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Modelling Pedestrian Escalator Behaviour

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Summary
This paper presents an escalator model for use in circulation and evacuation analysis. As part of the model development, human factors data was collected from a Spanish underground station. The collected data relates to: escalator/stair choice, rider/walker preference, rider side preference, walker travel speeds and escalator flow rates. The dataset provides insight into pedestrian behaviour in utilising escalators and is a useful resource for both circulation and evacuation models. Based on insight derived from the dataset a detailed microscopic escalator model which incorporates person-person interactions has been developed. A range of demonstration evacuation scenarios are presented using the newly developed microscopic escalator model.

1 Introduction

Escalators provide a means for pedestrians to traverse a small number of vertical levels (typically 1-5 floors) in a relatively short period of time, providing greater comfort and requiring less physical exertion compared with equivalent stairways. Consequently it is common to find escalators as the primary form of vertical transport in underground/subway stations. They provide a more attractive and efficient alternative to long stairs in both circulatory and evacuation situations. However, in the event of an emergency evacuation, escalators are typically turned off, in some cases they may be closed, preventing occupants from even using them as a stair and in other 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, most notably the possibility that the moving escalator may be carrying people to, rather than away from danger. Regardless of these concerns, escalators have been used both in the "off" and "on" condition to good effect 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 [2] while in the South Tower survivors reported using moving escalators during the "unofficial" evacuation prior to the South Tower being hit [2]. It is clear that escalators are used for evacuation purposes and so there is a need to represent escalators within both evacuation and pedestrian dynamics circulation models. 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 and a subsequent lack of understanding.

2 Data Collection

As part of the EU FP6 project AVATARS, human factors data associated with escalator usage in underground stations was collected. The data was collected within the Provença station, Barcelona Spain using CCTV (Closed Circuit Television) video footage. Data was collected in both rush-hour and non rush-hour conditions. Two escalators were studied, an escalator moving in an upwards direction and an escalator moving in a downwards direction. Analysis of the video footage allowed the formation of a human factors dataset containing information pertaining to: escalator/stair choice, boarding/alighting behaviour, escalator side preference, proportion of walkers to riders, walker speeds and entry/boarding and exit/alighting flow-rates. In total some 7,206 data points were collected from the video footage relating to 1,283 people. The rush-hour data was collected from 895 people while the non rush-hour data was collected from 388 people.

3 Escalator Model

The core software used in this paper is the buildingEXODUS V4.0 evacuation model [3]. The basis of the model has frequently been described in other publications and so will not be described here. Here we describe the extension of the model to include escalators for both evacuation and circulation. The microscopic escalator model requires the identification and quantification of appropriate agent behaviour associated with the use of escalators and the development of appropriate behaviour rules to represent the behaviour.

3.1 Microscopic Escalator Model

The behaviour rules incorporated in the prototype microscopic escalator model are based on the study of the AVATARS data and include: escalator/stair choice model, proportion of riders/walkers, side preference for riders and walker speeds. In addition to the behaviours identified from the data analysis, additional behaviours associated with the existing stair model, such as inter-person spacing (staggering/packing behaviour [3]) are also included within the escalator model. The logic of the microscopic escalator model is summarised in Fig. 1.

When an escalator and stair or indeed any type of vertical transfer device is closely co-located, pedestrians approaching the device are required make a point-of-choice decision as to which device they will adopt. There are a number of factors which influence the selection decision including; personal preference, levels of energy expenditure required, level of urgency felt. In circulation situations all of these factors may exert an influence on the decision making process while in evacuation situations the desire to minimise ones egress time may become the overriding factor. This later factor is incorporated into the current device selection model.

4 Escalator Model Evacuation Demonstration

A simple demonstration case was developed to demonstrate the application of the microscopic escalator model in an evacuation scenario. The geometry consisted of two levels connected via two stairs and an escalator. The vertical drop was 6 m and the width of the stairs and escalator was 1.2 m. The horizontal speed of the escalator was 0.5 m/s with a horizontal length of 10 m. A total of 400 people are used in the simulation. A total of eight different scenarios were examined. Each case was run five times and all the results presented below represent the average for five simulations.

