Simulation of Pedestrian Flow on Escalators

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***Abstract*—Standing on one side and walking on the other is a common practice on escalators. However, despite the potential risk of accidents associated with walking, it remains unclear whether single-side walking provides sufficient efficiency to justify its continued implementation. This study develops a pedestrian-flow simulation model for a two-lane escalator to quantitatively compare the transport efficiency between one-side walking and two-side standing operations. This results demonstrate that the one-side walking operation outperforms the both-side standing operation in transport efficiency only under specific conditions, with respect to the walking ratio, walking speed, and walking interval. These findings provide quantitative operational thresholds to support evidence-based escalator management.**

***Index Terms*—Escalator, pedestrian flow simulation, transport efficiency, walking ratio, walking speed.**

I. Introduction

A common practice has emerged in which one side is kept clear for walking. As summarized in historical reviews [1], and supported by early recorded announcements within the Tube network [2], the convention of standing on the right side of escalators in London appears to have been established in the early decades of the 20th century. The practice subsequently spread throughout the United Kingdom and later worldwide, becoming widespread in Japan after Hankyu Railway promoted the "keep one side clear" rule during the relocation of Hanshin Umeda Station [3].

However, the original escalator design did not anticipate walking [4], and a high rate of falls and trips was recorded when users walked on steps [5]. Approximately 40 % of all walking-related injuries were attributed to entrapment in machinery while running upward or to tripping while walking [6]. Although single-side walking may enhance operational efficiency, it poses notable safety concerns. Consequently, city ordinances and guidelines now require passengers to stand on both sides of the escalator. Station posters advise riders to hold handrails and refrain from walking. Despite these efforts, the custom of keeping one side clear while walking remains ingrained.

To date, debates have typically relied on experience and field observations. Quantitative criteria for determining whether one-sided walking or two-sided standing is efficient have not yet been fully developed. It is necessary to investigate whether single-side walking, despite its associated safety concerns, exhibits sufficient efficiency to justify its continued implementation.

II. Aims of this study

This study aims to fill this gap by conducting a pedestrian-flow simulation of two-column escalators under a mixed standing–walking operation versus two-sided standing. Specifically, this study aims to clarify how the walking ratio, walking-speed distribution, and walking spacing influence escalator throughput efficiency. These analyses will contribute to providing quantitative criteria that demonstrate the efficiency advantages of one- and two-way standing to optimize the balance between operational efficiency and passenger safety.

III. Previous research

A. Research on the Maximum Throughput of Station Vertical-Circulation Facilities

Morita et al. [7] developed a mobile-phone-based system that tracks boarding and alighting on stairways and escalators with one-second resolution. By applying this method to the relationship between train headway and the number of passengers processed, they demonstrated that a simple linear regression model could accurately describe the observed throughput. This finding lends quantitative support to the hypothesis that, even under congested conditions, a certain amount of "slack time" persists in passenger flows. Moreover, Morita et al. demonstrated that when passengers from one train are not fully cleared from the facility before the next train arrives, both the processing capacity of the facility and the extent of passenger spillover deteriorate.

B. Field Experiment on Two-Sided Standing

Harrison et al. [8] conducted a social experiment at the Holborn station escalators on the London Underground, comparing the conventional "one-side stand + one-side walk" operation with a "two-sided stand" regime. The experiment had three objectives: (i) improve safety by reducing falls and trips associated with walking on escalators, (ii) alleviate crowding through more effective use of escalator capacity, and (iii) observe changes in passenger behavior. The authors assumed that the escalator speed was 30 m/min, the walking relative speed was 45 m/min, the stop interval was one step, and the walking interval was two steps. Under these conditions, they calculated that the transport efficiency of single-side walking was almost the same as that of both-side standing. In the one-sidewalk condition, approximately 12,745 passengers used the escalator per week. When the operation was switched to two-sided standing, the weekly throughput increased to 16,220, an increase of approximately 30 %. Passenger feedback was largely favorable with respect to enhanced safety, although certain users expressed concerns about losing the opportunity for exercise or inconveniences when in a rush. Harrison et al. cautioned that the observed throughput gains may depend on the physical characteristics of the facility (e.g., inclination angle and step width), and recommended further validation before applying two-sided standing in other contexts.

