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TABLE OF CONTENTS

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EXTENDED MODEL OF PEDESTRIAN ESCALATOR BEHAVIOUR BASED ON DATA COLLECTED WITHIN A CHINESE UNDERGROUND STATION

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ABSTRACT

This paper presents data relating to pedestrian escalator behaviour collected in an underground station in Shanghai, China. While data was not collected under emergency or simulated emergency conditions, it is argued that the data collected under rush-hour conditions - where commuters are under time pressures to get to work on time - may be used to approximate emergency evacuation conditions – where commuters are also under time pressures to exit the building as quickly as possible. Data pertaining to escalator/stair choice, proportion of walkers to riders, walker speeds and side usage are presented. The collected data is used to refine the buildingEXODUS escalator model allowing the agents to select whether to use an escalator or neighbouring parallel stair based on congestion conditions at the base of the stair/escalator and expected travel times. The new model, together with the collected data, is used to simulate a series of hypothetical evacuation scenarios to demonstrate the impact of escalators on evacuation performance.

INTRODUCTION

In certain situations such as in deep underground/subway stations, which are well catered for by escalators for normal pedestrian flows, escalators can provide an attractive and efficient alternative to long stairs in evacuation situations. In emergency situations, escalators also offer a larger throughput capacity than a typical single lift/elevator car for the same number of floors as there is no service wait time for occupants. However, in the event of an emergency evacuation, escalators are typically turned off, in some cases they may even be closed, preventing occupants from using them as a stair and in some cases escalators may be used only if staff are present to supervise[1].

There are many reasons for the restricted use of escalators in emergency situations including; the possibility of an unexpected shut down during operation possibly causing some riders to fall, the possibility that pedestrians may be trapped in a location because they can not traverse in the opposite direction to which the escalator is moving, and the possibility that the moving escalator may be carrying people to, rather than away from danger. In situations where the escalator has stopped, the high riser height makes it difficult for some people to utilise the escalator as a stair and the uneven riser height for some of the treads increases the probability of a miss step resulting in a fall.

Regardless of these concerns, escalators have been used both in the "off" and "on" condition in some evacuation situations. In the 9/11 World Trade Center evacuation escalators were used as a means of evacuation in both the North and South towers to move people from the Mezzanine to the lobby[2]. In both towers escalators were used as stationary stairs while in the South Tower survivors reported using moving escalators during the "unofficial" evacuation prior to the South Tower being hit[2]. As a result there is a need to understand and quantify pedestrian behaviour associated with the use of escalators.

Despite this, at present, there is little data pertaining to micro-level pedestrian dynamics on and around escalators (see[3] for example) and a subsequent lack of understanding. Consequently evacuation and circulation models that attempt to represent escalators typically do so at a macro-level, simply specifying escalator flow rates. However, flow rates are usually derived from manufacturer specifications which are based on ideal assumptions of usage, seldom achieved in practice.

A micro-level escalator model was developed for the buildingEXODUS software based on data collected within a Spanish underground/subway station[4] to represent more accurate pedestrian behaviour during circulation/evacuation scenarios. Here we present additional data collected from a Chinese underground/subway station, where higher densities of people were involved at the base of the stair/escalator making the decision to use the stair/escalator more complex. In this paper we present the newly collected Chinese escalator data along with modifications to the escalator model that take into consideration crowd density in the decision to board the escalator or stair.

DATA COLLECTION

The data was collected in the Peoples Square underground/subway station, Shanghai, China. The station itself is located in the very centre of the city and as such is located near a number of large office buildings, shopping centres and tourist attractions. Consequently it is used by a large number of people everyday, especially during the peak rush-hour periods where platform crowd densities often exceed 2 people/m². Within this study, two identical escalators were videoed at different times, both moving in an upwards direction linking the platform level to the above lobby level identified as Escalators A and D. Each escalator has a horizontal speed of approx 0.5 m/s, a vertical drop of 4.2 m with a total length of 12.49 m (length of horizontal parts and length of incline). Stairways run parallel with both escalators and so provide an alternate means to traverse the area. The effective width of the stair is 3.6 m while the effective width of the escalator is 1.1 m. The platform is double sided, which means that trains arrive on both sides of the platform (going in opposite directions). Subsequently pedestrians on the platform level can approach the escalator/stairway from either the stairway or escalator side. Escalator A was videoed during the rush-hour and Escalator D was videoed during non-rush hour. For each escalator, two digital video cameras were used to record the footage. Both the escalator entrance (on the platform level) and the exit (on the lobby level) were videoed. Each camera recorded footage for 1 hour (the total amount of footage collected was 4x1hrs = 4 hours). Analysis of the video footage allowed the formation of a human factors dataset contained information pertaining to: escalator/stair choice, escalator side preference, proportion of walkers to riders, walker speeds and entry/boarding and exit/alighting flow-rates.

