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Mixed logit model of vertical transport choice in Toronto subway stations and application within pedestrian simulation

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Abstract

Pedestrian choice between co-located stairs and escalators in Toronto transit stations was modelled using a set of standard binary and mixed-logit models, incorporating dynamic variables like crowding. While all models had good fit, the ascending direction and restricted-mobility individual choice were more readily predicted. Performance was measured predictive ability of ten-second aggregate flows after implementation in the pedestrian simulator MassMotion. The mixed-logit models performed consistently better than the standard models, with all showing good predictive ability (nearing 90%). There were also significant spreads of accuracy of up to 10% when the way the models were applied by simulation agents was varied.

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Keywords: discrete choice modelling; pedestrian simulation; stairs; escalators; interchange subway stations

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1. Introduction

In recent years, after initially focusing on the modelling of short-range movement, pedestrian-specific route choice models have been a focus of research efforts. Developing a proper understanding of pedestrian choice behavior is particularly important in contexts that consistently experience large movements of people and have multiple levels, such as in mass transit stations. With respect to how pedestrians make level changes, a discrete-choice modelling framework has been a popular methodology for explaining how individuals choose between

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vertical transport (VT) elements like stairs, escalator and elevators. Prior studies, however, have generally considered traditional cost measures like distance and travel time, predominantly ignored dynamic factors, have been limited in the breadth of locations and conditions observed, and/or produced models difficult to apply within a pedestrian simulator, signalling the need for a more expansive and applicable model. To tackle this deficit, this study aimed to devise a set of VT discrete choice models for use in pedestrian simulation, tested within Arup's commercial pedestrian simulator MassMotion. Also of interest was a better understanding of the sensitivity of model performance to the method of application by simulation agents.

2. Existing models of VT choice

The earliest effort of analyzing VT choice was in 1998, when Cheung and Lam investigated pedestrian choice in both directions between adjacent escalators and stairs in six subway stations in the Hong Kong Mass Transit Railway (Cheung and Lam, 1998). In formulating their models, the researchers considered only perceived travel time as influential to a person's choice of facility (Cheung and Lam (1998)). Through the use of a logistic regression model, a preference was found for the escalator in the ascending direction, even in the face of delays, while being sensitive to these delays while descending (Cheung and Lam (1998)).

Several years later, Daamen et al focused on the influence of the presence of different types of vertical transport on the route taken by pedestrians navigating a subway station, by following almost a thousand individuals through two Dutch railway stations. Route choice was examined under various configurations of trip length and trip factors, while ignoring any issues of congestion *a priori* as not being significant. Data was collected in late fall and winter, and included route, personal, and trip characteristics. However, the mathematical model (a multinomial logit with a path-size variable added to handle overlapping routes) contained only observed travel time on each of the segments of the trip (levels, stairs, ramps, escalators) and the direction of travel (Daamen et al. (2005)).

Most recently, three studies refocused on the question of adjacent stair-versus-escalator choice. Zhang et al investigated choice between stairs and escalators during peak hours in three stations in China with varying heights and escalator directions. A disaggregate binary-logit model was developed, with utility functions incorporating distance, walking time, gender and age, and inherent mode bias. Age was only found to be marginally significant for a single station, with walking time only significant in the ascending direction. In addition, a consistently positive and significant value for escalator bias was found. (Zhang et al. (2011))

The second study was conducted at one stair/escalator pair in an Austrian station. In lieu of travel time, a revealed preference (RP) survey of 200 individuals was conducted to acquire their trip purpose, frequency of visit to the location and self-reported walking speed. In addition, some dynamic factors were considered, by taking note of the number queuing with and without luggage. In addition, a stated preference (SP) method was employed by showing individuals video sequences of the location with different levels of crowding and asking them to choose between using stairs or escalators. Mixed-logit models were developed with the results showing a severe overestimation of claims of stair use (SP) compared to what actually occurred (RP). In addition, only the level of luggage-based queuing was found to be significant for the RP study, while differences in perception were found across age, perceived speed and general queuing (Zeiler and Rudloff (2011)).

Lastly, as a precursor to the presented research, a study was conducted using data collected across six subway stations in Toronto. A set of logistic models for use by transit practitioners were developed to predict 10-sec flow splits between escalator and stairs. Variables considered included total flow into the facilities, the level of opposing flow, the mobility of the individuals and the approach direction (Srikukenthiran et al. (2014)).