C. Comparative Study of High-Speed and Standard-Speed

Motoda [9] compared passenger walking behavior on two up escalators at Tokyo Metro Toyosu Station operating at 30 m/min and 40 m/min. He found that the walking rate on the escalator, clearance time, and passenger flow rate were linearly correlated; that the walking rate on the 40 m/min escalator was 5–8 percentage points lower than on the 30 m/min escalator; and that the relative walking speed (net walking speed minus escalator speed) was approximately 9 % lower on the high-speed escalator. These findings indicate that higher escalator speeds can suppress walking behavior to certain extent, although the effects are limited in magnitude.

D. Quantitative Analysis of Walking Behavior on Escalators in Urban Stations

Ōtake et al. [6] analyzed escalator usage data from multiple urban stations and showed that walking rate rises with overall passenger throughput but falls as the vertical rise increases, and that features such as high-speed escalators, tourist traffic, or adjacent stairways tend to suppress walking. They further demonstrated that a logistic regression model explains walking rate with high accuracy and introduced a flow-efficiency index β, which peaks at moderate walking rates; stations with low walking rates achieve higher β under two-side standing, whereas those with high walking rates perform best under the standard one-side-stand/one-side-walk operation. In the present study, the walking rates, speed distributions, and efficiency indices reported in all four prior investigations are used as reference benchmarks to inform the selection of simulation parameters and to validate the pedestrian-flow model.

IV. Methodology

The efficiency of passenger transportation was compared for different escalator operation patterns using a human flow simulation.

A. Construction of a Virtual Escalator Model

For simulation purposes, passenger movement along the 4 m-high, 30°-inclined ascending escalator slope was projected onto a one-dimensional vertical axis. In this model, two operating modes were compared. In the one-side walking mode, passengers stand in one lane at one-step intervals while walking in the other; in the both-side standing mode, passengers form single-file standing columns in both lanes at one-step intervals.

B. Simulation Parameters

Based on previous research, we defined four control variables expected to influence escalator transport efficiency as follows:

i) Walking rate (α): the ratio of walking passengers to all users.
ii) Escalator speed (v_e): the operating speed, set within a range, such as 30–45 m/min.
iii) Walking speed (v_p): the relative speed of walking passengers on the escalator.
iv) Step spacing (s): the number of steps between the passenger and the front.

C. Evaluation Indicator

In order to compare passenger-flow efficiency in the simulation results, the following three metrics were employed:

i) Clearance time (T_{clear}): the time required for all passengers in the model to exit the escalator.
ii) Waiting time (T_{wait}): the mean waiting time from each passenger's arrival at the escalator boarding area to the moment of boarding.
iii) Throughput (N_{pass}): the number of passengers boarding the escalator over a 30-second interval.

Shorter clearance and waiting times and a higher throughput indicate greater efficiency.

D. Two Arrival-Interval Models

Two arrival-interval models were compared. In the constant-interval model, passengers arrived at perfectly regular intervals. In the station-platform model, interarrival times were generated to match observations on a straight side platform serving six-car trains with the escalator located at the fifth-car boarding zone. Each passenger's arrival time T was computed as $T = D/V$, where D is the walking distance from the disembarked car-modeled as a uniform random variable over a 20 m car length with a single central door-and V is the platform walking speed, assumed to follow a truncated normal distribution (60–100 m/min, median = 80 m/min) [11]. To characterize this distribution, 600 simulated passengers were used (Figure 1). Separately, we estimated peak-hour demand at a commuter-oriented station (18000 daily riders, 8–9 evening trains per hour, 20 Using these two arrival-interval models, we then quantitatively compared one-side walking versus both-side standing operations in terms of transport efficiency.