ESCALATOR USAGE OBSERVATIONS

In total around 4,787 people were recorded using each escalator; 2,752 during the rush hour (Escalator A) and 2,035 during the non-rush hour (Escalator D). In addition, some 2,451 stair users adjacent to Escalator A during the rush-hour period were also recorded.

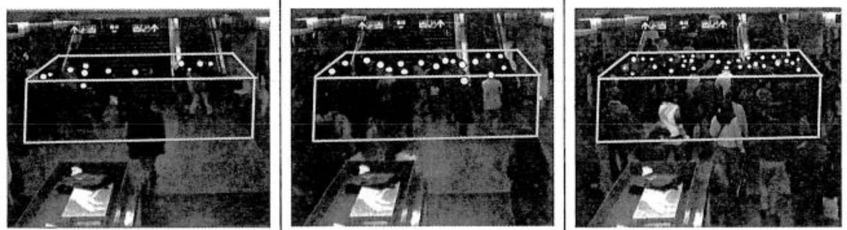
Escalator/Stair choice

When pedestrians approached each of the escalators, they were presented with a choice to use either the escalator or the adjacent stair. The frequency of pedestrians that used Escalator A (i.e. rush-hour) and the adjacent stairway was recorded. The camera view used for Escalator D (i.e. non-rush hour) did

not provide a full-length view of the stairway and subsequently the frequency of stair users was not recorded.

People arrived at the stairs in batches corresponding to the arrival of trains. The congestion at the base of the stair/escalator varied with each batch and during the time that the batch passed through the stair/escalator. The frequency of stair and escalator users appeared to vary with the density at the base of the stair/escalator. To facilitate a consistent method of measuring the crowd density at the base of the stair/escalator, a region measuring approximately 3m x 6m in front of the staircase and escalator (including the escalator flat section) was defined (see Figure 1). The number of people within this region was counted every few video frames to determine the number of people within the region and hence the crowd density within the region. Presented in Figure 1 are three views of the region showing three different crowd densities.

To highlight each person within the catchment area a white circle has been placed on each occupant's head. This region was then considered "congested" when the number of people in the area, who intended travelling up the stair/escalator, equalled or exceeded 18. This represented an average of 1+ people/m^2 and approximately corresponds to Fruins' level of service D and above (i.e. 0.72-1.1 people/m^2)[3]. Level of service D was selected as the critical crowd density as it represents the situation in which normal walking speeds are reduced for the majority of occupants due to difficulty in bypassing slower occupants. The critical level of congestion (i.e. 18 people in the 3m x 6m catchment area) is presented in Figure 1b. This density is intended to represent the lowest accepted level of congestion during the congested periods. A significant difference in the level of congestion is evident by comparing the heavily congested period shown in Figure 1c with the low congestion period shown in Figure 1a. For any one batch, a start up period of time was required before the density at the base of the stair/escalator reached the critical density. Having reached the critical density, it would normally remain at or above the critical density until just before the end of the batch. Thus for any one batch, it could be possible to measure people using the stair/escalator during congested and non-congested periods.



(a): Approximately 12 people (0.67 p/m^2 average)	(b): Approximately 18 people (1 p/m^2 average)	(c): Approximately 31 people (1.7 p/m^2 average)

Figure 1: Different levels of congestion at the base of the stair/escalator

In total 4,531 pedestrians were recorded ascending to the upper level using the escalator or the adjacent stair; 1,182 during non-congested periods (20 train arrivals) and 3,349 during congested periods (8 train arrivals) (see Table 1). During the non-congested periods 907 escalator users were recorded and 275 stair users were recorded. During the non-congested period, regardless of arrival side, the escalator was the most preferred device. Approximately 76% of the pedestrians that arrived on the escalator side preferred to use the escalator and 75% of the pedestrians that arrived on the stair side preferred to use the escalator. This suggests that the side of approach to the device does not exert an influence on the choice to use a particular device. Furthermore, if the stair and escalator were equally attractive we would expect that 50% of the pedestrians would make use of each device however; we find that the escalator attracts almost 77% of the pedestrians which suggests that there is a strong bias to use the escalator. It should be noted that these results only apply for vertical drops equivalent to that in the trial and only in non-congested conditions.

