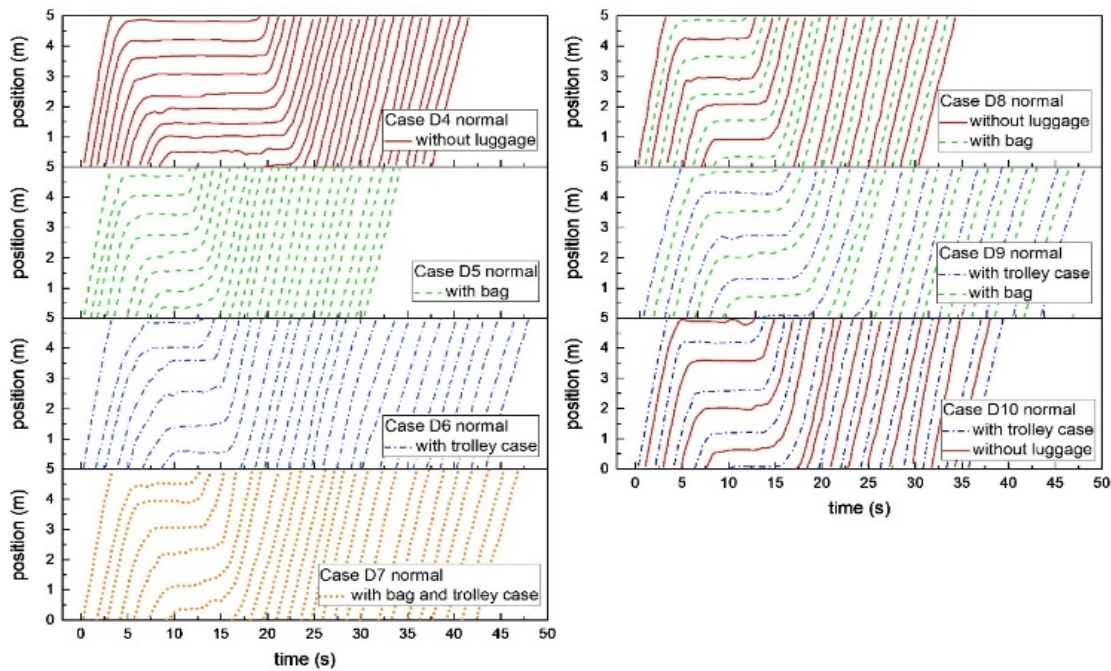


Fig. 3 The x-t curves of the luggage-laden single-file pedestrian movement in each test case

C. Impact of Narrow Seat Aisle

The summary of walking speed and distance headway has been listed in Tables II and III. The result shows that, when pedestrian queue moves through the narrow seat aisle (width = 0.5 m), they are able to walk at 1.33 - 1.51 m/s at normal speed condition and 1.63 - 1.77 m/s at fast speed condition, respectively. It is found that the luggage has little effect on reducing the walking speed, no matter if it is a bag or a trolley case. On the contrary, significant differences can be observed in distance headway. When pedestrians are walking down the aisle one by one, they used to keep a distance of about 1.25 m to their predecessor. Due to the fact that the size of bag is small, the increase in pedestrian spacing is not obvious. However, in the tests with large luggage (trolley case), the distance headway of each pedestrian individual increases by 0.4 - 0.5 m. This phenomenon can be more clearly observed in the cases of fast walking. In addition, it is also obtained from the curve that, when the pedestrians stop or start to walk, the average acceleration is about 0.62 m/s^2 for normal walking condition and 0.85 m/s^2 for fast walking condition, respectively. Carrying luggage is found to have little impact on acceleration.

TABLE II
SUMMARY OF MAXIMUM WALKING SPEED AND DISTANCE HEADWAY OF PEDESTRIANS IN A SEAT AISLE (WIDTH = 0.5 M)

Case No.	maximum speed (m/s)		distance headway (m)	
	normal	fast	normal	fast
D4	1.42	1.77	1.24	1.25
D5	1.41	1.73	1.29	1.29
D6	1.51	1.65	1.68	1.68
D7	1.33	1.67	1.74	1.79
D8	1.35	1.72	1.21	1.32
D9	1.38	1.71	1.46	1.59
D10	1.47	1.63	1.56	1.56
Average	1.41	1.70	1.45	1.50

TABLE III
SUMMARY OF MAXIMUM WALKING SPEED AND DISTANCE HEADWAY OF PEDESTRIANS IN AN OPEN ENVIRONMENT

Case No.	maximum speed (m/s)		distance headway (m)	
	normal	fast	normal	fast
E4	1.48	1.84	1.26	1.35
E5	1.49	1.77	1.28	1.31
E6	1.46	1.85	1.51	1.59
E7	1.42	1.91	1.47	1.65
E8	1.55	1.84	1.31	1.35
E9	1.44	1.91	1.34	1.48
E10	1.43	1.95	1.28	1.54
Average	1.47	1.87	1.35	1.47

By analyzing the instantaneous data of each pedestrian, a fundamental diagram can be obtained using the mean value of each experiment test case. The fundamental diagram can graphically show the relationship between pedestrian walking speed and occupant density.