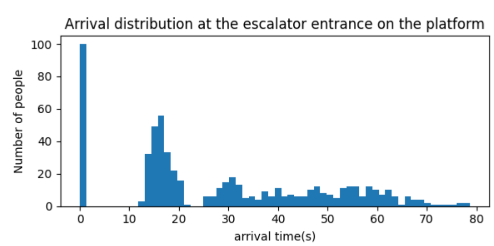

Fig. 1. The number of people arriving at the escalator entrance on the platform over time.

V. Results and Discussion

As mentioned earlier, the simulation was conducted under the assumption that passengers arrive at the escalator at regular intervals during the first half.

A. Constant-Interval Arrival Model

1) Baseline of the Both-Side Standing Operation: As the baseline condition, a both-side standing operation was analyzed, where passengers remained stationary in both lanes with one-step spacing between individuals. This setting was used to measure basic transportation efficiency, which is expressed as clearance time (T_{clear}). When the escalator speed was set to 30 m/min with a step height of 0.2 m, the clearance time was 174 s. When the escalator operated at a higher speed of 45 m/min, the clearance time decreased to 116 s. These results were used as a reference for comparison of various one-sided walking scenarios in the following analysis.

2) Effect of Walking Rate in the One-Side Walking Operation: The effect of the walking rate α (the percentage of passengers walking on one side) was analyzed (Figure 2). The walking rate was varied from 0 % to 100 % in 5 % increments, while the other parameters were fixed as follows: escalator speed, 30 m/min; walking speed, 45 m/min; and step spacing, two steps. As α increased from 0 % to 50 %, the clearance time decreased steadily and reached its minimum value at 50 %. When α exceeded 50 %, the clearance time increased again, indicating a decline in transportation efficiency. Compared with the two-sided standing operation (174 s), the one-sided walking operation showed better performance only when $\alpha \approx 50$ %.

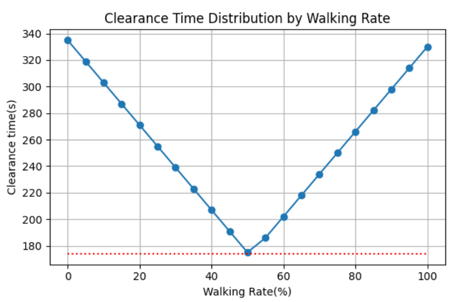

Fig. 2. Line graph showing change in clearance time due to walking rate.

3) Effect of Walking Speed in the One-Side Walking Operation: To examine the influence of walking speed, the walking rate α was fixed at 50 % such that the number of passengers in each lane became equal. The walking speed v_p was varied from 30 to 120 m/min in 5 m/min increments, whereas the escalator step spacing was maintained constant in two steps. The influence of walking speed v_p was analyzed under a normal escalator speed of 30 m/min. As v_p increased, the clearance time was exponentially shortened (Figure 3). The boundary at which the clearance time became shorter than that of the both-side standing operation (174 s) was identified near a relative speed of v_p = 45 m/min. Under identical conditions but with the escalator speed raised to 45 m/min, we repeated the simulation across the same range of walking speeds v_p. The resulting curve was identical to the 30 m/min case and the both-side standing mode achieved a shorter clearance time than the one-side walking mode for $v_p \geq 65$ m/min. Accordingly, a walking speed of at least 1.5 times the escalator speed relative to the escalator is required to improve transportation efficiency.

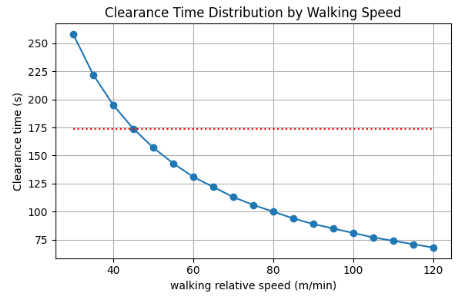

Fig. 3. A line graph showing the change in clearance time depending on walking speed. Run on a regular escalator at 30 m/min.