Table 1: Non-congested escalator/stair users

Train Arrival Side	Arrival Frequency	Escalator User Frequency	Stair Users Frequency	% Escalator Users
Escalator	7	532	172	75.6%
Stair	9	184	63	74.5%
Both	4	191	40	82.7%
Overall	20	907	275	76.7%

In the congested periods over twice as many pedestrians were observed compared to the non-congested periods in under half as many train arrivals. Also, during the congested periods, none of the trains arrived only on the escalator side. Approximately the same proportion of pedestrians were observed to use the escalator when trains arrived from either the stair or both sides simultaneously. This suggests that during congested periods the side of approach has little influence upon stair/escalator usage. However, significantly more pedestrians utilise the stair compared to the escalator. During congested periods, crowds form around, the entrance of the escalators, the base of the stair and along the platform. In these circumstances some pedestrians will be forced into using a device simply based on proximity to the device.

Table 2: Congested escalator/stair users

Train Arrival Side	Arrival Frequency	Escalator User Frequency	Stair Users Frequency	% Escalator Users
Stair	3	250	463	35.1%
Both	5	923	1713	35.0%
Overall	8	1173	2176	35.0%

In these circumstances, the relative width of the escalator and stair is expected to have a significant influence on the proportion using either device. Given that the stair is some 3.3 times wider than the escalator, if there were an equal preference to use the stair and the escalator based on width alone then we would expect the stair to attract some 330% more users. However, we find that the stair attracts some 190% more users. Thus, while the relative widths of the devices are exerting an influence on whether or not pedestrians use a particular device, pedestrians are also exercising some discretion concerning device usage. Thus, during non-congested periods, pedestrians can exercise a clear choice as to which device they use. However, during congested periods, while some pedestrians are forced into using a device simply based on proximity to the device other pedestrians exercise some choice in device usage.

Proportion of Walkers and Riders

When boarding an escalator, pedestrians can either ride or walk along the escalator. Walking along the escalator decreases the transit time relative to simply riding the escalator. Whether pedestrians

elected to walk or ride the escalator was recorded during both the rush-hour and non-rush hour period. It was observed in most train arrivals within the data that riders who typically were among the first to board the escalator from an arriving train blocked pedestrians behind them from having a choice to walk up the escalator. This meant the proportion of walkers in the data was often not a reflection of pedestrian choice but a by-product of decisions made by other pedestrians to ride. Almost all walkers were among those pedestrians who boarded the escalator first. The frequencies of walkers and riders during the rush-hour and non-rush hour period can be seen in table 3. While there are slightly more walkers in the rush-hour period, the overall number of walkers is only 2.4%.

Table 3: Walker/Rider frequencies during rush-hour and non-rush hour periods

	Train Arrival Frequency	Walker Frequency	Rider Frequency	% Walkers
Rush-hour	28	92	2,660	3.3%
Non-rush hour	25	27	2,008	1.3%
Overall	53	119	4,668	2.4%

Side Preference Behaviour

When pedestrians board an escalator, they occupy a particular location on the escalator tread, either left or right. The side can be dictated by national custom though can be violated by foreign visitors or the careless. The side occupied by the escalator user can impact the efficiency of the escalator since if a large number of riders do not adopt a common side preference, they can inhibit other pedestrians from walking up the escalator. The side which all escalator users occupied was recorded during the non-rush hour period. The breakdown of side preference of walkers and riders is summarised in Table 4. It can be seen that overall almost all occupants adopted either the left or ride side to traverse the escalator. Approximately equal numbers of walkers used the left and right side and approximately equal numbers of riders elected to use either the right or left side of the escalator. The left and right users do not add up to the total as some pedestrians used the centre or changed location during their travel and these are not included.

The data shows that there appears to be no common side preference whereby walkers and riders elect to use opposite sides of the escalator as found in other countries[4]. As a result higher crowd densities were observed on the escalator compared to those escalators where there is a walker and rider lane (i.e. walkers require at least tread spacing in order to walk whereas riders can occupy each tread).

Table 4: Side preference for escalator users during the non-rush hour period

		Left	Right	Total
Non-rush-hour	**All**	964	993	2,035
		47.37%	48.80%	
	Walkers	9	8	27
		33.33%	29.93%	
	Riders	984	956	2,008
		49.00%	47.61%	

Walker Speeds

Due to obstructed views it was not possible to measure the walking speeds of all the escalator walkers. However, the average speed of 79 walkers traversing each escalator was determined. Due to the blocking behaviour of riders, the walker speeds were typically of those who were among the first occupants to board the escalator. In total 57 walkers were recorded in the rush-hour with an average horizontal speed of 0.9 m/s. During the non-rush hour period, 22 walkers were recorded with an average horizontal walking speed of 0.67 m/s.