As illustrated in Fig. 4 (a), the average safety margin of the pedestrians in such seat aisle is about 0.7 m. It means that the pedestrians are willing to move forward only when there is 0.7 m distance free space ahead. The slope of deceleration and acceleration phase curve is approximately 2.5 s^{-1} , which means that pedestrians may walk 2.5 m/s faster with every meter distance of greater headway. It is found that when the distance headway is larger enough, the speed will stabilize at the maximum. The critical distance can be 1.3 m for normal walking condition and 1.5 m for fast walking condition. Fig. 4 (b) shows the relationship of average walking speed and linear density, compared with previous study in open environment [8]. Based on the fact the curves are almost overlapping, it can be concluded that the pedestrian dynamic pattern of these cases

are similar. The scatter point of the seat aisle experiment is distributed more discrete, indicating that the randomness of

pedestrian behaviour is greater.

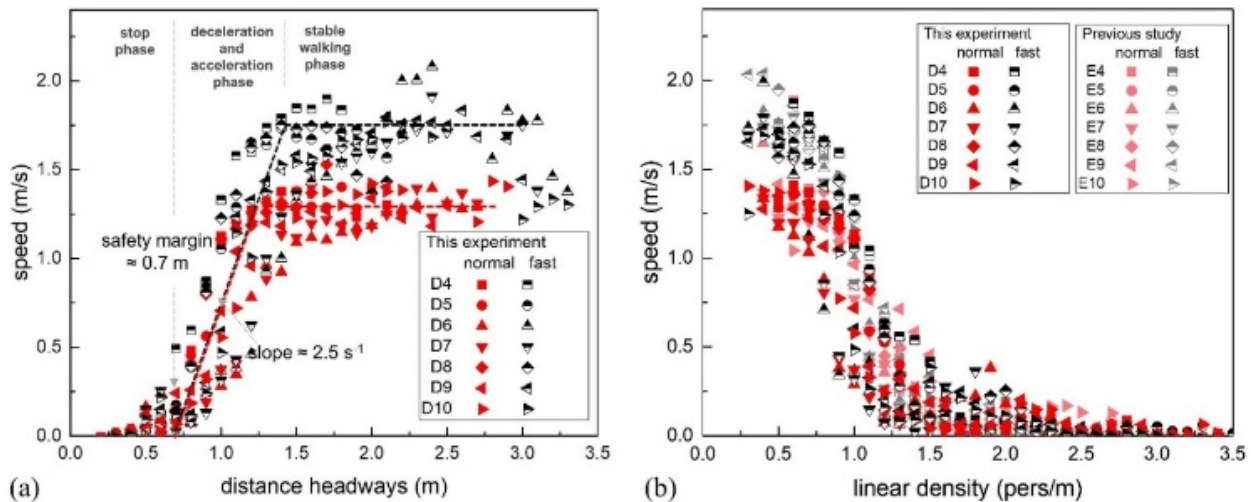


Fig. 4 The (a) speed-distance plot and (b) speed-density plot of single-file pedestrian movement in seat aisle (width = 0.5 m) and previous study in open environment

IV. CONCLUSION

The luggage-laden pedestrian dynamic pattern in a narrow seat aisle is investigated in this study. By conducting a series of pedestrian walking experiments, walking speed and distance headway are analyzed. It is found that the individual pedestrian walks at about 1.5 m/s for normal walking condition and 1.7 m/s for fast walking condition. When there is a single-file pedestrian walking through the seat aisle, they tend to keep a distance of about 1.25 m to their processor. Carrying large luggage such as trolley case will significantly increase the distance headways, about 0.4 – 0.5 m. By drawing the fundamental diagram and making comparison with previous studies, the pedestrian dynamic pattern in a narrow seat aisle is found to be similar to that in the open environment. Nevertheless, the hindrance effect of seat configuration makes the randomness of pedestrian behavior obviously greater.

ACKNOWLEDGMENT

This research was supported by The National Key Research and Development Program of China (2016YFB1200403) and the Research Grants Committee of Hong Kong (CityU 11300815).

REFERENCES

- [1] Fang, Z. M., et al., Observation, simulation and optimization of the movement of passengers with baggage in railway station. *International Journal of Modern Physics C*, 2015. 26(11): p. 1550124.
- [2] Young, S., Evaluation of pedestrian walking speeds in airport terminals. *Transportation Research Record: Journal of the Transportation Research Board*, 1999(1674): p. 20-26.
- [3] Sun, J., et al., An experimental study on individual walking speed during ship evacuation with the combined effect of heeling and trim. *Ocean Engineering*, 2017.
- [4] Jelic, A., et al., Properties of pedestrians walking in line. II. Stepping behavior. *Phys Rev E Stat Nonlin Soft Matter Phys*, 2012. 86(4 Pt 2): p. 046111.

- [5] Cao, S., et al., Pedestrian dynamics in single-file movement of crowd with different age compositions. *Phys Rev E Stat Nonlin Soft Matter Phys*, 2016. 94(1-1): p. 012312.
- [6] Jelic, A., et al., Properties of pedestrians walking in line: fundamental diagrams. *Phys Rev E Stat Nonlin Soft Matter Phys*, 2012. 85(3 Pt 2): p. 036111.
- [7] Huang, S., et al., Experimental study of individual and single-file pedestrian movement in narrow seat aisle. *Physica A: Statistical Mechanics and its Applications*, 2018.
- [8] Huang, S., et al., Experimental study on one-dimensional movement of luggage-laden pedestrian. *Physica A: Statistical Mechanics and its Applications*, 2018.
- [9] Boltes, M., et al., Automatic extraction of pedestrian trajectories from video recordings, in *Pedestrian and Evacuation Dynamics 2008*. 2010, Springer. p. 43-54.
- [10] Boltes, M. and A. Seyfried, Collecting pedestrian trajectories. *Neurocomputing*, 2013. 100: p. 127-133.