4) Effect of Step Spacing in the One-Side Walking Operation: Subsequently, the step spacing s between walking passengers was varied from 1.0 to 5.0 steps in 0.5 step increments while maintaining the walking rate at 50 %, escalator speed at 30 m/min, and walking speed at 45 m/min.

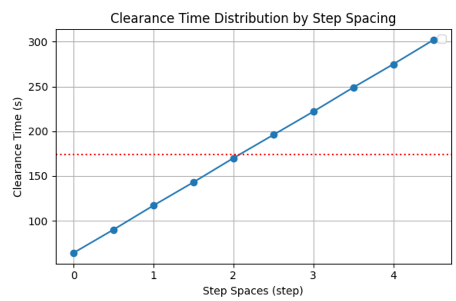

Fig. 4. A line graph showing the change in clearance time depending on walking gap.

As s increased, the clearance time increased almost linearly (Figure 4). The value coinciding with two-sided standing baseline (174 s) was found near $s \approx 2$ steps. Therefore, the commonly observed spacing of approximately two steps can be regarded as nearly optimal. If the spacing is significantly small, it causes congestion and collision risks; if considerably large, it results in wasted space. This relationship was quantitatively demonstrated through the simulation.

From these results, the optimal parameters for the one-sided walking operation were determined as: walking rate $\alpha \approx 50\,\%$, relative walking speed $v_p \approx v_e \times 1.5$ m/min, and step spacing $s \approx 2$ steps. These findings quantitatively clarify the balance between efficiency and safety in comparison with the two-sided standing operation.

B. Station-Platform Arrival Interval Prediction Model

As mentioned earlier, the latter half of the simulation utilized a predictive model of passengers arriving at escalators on the platforms of actual stations.

1) Baseline of the Both-Side Standing Operation: As the baseline condition, a both-side standing operation was analyzed with the station–platform arrival interval prediction model, in which passengers remained stationary in both lanes with a one-step spacing between individuals. The group occupying the car closest to the escalator arrived first, resulting in an initial surge in the arrival count, followed by a gradual increase as passengers from other cars reached the escalator. For this scenario, the total clearance time (T_{clear}) was calculated to be 88.72 s, the average waiting time (T_{wait}) was 1.82 s, and the number of people who passed through (P_{pass}) in 30 seconds was 78. These results were used as a reference for comparison of various one-sided walking scenarios in the following analysis.

2) Effect of Walking Rate in the One-Side Walking Operation: The influence of the pedestrian rate, α (i.e., the proportion of passengers walking on one side during one-sided walking operation), was analyzed using the station–platform arrival interval prediction model, while the other parameters were fixed as follows: escalator speed, 30 m/min; walking speed, 45 m/min; and step spacing, one step. Figure 5 presents box plots of clearance time, waiting time, and the number of passengers passing, based on ten simulation trials conducted for each 5 % increment in the walking rate. For comparison with two-sided operation, a red dotted line indicating the corresponding baseline value is included in all graphs.

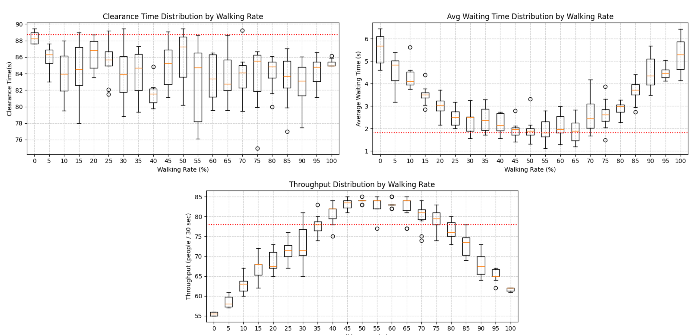

Fig. 5. Box-and-whisker plots showing the change in clearance time, waiting time, and throughput due to walking rate in one-sided walking operation with station–platform arrival interval prediction model.