More aggregated regression methods have also found their place in relating rates of stair and escalator use to physical variables. Simpler in use and application, these techniques are of particular interest in the health and well being field, where there is a wish to promote stair use to improve overall health. They, however, have elucidated some interesting behavior and relationships with respect to pedestrians and stair-escalator choice. Of particular note are findings of behavioral mimicry within stair/escalator choice (pedestrians are more likely to use the stairs if observing others using the stairs when they arrive) (Webb et al. (2011)) and the diminishing return of stair usage with increasing stair width (Eves et al. (2008)).

3. Data collection

Data used for the VT choice models was collected at six stations spread across the subway network in the City of Toronto, Canada. These included the three busiest stations in the network, located in the downtown core, Bloor, St. George and Union, and three suburban stations, Finch, Downsview and York Mills. All platform vertical transitions were surveyed for pedestrian flow, as well as transitions between the upper concourse levels for Finch, Downsview and York Mills. The stations vary in layout and design, but generally consist of a platform level, a surface/bus interchange level and an intermediate concourse level. Multiple stairs, escalator and elevator options exist for pedestrian transition between levels, and stairs and escalators are frequently paired. Observations were made at these co-located stair and escalator pairs, which had varying physical dimensions; stair width ranged from 1.16m to 2.16m, step height of 15-17cm and total heights of 3.4-6.3m, with a single facility at over 13m.

Data collection was completed at each station on Saturday April 14th, Tuesday April 17th and Wednesday April 18th of 2013. Observations occurred over a 15-minute period in each of the weekday morning and afternoon peaks, as well as during the Saturday afternoon shopping period. This spread of time periods was intended to give a wide distribution of pedestrian flow densities and peak flow directions. Two methods of data collection were used. Video recordings were completed at two vertical transitions per station using hand-held devices. Footage was subsequently reviewed manually to extract data.

4. Data processing

Data extraction from video was performed manually, due to the lack of available software capable of automating the process. The data collected included the direction of the escalator, the time of entry of each pedestrian into the facility to the nearest second, the route choice between stair or escalator, the approach direction, and the type of pedestrian, using the London Underground Persons with Restricted Mobility (PRM) categorization which include categories for wheelchair users, luggage, strollers, and other disabilities (Pearce et al. (2008)). It was believed that grouping by this method would be most applicable for mode choice of stair or escalator compared to traditional demographic categories (age, gender, etc.). In addition to these demographic categories not being found significant in prior research, PRM categorization is easier to accomplish and less prone to subjectivity. Across the six stations and 14 stair/escalator pair locations, over 25 thousand individual pedestrian choices were extracted from video.

The models of VT choice were developed based on the assumption that individual's decision of which facility to take would be dependent on the physical characteristics of the facility, the mobility group of the agent, overall pedestrian flow, the decisions of other pedestrians, and how the facility is approached. Since only the time of entrance, the mobility group and choice of facility were reliably extractable from the video, information about queuing levels and overflow had to be derived from this entrance-time data as detailed below.

Under these conditions, it was not feasible to discern the exact queue size and the range of pedestrians at the stair-escalator set ahead of a given pedestrian that influenced his choice. As a result, a different approach was used in this study, by simultaneously determining the appropriate time ranges to use to calculate the queue length and stair-escalator occupancy while estimating the models. To accomplish this, software was written to allow for on-the-fly calculation of the variables of interest from the individual entrance-time points, paired with batch estimation of the models. The ranges chosen were those that produced models with the highest degree of fit. This method was dependent on the assumption that the proper durations to use when determining queuing and stair and escalator usage would be the ones that maximized the predictability of the developed models. Because it was expected that pedestrians might consider these ranges differently depending on the direction, these values were calculated separately for the ascending and descending directions.

Using this approach, the following variables were extracted for each person moving in the direction of the escalator, in addition to their direction and whether they fell under a PRM category. The variables chosen were those that could be realistically used when the model was implemented within MassMotion:

Stair Use Factor – SF: Number of pedestrians who had entered the stairs in advance of the pedestrian at the time of choice multiplied by the ratio of staircase lanes to the total lanes (75cm lane-width for stairs as per TCQSM guidelines, and the observed number of lanes for escalators). The use of relative stair capacity was predicated on the expectation that the coefficient would be positive based on the follow-the-leader behavior and diminishing returns of stair width found in prior research (Eves et al. (2008); Webb et al. (2011)).

Opposing Density – OD: Number of pedestrians per lane who would be opposing the pedestrian if they chose to use the stairs. This was assumed to be the number of pedestrians who would have entered the opposite end when any given pedestrian began his/her ascent or descent. Since no data was collected at this opposite entrance, a time period of aggregation was used based on the average walking speed up or down stairs as measured in the field.

Escalator Use Factor – EF: Number of pedestrians who had entered the escalator in advance of the pedestrian at the time of choice multiplied by the ratio of escalator lanes to the total number of lanes.