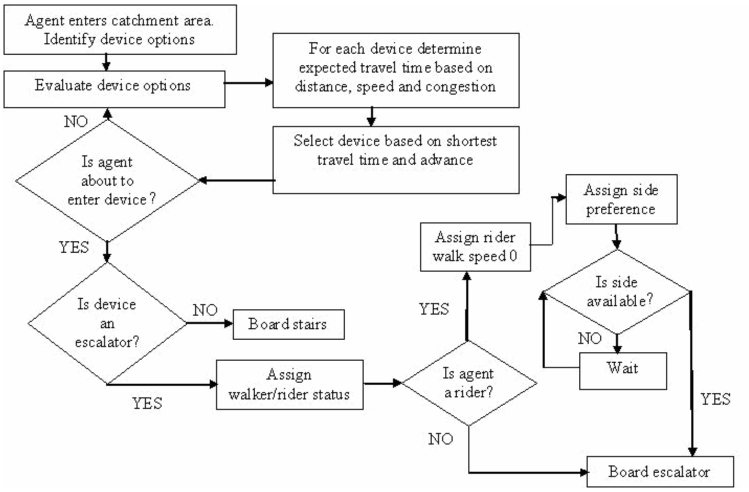

Fig. 1. Microscopic escalator model logic

4.1 Evacuation Results

The results for the various scenarios are summarised in Table 1, it should be noted that in these scenarios, stair 2 is immediately adjacent to the escalator. Very early in the evacuation crowds develop at the head of the stairs/escalator and persist until near the end of the evacuation. In all scenarios the shortest travel time device selection algorithm ensures that "reasonable" use is made of the devices throughout the simulation. Without the device selection algorithm, agents would either use their nearest or their assigned device rather than use an alternative nearby device irrespective of local conditions such as queue length/congestion levels, possibly resulting in unrealistic longer than required evacuation times. In all other cases where the escalator is operating, the escalator takes the greater number of users due to the expected greater speed of transit afforded by the escalator.

With just two stairs in operation the average Total Evacuation Time (TET) is 302 s (see Scenario 1), when the stopped escalator is made available the average TET reduces to 229 s (see Scenario 2), a reduction of some 26%. Clearly, even a stopped escalator can provide considerable advantage however, it should be noted that these simulations do not attempt to represent the likelihood of trips or falls on the escalator (or stairs). When the escalator is functioning (Scenario 3) and we assume that 100% of the population will walk down the escalator the average TET reduces to 196 s, some 35% better than having two stairs only and 14% better than the case with the stopped escalator available. We also note that in Scenario 3 almost 50% of the population utilise the escalator and that the average maximum density at the entrance to the stairs/escalator and the average CWT attain their minimum values for this scenario. The evacuation time achieved in this scenario is the quickest of all the scenarios and indicates the advantage a moving escalator can have during an evacuation. Also, by reducing the average density at the entrance to the stair/escalator, the use of the escalator can be argued to reduce the possibility of adverse crowd related incidents occurring.

Table 1: Summary results for escalator evacuation demonstration scenarios

Scenario	Av. TET (s)	Av. CWT (s)	Av. Max Density (p/m^2)	Escalator usage	Stair 2 usage	Stair 1 usage
Scenario 1: Two stairs	302	61.0	4.0	0	203	197
Scenario 2: Two stairs + stopped esc	229	27.0	3.9	127	137	136
Scenario 3: Two stairs + escalator 0% riders	196	16.5	2.6	193	115	92
Scenario 4: Two stairs + esc 100% riders, 50% left, 50% right	210	16.9	3.1	198	101	101
Scenario 5: Two stairs + esc 100% riders, 100% right	221	20.7	3.6	169	117	114
Scenario 6: Two stairs + esc 50% riders, 100% right	210	18.0	3.1	197	101	102
Scenario 7: Two stairs + esc 50% riders, 50% left, 50% right	212	19.7	3.1	197	103	101
Scenario 8: Two stairs + esc 76% riders, 28% left, 72% right	211	18.5	3.1	193	104	103