Across all pedestrian rates, one-sided walking operation resulted in shorter clearance times than two-sided operation. Two minima were observed, with the shortest clearance times occurring at walking rates of approximately 40 % and 60 %. The waiting-time plot exhibited a convex-down quadratic trend, with one-sided walking operation slightly outperforming two-sided operation particularly in the 45–65 % range. The number of passengers passing followed a gently concave quadratic pattern, with one-sided walking operation outperforming two-sided operation particularly in the 35–75 % range.

Based on these three performance indicators, the analysis indicates that pedestrian rates in the range of approximately 45 % to 65 % provide the highest transport efficiency for one-sided walking operation within the station–platform arrival interval prediction model.

3) Effect of Walking Speed in the One-Side Walking Operation: The influence of walking speed v_p (the relative speed of passengers walking on one side) during one-sided walking operation was analyzed using a station/platform arrival interval prediction model, while the other parameters were fixed as follows: escalator speed, 30 m/min; walking rate, 50 %; and step spacing, one step. Box plots showing the clearance time, waiting time, and number of passengers passing for 10 trials per 5 m/min walking speed are shown in Figure 6. For comparison with two-sided operation, a red dotted line indicates the baseline value for two-sided operation on all graphs. Overall, clearance time was shorter for single-side operation than for two-side operation at all pedestrian rates. However, there were slight fluctuations, but no specific characteristics were observed in how walking speed affected clearance time. Regarding waiting times, no particular characteristics of variation due to walking speed were observed, and furthermore, the difference in waiting times between one-way and two-way driving was not significant. For the number of passengers passing through, no particular characteristics of variation due to walking speed were also observed. However, for any walking speed, the values were larger for single-side operation than for double-side operation.

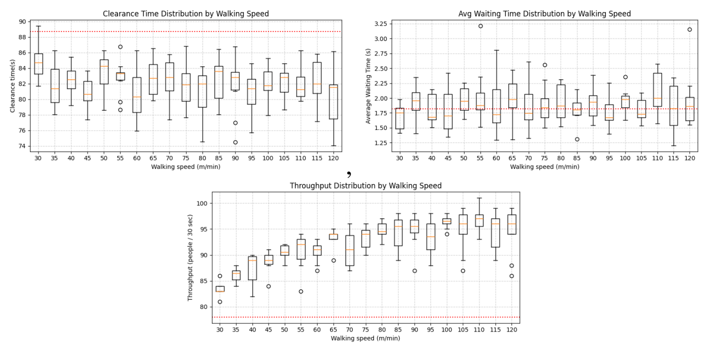

Fig. 6. Box-and-whisker plots showing the change in clearance time, waiting time, and throughput due to walking speed in one-sided walking operation with station–platform arrival interval prediction model.

Based on these three evaluation metrics, the station–platform arrival interval prediction model indicates that one-sided walking operation outperforms two-sided operation in terms of clearance time and passenger throughput. However, variations in walking speed did not result in a substantial difference in overall transport efficiency.

4) Effect of Step Spacing in the One-Side Walking Operation: The influence of walking step spacing s during one-sided walking operation was analyzed using a station/platform arrival interval prediction model, while the other parameters were fixed as follows: escalator speed, 30 m/min; walking speed, 45 m/min; and walking rate, 50 %. Box plots showing the clearance time, waiting time, and number of passengers passing for 10 trials per 1 steps walking spacing are shown in Figure 7. For comparison with two-sided operation, a red dotted line indicates the baseline value for two-sided operation on all graphs. Overall, the curve exhibits exponential growth as

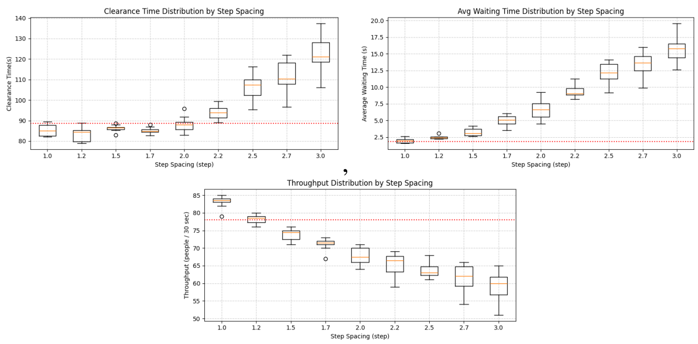

Fig. 7. Box-and-whisker plots showing the change in clearance time, waiting time, and throughput due to walking step spacing in one-sided walking operation with station–platform arrival interval prediction model.