Queue Factor – QF: Number of pedestrians queuing at the escalator and stairs together at the time the choice was made. Without a proper assessment of whether queuing was in fact occurring based on the time-series data, a 'queue' in this case was assumed to consist of any pedestrian ahead of the individual at the time of choice. As with the staircase density, this value was multiplied by the percent of lanes that were stairs.

Stair Approach – SA: A 0 or 1 value representing whether a pedestrian accessed the facility from the stair side.

Height – H: The total height of the facility in meters.

5. Model framework

Both standard binary logit and binary mixed-logit models were developed. With insufficient numbers of , binary logit models were only attempted for that type of individuals; both binary logit and mixed logit models were estimated for those without restricted mobility (referred to as PRMN). The mixed-logit is a generalized and more flexible form of the logit model, eliminating limitations with the base model by allowing for taste variation and time-based correlation of unobserved factors over time (Train (2009). This ability to introduce taste variation is particularly useful for pedestrian modelling, permitting parameter coefficients to have a distribution rather than remain fixed for all individuals. The formulation is stated as shown below for the probability of decision maker *n* selecting alternative *i* with utility $V_{ni}(\beta)$ and parameters β:

$$P_{ni} = \int \frac{e^{V_{ni}(\beta)}}{\sum_j e^{V_{nj}(\beta)}} f(\beta) d\beta \tag{1}$$

Separate models were estimated for the two directions, ascending and descending. The utility functions were similarly structured, but with slightly different variables, most noticeably either a normal or lognormal distribution for the queue density parameter; the former assumed that it is possible that pedestrians might be attracted to queues, while the latter assumes that they either generally ignore queues or are repulsed by them. The two utility functions for the stairs str and escalator esc are shown in Equations 2 and 3. The height variable H provides the base preference for the escalator.

$$V_{str} = \beta_{OD}OD + \beta_{SF}SF + \beta_{SA}SA \tag{2}$$

$$V_{esc} = \beta_H H + \beta_{EF}EF - \beta_{QF}(\mu, \sigma)QF \tag{3}$$

For the standard binary logit models, the two utility functions were identical to those in Equations 2 and 3, but with a σ value of 0 for the queue factor parameter.

6. Model estimation

The process of model estimation was simultaneously performed along with data extraction through a developed program, with estimation handled by the discrete choice modelling software BioGEME. Since the mixed-logit model uses an arbitrary distribution for specified parameters, the software uses a simulation process to minimize the log-likelihood function. Each step in the software involved generating the variable data based on the corresponding combination of variable aggregation periods before estimation with BioGEME. After all runs, the resulting model estimation output was processed to consolidate results and extract goodness-of-fit data and final parameter values. The goodness-of-fit measure used was ρ, defined as the change in log-likelihood relative to the null model.

The final models for use in the next step were those that maximized ρ, with one selected for each type (binary or mixed logit), direction (ascending and descending), for a total of 6. A step-wise backward elimination process was conducted for non-significant variables (α of 0.05) to result in the final models shown below, where t-values are provided in brackets for the parameters and the p-value for the model in brackets beside the utility name. As is clear in the equations, better results were found in estimation models for the ascending direction, with pedestrians known to distinguish less between stairs and escalators in the descending direction due to the reduced effort required. All parameter signs were as expected, with the positive stair and escalator factor parameters both reflecting the mimic or follow-the-leader behavior of pedestrians, and negative parameters for opposing stair flow and queuing. With ρ values not directly comparable between different model types, evaluation of the mixed-logit versus binary-logit was left to the validation step.

6.1. PRMN models

$$\begin{aligned} V_{asc,mixed}(\mathbf{0.394}) = {} & 0.313\,SF\,(\mathbf{8.86}) - 0.275\,OD\,(\mathbf{-9.28}) + 0.452\,H\,(\mathbf{25.11}) \\ & + 0.584\,EF\,(\mathbf{9.52}) - LogN(-0.663,0.944)\,QF\,(\mathbf{-7.78,14.13}) \end{aligned}$$

$$\begin{aligned} V_{asc,binary}(\mathbf{0.385}) = {} & 0.151\,SF\,(\mathbf{8.49}) - 0.170\,OD\,(\mathbf{-12.79}) + 0.392\,H\,(\mathbf{32.78}) \\ & + 0.286\,EF\,(\mathbf{11.62}) - 0.486\,QF\,(\mathbf{-17.07}) \end{aligned}$$