If we now assume that 100% of the escalator users will ride the escalator and they will equally utilise the left and right location on the escalator tread (Scenario 4) we find that the TET has increased slightly to 210 s. At first glance, this modest 7% increase in evacuation time compared to Scenario 3 does not appear to be logical however, when it is recalled that escalator walkers attempt to keep two treads between them and the person ahead the difference becomes more understandable. When full of walkers, the escalator has a reduced capacity compared with the situation in which it is full of riders. Thus in Scenario 4 the increased apparent capacity of the escalator partially compensates for the reduced travel speed produced by the stationary riders. Thus from a global perspective, in evacuations in which there is expected to be heavy use of escalator/stair combinations, there is little to be gained by having the escalator users walk down the moving escalator. Indeed, there may be advantages in reducing the chances of injury resulting from trips or miss steps by preventing the escalator users from walking. However this conclusion is derived from taking a global perspective, from an individual person's perspective, their personal evacuation time will be reduced by walking down the escalator and so this type of behaviour may be difficult to enforce.

If we consider the extreme of inefficient escalator usage and assume that 100% of the people will ride the escalator and 100% will utilise the right side (Scenario 5) – effectively halving the capacity of the escalator we note that the evacuation time increases to 221 s, a 5% increase over Scenario 4 and a 13% increase over Scenario 3. At first sight this modest increase in the total evacuation time is surprising however, it should be noted that the number of escalator users has decreased by some 15%. Thus the device algorithm has allowed the agents to make use of under utilised capacity on the neighbouring stairs. Had the escalator been the only device linking the two levels, we would have expected to incur a significantly greater increase in evacuation time.

With 50% the escalator users walking down the escalator and all the riders utilising the right side of the escalator (Scenario 6) the average total evacuation time is 210 s, which is 7% slower than the case with 100% walkers (Scenario 3) and equal to the case with 100% riders with an equal usage of both sides of the escalator tread (Scenario 4). This is a complex case with competing trends resulting from increased capacity and decreased speed due to the riders (all to one side) and decreased capacity and increased speed due to the walkers. These effects almost cancel each other however, we also note that the average Cummulative Wait Time (CWT) for Scenario 6 is larger than that for Scenario 3 in which there are 100% walkers. This increase in CWT is consistent with only a single lane being available for the walkers, thus if a walker is caught behind a slower walker, there is no chance for them to overtake and hence they will be forced to travel at the slower speed, hence increasing their personal CWT. We note that for Scenario 7, in which 50% of the escalator users are walkers – as in Scenario 6 - but in which the riders occupy both the left and right lanes, the total evacuation time has increased slightly to 212 s, with a further increase in the average CWT. This is due to the walkers now being impeded in both lanes by riders, making it more difficult for them to pass without increasing their personal CWT.

The final scenario consists of the same distribution of riders with the same distribution of left/right usage as found in the AVATARS data (Scenario 8) i.e. 76% riders with 28% of riders occupying the left lane. Thus the break down of walkers to riders and left/right usage is the same as may be expected in a non-emergency circulation example. Here we find the total evacuation time is 211 s and is consistent with other cases involving 100% riders (Scenario 4) producing a total evacuation time of 210 s and 50% riders (Scenarios 6 and 7) producing evacuation times of 210 s and 212 s. This suggests that virtually any situation with more than 50% riders will produce similar total evacuation times.

5 Concluding Comments

This paper has presented a summarised analysis of human factors data relating to pedestrian escalator behaviour within a Spanish underground station. The dataset provides insight into pedestrian behaviour in utilising escalators and is a useful resource for both evacuation and circulation model developers.

A range of demonstration evacuation scenarios were performed using the newly developed model. The results suggest that under evacuation conditions, in which the simulated agents are assumed to select the device which is expected to produce the minimum total transit time, the best evacuation times can be obtained if all the escalator users walk down the escalator. However, if we assume that all the escalator users ride down the escalator, and that they display an equal preference for the left and right lanes on the escalator there is only a marginal increase in the total evacuation times. These results suggest that from a global perspective, there is little to be gained by walking down the escalator, indeed, under crowded emergency conditions suggesting that escalator users ride the escalator may be a better strategy as it reduces the risk of injuries arising from miss steps. However this conclusion is derived from taking a global perspective, from an individual person's perspective, their personal evacuation time will be reduced by walking down the escalator and so this type of behaviour may be difficult to enforce. In addition, it must also be considered that this analysis is based on a single escalator/stairway group, and any difference between scenarios is expected to be magnified with the addition of other escalators/stairways groups in the geometry.

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