the walking spacing step increases. When the pedestrian step spacing was two segments or less, the clearance time under single-lane operation was shorter than that under dual-lane operation. Regarding waiting times, the curve also exhibits exponential growth as the walking spacing step increases. For the number of passengers passing through, the results show an exponential decay in clearance time with higher walking spacing steps. Single-lane operation achieved shorter waiting times and higher passenger throughput than dual-lane operation only when the pedestrian interval was reduced to one segment.

Based on these three evaluation metrics, shorter pedestrian intervals were associated with higher transport efficiency. Furthermore, the station–platform arrival interval prediction model showed that single-lane operation consistently outperformed dual-lane operation across these measures.

5) Calculating the optimal solution using a multi-objective evolutionary model in the One-Side Walking Operation: Based on the preceding experimental results, we were able to identify parameter ranges in which adjusting either the walking rate or the walking interval individually led to improved performance. However, because the characteristics of walking speed and the trade-off relationships among the three parameters could not be adequately captured, we next sought to determine the optimal combination of all three parameters simultaneously. Using the same evaluation criteria—clearance time, average waiting time, and passenger throughput—we applied the NSGA-II multi-objective evolutionary optimization approach to identify the optimal parameter set. In this formulation, the explanatory variables were walking rate, walking speed, and walking interval, while the objective variables were clearance time, average waiting time, and passenger throughput. After performing this procedure three times, approximately 40 optimal solutions were obtained in each run. The distribution of Pareto-optimal solutions is shown in Figure 8. The graph first indicates that clearance time and waiting time are inversely related among the optimal solutions. Additionally, it was observed that a larger number of passengers passing through corresponds to

TABLE I
PARAMETERS FOR PREFERRED SOLUTIONS WITHIN THE SELECTED CRITERIA RANGE OBTAINED FROM THE OPTIMAL SOLUTIONS OF THE MULTI-OBJECTIVE EVOLUTIONARY COMPUTATION

α	v_p	s	T_{clear}	T_{wait}	N_{pass}
59.8	51.2	1	82.72	1.94	73
47.3	60.5	1	83.97	1.88	73
59.0	60.0	1	79.55	1.95	82
59.3	46.3	1	88.50	1.95	75
46.8	53.9	1	81.83	1.92	80

a larger product of clearance time and waiting time, whereas a smaller number of passengers passing through corresponds to a smaller product of these two metrics. Based on the

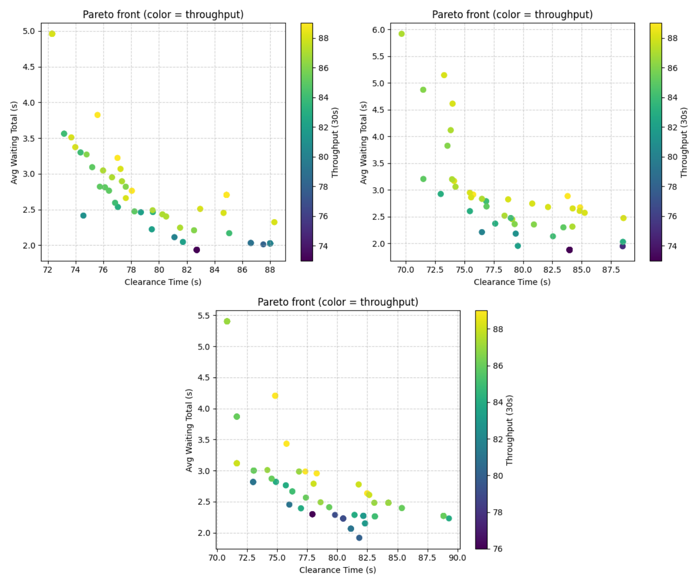

Fig. 8. Pareto front scatter plot constructed using three evaluation metrics, based on the optimal solutions obtained from three independent runs of the NSGA-II multi-objective evolutionary optimization.