ESCALATOR MODEL

The core software used in this paper is buildingEXODUS V4.1 beta[5]. The software can be used to simulate both evacuation and circulation scenarios. The existing escalator model within the software has the capacity to represent escalator/stair choice, proportion of riders/walkers, side preference for riders and walker speeds[4]. Using the data collected above, the escalator model was further refined to include a device selection algorithm based on levels of congestion at the base of the stair/escalator. Three approaches to represent agent device selection are incorporated within the modified escalator model. The first approach simply requires the engineer to prescribe a fixed proportion of device users, which may be based on observed data for up/down direction of travel and time of day. This approach is most appropriate for circulation scenarios and relies on data which is representative of the type of scenarios being considered. Using this approach, when an agent enters the catchment area they are assigned a device to use based on the assigned probabilities.

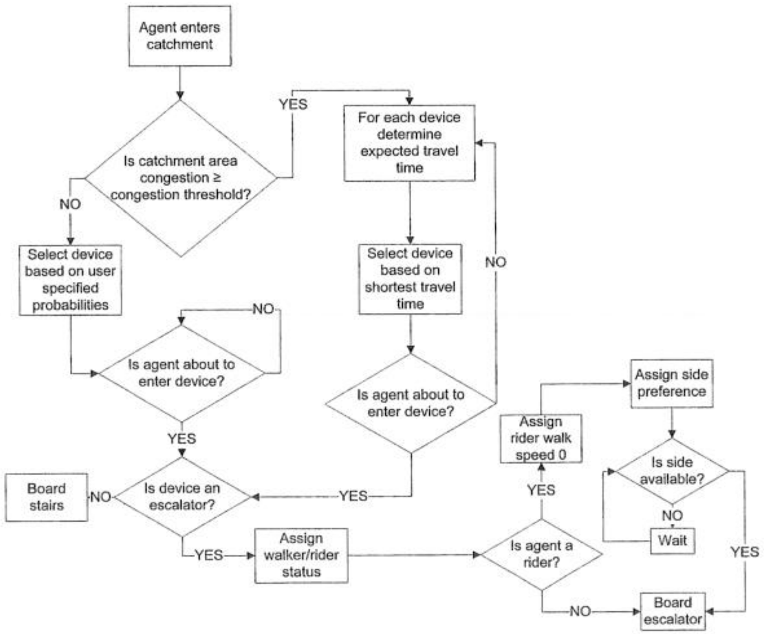


Figure 2: Microscopic escalator model logic

The second approach relies on the agent making a decision as to which device to use. The decision is based on the assumption that the main motivation of the agent is to reduce their overall travel time. This approach is most appropriate for scenarios involving highly motivated pedestrians such as those involved in an evacuation. The shortest perceived travel time selection system is a theoretical

framework which ensures that agents select the device which they expect to get them to their desired vertical level in the shortest period of time. This is determined by the agent initially estimating the time it would take to travel to the device based on the distance from their current position and their speed, taking the number of people along the straight-line path to the device into account. In addition, the expected travel time incurred on the device is also estimated. This calculation is based on the distance to be travelled on the device and the agents' device travel speed, taking into account travel direction and any additional speed afforded by the device e.g. moving escalator. The agent selects the device within the device group which provides the shortest expected travel time and moves towards the selected device. While in the catchment area and prior to boarding the desired device, the agent occasionally reassesses their personal situation and may select a more favourable route and device. In this way the agent adapts their path in response to the changing numbers of people within the catchment area ahead of their current location.

The third approach, which is the new methodology based on the data presented in this paper, incorporates the influence of congestion into the device selection process. This approach combines the fixed proportion model with the shortest travel time model influenced by local congestion levels. Below a specified threshold crowd density, the agents select the device to use based on specified probabilities. These probabilities are based on the observed pedestrian preferences under non-congested conditions. Above the threshold crowd density, pedestrians select which device to use based on the shortest travel time algorithm. The logical functionality describing the third approach is presented in Figure 2. As this approach is adaptive, it is suggested that this methodology can be used for both circulation and evacuation applications. The method requires several parameters to be specified by the user. These are the congestion threshold density (CT), which in this work is taken as 1 people/m^2 and the device preference probabilities under non-congested conditions, which from the data presented here is 77% bias towards the escalator for upward movement. These parameters are expected to be dependent on direction of travel and size of vertical drop. In addition, it is suggested that for circulation applications, these values may also be dependent on culture.