$$\begin{aligned} V_{desc,mixed}(\mathbf{0.176}) = {} & 0.198\,SF\,(\mathbf{5.59}) - 0.275\,OD\,(\mathbf{-5.42}) + 0.879\,SA\,(\mathbf{6.08}) \\ & + 0.333\,H\,(\mathbf{14.21}) + 0.246\,EF\,(\mathbf{3.98}) - LogN(-1.57,1.68)\,QF\,(\mathbf{-7.00,7.35}) \end{aligned}$$

$$\begin{aligned} V_{desc,binary}(\mathbf{0.171}) = {} & 0.141\,SF\,(\mathbf{4.91}) - 0.151\,OD\,(\mathbf{-6.96}) + 0.664\,SA\,(\mathbf{5.92}) \\ & + 0.277\,H\,(\mathbf{17.21}) + 0.099\,EF\,(\mathbf{2.95}) - 0.254\,QF\,(\mathbf{-7.69}) \end{aligned}$$

6.2. PRM models

$$\boldsymbol{V_{asc,binary}}(\mathbf{0.492}) = \mathbf{0.654}\,\boldsymbol{H}\,(\mathbf{11.03}) - \mathbf{0.776}\,\boldsymbol{QF}\,(-6.59)$$

$$\boldsymbol{V_{desc,binary}}(\mathbf{0.287}) = \mathbf{0.351}\,\boldsymbol{H}\,(\mathbf{-4.25}) - \mathbf{0.275}\boldsymbol{OD}\,(\mathbf{-2.07}) - \mathbf{0.539}\,\boldsymbol{QF}\,(\mathbf{5.75})$$

7. Model validation and performance

Model validation was performed in two stages. The first step involved analysis of the individual choice predictions of each of the models. The main validation, however, was in their performance within their intended target, pedestrian simulation software. In the initial step, the developed models were used to attempt to recreate the input choice data using Monte Carlo simulation in Excel, with the percent predicted correctly calculated. Simulations were repeated several hundred times for each model and averaged. Moderate success was found in predicting individual choices, with significantly better performance in the ascending direction (mid-high 70% versus mid 60%); the mixed-logit models also performed marginally better (around 1%) than the binary logit models, attributable to an improved failure rate in correctly predicting stair use.

The main form of validation used in this study was an analysis of the performance of the developed models when incorporated into Arup's pedestrian simulation software MassMotion. As VT choice is dynamic by nature, the performance of the models could only be properly assessed in the dynamic simulation environment where they could be combined with the software's walker model governing agent motion. There was also a need to examine how model performance was influenced by the way simulation agents applied them.

The models were incorporated by modifying the MassMotion route choice model to use the VT choice models in cases of grouped stair and escalator sets. This choice function override was programmed to determine the variables required at each simulation step, and then perform the choice between co-located VT facilities based on the input models (one for regular agents, and one for PRM groups). In addition to model parameters, model application settings were also incorporated to analyze the sensitivity of model performance to the way the models were applied by the simulation agents. Specifically, they allowed modification of the distance from the facility at which the initial choice was made, the cut-off distance after which agent choice would be finalized, and the maximum number and time between choices. As the situation faced by agents was dynamic, dependent on the choices made by those surrounding them, these settings affected the responsiveness of the agents to changing crowding conditions.

To perform the validation, 3D models of all the observed VT facilities were built in MassMotion, and separate software was developed that automated both the simulation runs under the different models and processed the output data to measure performance. For all combinations of PRM and PRMN models, the software generated streams of agents into MassMotion of varying number and PRM constitution, repeating the process thousands of times. This produced flows through the VT elements in the simulation model of varying characteristics. Output data was then processed to extract these 10-sec flow characteristics, namely the total incoming flow, the total opposing staircase flow, the % PRM, and the escalator split. Each 10-sec situation was examined individually against the real-world data, with a success rate determined as the percentage of situations where a statistical difference (α of 0.05) was not found. The results are summarized in Table 1, showing a 10% difference in accuracy based on model application parameters, but general good performance of the models; of particular note was the accuracy of the descending models, even while individual performance was mediocre.

Table 1. Model performance in predicting 10 second flows in MassMotion.

Direction	PRMN	PRM	Min Accuracy (%)	Max Accuracy (%)
Up	Binary	Binary	77	87
Up	Mixed	Binary	79	89
Down	Binary	Binary	78	87
Down	Mixed	Binary	82	91

8. Conclusions

This study was the final step in a collaborative research program to expand understanding of pedestrian choice at co-located stair and escalator facilities in transit stations. A set of discrete choice models were developed that showed a promising ability (nearing 90%) to predict aggregate flow splits within pedestrian simulation when time was taken to tune parameters of model application. Nevertheless, the environment studied, while common, was spatially localized, albeit at a key station bottleneck. As a result, there remains a research path open towards incorporating these results within a broader understanding of station routing behavior.

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