above graphs, preferred solutions were selected by comparing the baseline performance of the both-side standing operation with the other results. Clearance time and waiting time were prioritized as the primary evaluation criteria; specifically, solutions satisfying a clearance time of no more than 89 s and a waiting time of no more than 2 s were selected. As a result, the following five preferred solutions were obtained (Table I). Therefore, analysis of the five preferred solutions selected from the Pareto-optimal set revealed consistent trends across the three control parameters. Firstly, the walking rate α of all preferred solutions fell within a narrow range of approximately 46–60 %, indicating that a balanced proportion of walkers and standers yields the highest overall transport efficiency. Secondly, the pedestrian walking speed v_p ranged from 46 to 61 m/min. It suggests that moderate walking speeds are more effective than either slow or excessively fast walking, both of which degrade flow stability. Finally, all preferred solutions adopted a walking interval s=1 step, demonstrating that minimizing the spacing between passengers while preserving safe headway leads to higher throughput and shorter clearance time. Each of these satisfies the optimal range previously determined for each parameter.

VI. Conclusion

In this study, a pedestrian-flow simulation was carried out to quantify and compare the transport efficiency and safety of two operational modes on a dual-lane escalator: both-side standing and one-side walking. The main findings are summarized as follows.

Under the constant-interval arrival assumption, that is, passengers arrive onto the escalator at perfectly regular intervals, the one-side walking mode outperforms the both-side standing mode in transport efficiency when the parameters fall within the following ranges:

i) Walking ratio $\alpha \approx 50\ \%$
ii) Relative walking speed $v_p \geq 1.5 \times v_e$
iii) Walking step interval $s \leq 2$steps

Under the station-platform arrival-interval prediction model, the one-side walking mode outperforms the both-side standing mode in transport efficiency when the parameters fall within the following ranges:

i) Walking ratio $46\ \% \leq \alpha \leq 60\ \%$
ii) Relative walking speed $46\ m/min \leq v_p \leq 60\ m/min$
iii) Walking step interval $s \leq 2$steps (with s = 1 step being optimal)

Harrison et al. (2016), based on field measurements at a UK station, reported that two-side standing consistently outperforms one-side walking under their observed conditions. Our simulation refines this conclusion by showing that two-side standing only equals or exceeds one-side walking when the walking ratio α, relative walking speed v_p, or step interval s fall outside the optimal ranges we identify (46 % $\leq \alpha \leq$ 60 %, 46 m/min $\leq v_p \leq$ 60 m/min, $s \leq 2$ steps); within these bounds, one-side walking delivers superior throughput. Moreover, while Ōtake et al. (2017) suggested a 50 % walking-ratio threshold, our results quantitatively confirm and sharpen this benchmark—identifying optimal walking-ratio windows of 46 %–60 % under realistic station-platform patterns—and, for the first time, establish precise thresholds for relative speed and step interval.

The present model is limited to a single, uniform platform geometry. Future work will extend the simulation framework to more complex station layouts and interconnected platforms. In parallel, empirical validation using field measurements will be conducted to ensure that the model accurately reflects real-world pedestrian behavior. Moreover, although this study focuses primarily on transport efficiency, further research is needed to examine the trade-off between efficiency and safety by incorporating safety-related risks. These enhancements will improve the realism and applicability of pedestrian-flow simulations and provide quantitative guidance for escalator design and operational management in high-demand facilities.

VII. Use of Large Language Models (LLMs)

We used ChatGPT for language polishing of author-written text. All results were reviewed, run, and validated by the authors. All scientific ideas, model designs, proofs, and claims are the authors' work; the LLM is not an author.

Acknowledgment

This work was supported by Toyo University Top Priority Research Program. We would like to thank Editage (www.editage.jp) for English language editing.

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