ESCALATOR MODEL EVACUATION DEMONSTRATION

A simple case was developed to demonstrate the extended the microscopic escalator model in an evacuation scenario involving 400 agents. The geometry consisted of two levels connected via two stairs and a dual lane escalator (see Figure 3). The vertical drop was 4.2 m and the width of the each stair and the escalator was 1.1 m. The horizontal speed of the escalator was 0.5 m/s with a horizontal length of 11.5 m. The catchment area at the entrance to the group of stairs/escalator measures 8.5 x 3.5m. A total of seven scenarios are examined, requiring the agents to travel from the lower to the upper level. These consisted of various combinations of stair/escalator users and escalator model parameter configuration. The escalator walk speed distribution used in these simulations was selected from the maximal values in the dataset presented in this paper.

The results for the various scenarios are summarised in Table 5, it should be noted that in these scenarios, stair2 is immediately adjacent to the escalator. Very early in the evacuation crowds develop at the foot of the stairs/escalator and persist until near the end of the evacuation. The extent of this congestion in each scenario is dependent on how well balanced the device usage was, which is in turn dependent on the throughput of each device and the device selection method employed. We also note that in the case where the escalator is static (scenario 2), there is almost equal usage of the devices effectively treating the static escalator as a third staircase. Whilst in reality a static escalator may prove more physically taxing to traverse than a stair due to the increased tread height on the escalator, no data was collected regarding escalator/stair choice using a static escalator, nor pedestrian performance on a static escalator.

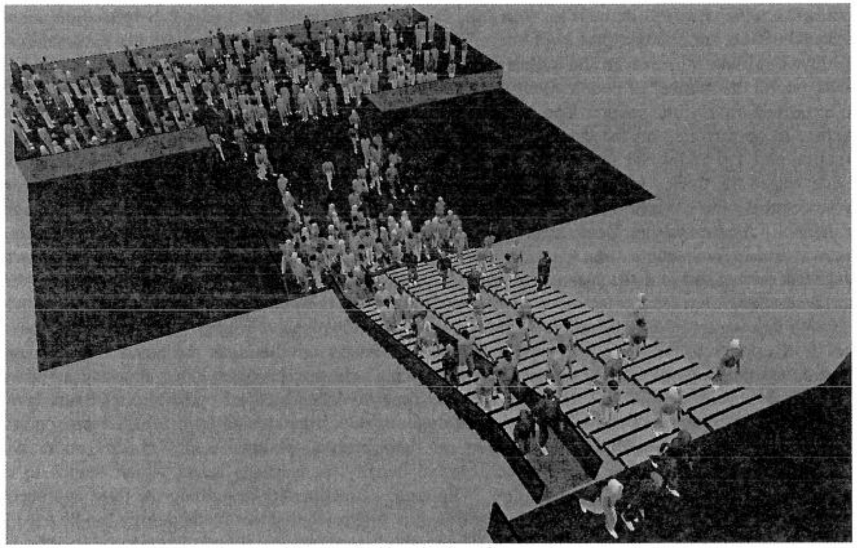


Figure 3: Simulation Geometry

Scenario 1 represents a situation akin to common practices in an actual evacuation whereby the escalator is turned off and cordoned off whilst pedestrians are required to use only the stairs. Out of all scenarios run this produced the longest Total Evacuation Time (TET) of 383s. Another common practice during an evacuation is to turn the escalator off but allow pedestrian to walk up the device. If we assume that pedestrians are evenly assigned to use each device, regardless of the number of people in front of them or device queue length (scenario 2), the TET reduces to 282s, a decrease of 26.2% compared with scenario 1, along with reductions in average Cumulative Wait Time (time lost to congestion – CWT). When the escalator is turned on, using the perceived shortest time selection method with all escalator users riding (scenario 3), the TET reduces to 257s, a 9.0% (25s) decrease compared to when the escalator is off and used as a stair (scenario 2). If we now assume that all escalator users walk on the moving device (scenario 4), the TET reduces to 231s, a decrease of 18.3% compared to scenario 2. During this scenario on average 84% of the population used the escalator, highlighting the influence of higher effective travel speeds on the escalator compared to the adjacent stairs. This scenario produces the minimum evacuation time and is perhaps somewhat unrealistic as not all pedestrians would be able to walk up the escalator e.g. elderly, obese, disabled.

In simulations using the more advanced device selection algorithm we note that results are strongly dependent on the value of the CT (see scenarios 5 and 6). With the CT set to 4p/m² and an even distribution between the devices in non-congested situations (scenario 5), the TET becomes 280s which is comparable with the case with the stopped escalator (scenario 2). This poor performance is due to the level of congestion in the decision area never exceeding the CT and as a result, the pedestrians were not free to select which device to use.

Furthermore, the last pedestrian to utilise the escalator did so some 51.9s before the last stair user alighted the stairs. Thus the stairs are seen as the bottleneck in this scenario and hence the results for scenario 5 are similar to those for scenario 2. In scenario 6 the CT is set to 1 p/m² while all other parameters are identical to scenario 5. Here we find that the TET is 250s, a decrease of 10.7% compared to scenario 5. The improvement in TET is due to the agents being able to exercise a choice

(based on minimising perceived travel times) in which device to use and as a result, more agents selecting the escalator. The better throughput provided by the escalator also reduces the average density at the foot of the stair/escalator compared with scenario 5.

Table 5: Summary results for escalator evacuation demonstration scenarios

Scenario	Av. TET (s)	Av. CWT (s)	Av. Max Density (p/m^2)	Av Escalator usage	Av. Stair2 usage	Av. Stair1 usage
1: 2 stairs (50% on each)	383	73.4	3.9	0.0	197.6	202.4
2: 2 stairs + stopped Escalator (33.3% on each device)	282	23.2	2.6	140.3	123.8	136.0
3: 2 stairs + Escalator (shortest time, 100% Ride)	257	15.2	2.1	238.0	81.8	80.3
4: 2 stairs + Escalator (shortest time, 100% Walkers)	231	7.5	1.4	334.3	52.8	13.0
5: 2 stairs + Escalator (CT = 4 p/m², 33.3% on each device, 100% Walkers)	280	17.6	2.2	143.6	134.6	127.8
6: 2 stairs + Escalator (CT = 1 p/m², 33.3% on each device, 100% Walkers)	250	8.6	1.2	185.8	106.8	107.4
7: 2 stairs + Escalator (CT = 1 p/m²; 11.65% Stair1, 11.65% Stair2, 76.7% Escalator; 97.6% riders, 50% left + right)	254	11.8	1.9	190.8	104.0	105.3

The final scenario is configured based on the data collected from the Shanghai underground station with the CT= 1p/m^2. In this case the TET is 254s and is; 9.9% faster than the case when the escalator is stopped and used as a stair (scenario 2), 33.7% faster than the case where the escalator is closed (scenario 1) and about the same time as when everyone walks up the working escalator with an even split between devices in the non-congested periods (scenario 6). Of all the scenarios, we suggest that scenario 6 is the most realistic evacuation scenario (at least for a Shanghai based evacuation) as it uses relevant human factors data.

CONCLUDING COMMENTS

This paper has presented an analysis of human factors data relating to pedestrian escalator behaviour within a Chinese underground station. The presented data relates to: escalator/stair choice, rider/walker preference, rider side preference and walker travel speeds. Key findings from this analysis include; below a critical threshold crowd density, 77% of pedestrians prefer to use the escalator to travel up (non-congested conditions) and above the critical threshold density (congested conditions) this decreased to 35% of pedestrians, thus in congested periods, while more pedestrians elected to use the escalator than would be expected based on relative widths, the ability to choose a device was severely limited; pedestrians did not exhibit a side preference when using the escalator; 97% of the pedestrians rode the escalator up; walker speeds in the up direction were faster during the rush-hour compared to non rush-hour periods. These observations are expected to be dependent on direction of travel and size of vertical drop. In addition, it is suggested that for circulation applications, these observations may also be dependent on culture.

The dataset provides insight into pedestrian behaviour in utilising escalators and is a useful resource for both evacuation and circulation model developers. The existing escalator model within EXODUS has been extended using the newly collected data. The current escalator model has the capacity to represent three different device selection methods: assigned probabilities, shortest perceived travel time and congestion influenced device selection. The model was used to examine a hypothetical evacuation in which the pedestrians had to travel up a single level with an escalator and two stairs located side by side linking the two levels. The results suggest that under evacuation conditions, allowing the escalator to function as normal can provide significant benefit to pedestrians by reducing overall evacuation times. Significant benefit could be derived from the escalator even in situations where all the pedestrians rode up the escalator.

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