# HUMAN MOVEMENT BEHAVIOUR IN SOUTH AFRICAN RAILWAY STATIONS: IMPLICATIONS FOR DESIGN

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## ABSTRACT

The results of a video-based observational study aimed at exploring pedestrian movement behaviour within South African railway station environments is presented, in particular the macroscopic fundamental relationships of speed, density and flow incorporating the ways in which these variables might be influenced by the various personal, situational, and environmental factors that characterise the context in which pedestrians move. The movement trajectories of 24410 pedestrians were investigated in a video-based observational study of three infrastructure environments viz. platforms, stairs and skywalks at Maitland and Bonteheuwel stations in Cape Town, South Africa. Assessment of boarding and alighting rates of 7426 passengers was also observed at these stations. Age, gender, body size, mobility, group size, time of day, and location were contributory attributes observed with each dataset.

Tracking pedestrians was done via the use of an in-house developed "video annotator" software tool, to enable an operator to manually mark pedestrians on video files. The marks form a track for each pedestrian, and all the tracks on a video file are recorded into a corresponding data text file.

The operator can further document each tracked pedestrian with additional attributes, such as gender, age, type of luggage carried, impairment/disability, destination, activity, or any other recognisable criterion we may want to study.

The objective of the study was the determination of various walking speed histograms and the development of macroscopic fundamental relationships that can be applied to calibrate microscopic pedestrian models for local conditions.

## 1 INTRODUCTION

Modellingpedestrian movement patterns through space is becoming an increasingly important goal of transport station planners, particularly when addressing the needs of individual station users based on the trade-off between LOS and infrastructure costs. Modelling aids in avoiding both under-provision (detrimental to operations) and oversizing of railway station sizing requirements (with obvious financial implications).

Such modelling is howevercomplicated as a result of the large number of variables, relating to both the pedestrians themselves and to the situations and environments in which they find themselves.

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Simulation models offer a potential means by which planners can predict the movement patterns of large numbers of pedestrians as they ambulate through various urban spaces. However, in order to be ofvalue as an evaluative tool, any microscopic model must yield a meaningful output that can be readily used by planners to evaluate the adequacy of pedestrian areas.

The understanding of how pedestrians behave at a microscopic level, and how their behaviour is shaped by the various personal, situational, and environmental factors that characterise their interactions with urban spaces remains poor with limited research carried out in this country. Accordingly, there is widespread agreement that a more comprehensive appreciation of how pedestrians negotiate space is required to enhance the validity and reliability of models (see Hoogendoorn*et al.* 2003; Kerridge*et al.* 2001; Turner and Penn, 2002). The empirical observations undertaken in this research are the direct inputs that are required in most pedestrian microscopic models.

In this paper, we attempt to partly address this shortcoming through the empirical study of pedestrian movementsobserved attwo local train stations. Specifically, our study aims to characterise the elements of behaviour fundamental to all pedestrian models (namely, walking speed and fundamental relationships), and how they vary according to personal, situational, and environmental characteristics. The study forms part of a larger research project concerned with developing a spreadsheet-based model for the evaluation of spatial parameters of railway stations (SP-Model). The findings should prove useful to any researcher in South Africa interested in designing more effective pedestrian spaces and in modelling pedestrian behaviour at a microscopic level. The research was limited to walkways, platforms and staircases only.

## 2   DATA COLLECTION

### 2.1   Background

The study represents the first survey of microscopic movement pedestrian behaviour in railway station environments in South Africa using video-based techniques. There are several problems associated with this type of survey. Firstly, the main disadvantage with thistypeof approach is thelimited video depth of field, which arises when the camera is not positioned 90° above the observed area. Secondly, tracking the trajectories of pedestrians as they negotiate the observation areais technologically challenging, and laborious. Recent developments in digital image capture and processing provide the potential for more accurate, automated methods of trajectory tracking (for example, Hoogendoorn*et al.*, 2003;Teknomo*et al.*, 2001): but no techniques are yet available that allow for the automatic tracking of pedestrians with an acceptable degree of reliability. For the purposes of this study, a semi-automatic tracking computer programwas developed.

#### a.   Sample

The microscopic movement trajectories of 24410 pedestrians were observed in a video-based observational study of three infrastructure environments viz. platforms ($n = 3455$), stairs ($n = 9520$) and skywalks ($n = 11435$) at Maitland and Bonteheuwel stations in Cape Town, South Africa. Observations of boarding and alighting rates of 7426 passengers was also observed at these stations. Age, gender, body size, mobility, group size, time of day, and location were the contributory attributes observed.

b. Procedure

Video footage was collected for both stations using digital camcorders mounted on tripods located on the roof of the station building. The recording frame rate was 25 frames per second in all cases.

i. Data Recording

Pedestrian data collection through video recordings focused on a pedestrian area defined as the "measurement area"pre-marked with chalk.In all cases, the video camera views were from above but not necessarily from vertically above, which placed a restriction of the measurement area size that could be observed. The measurement area rectangle was projected vertically to produce a measurement plane of average "top-of-head" height at 1.65m. This was achieved by placing a calibration stick on corners of the measurement area (refer to Figure 1).
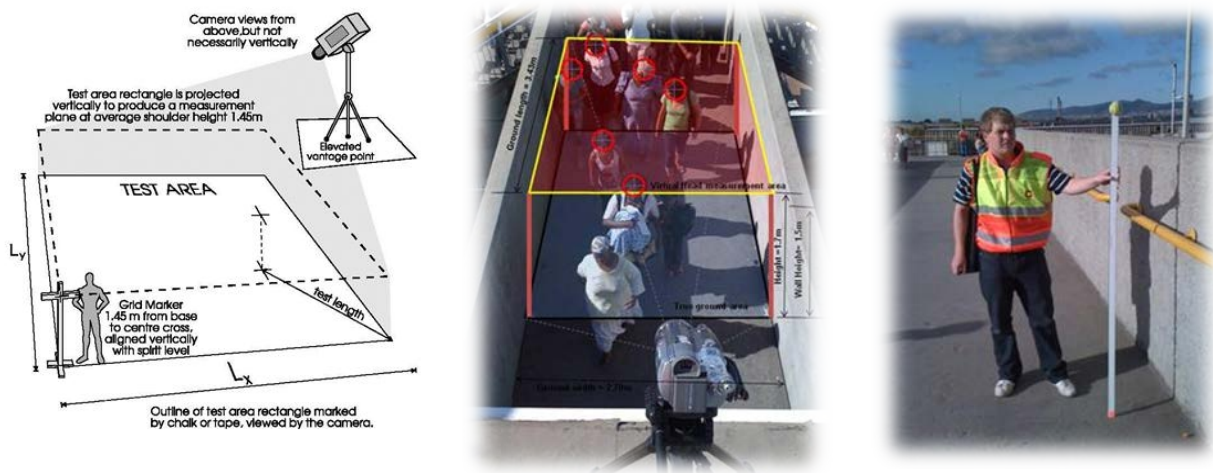


**Figure 1: Measurement area, project video plane and calibration stick**

Video recordings were conducted during the AM and PM peaks from 4 Dec 2009 to 9 Feb 2010 and restricted to one hour sessions per video camera due to tape length and battery life limitations. A total of 43 hours of footage was recorded for the various infrastructure categories.

ii. Development of Head Tracking Software

This section describes how the data was processed from raw video format to a quantative format. The data processingincorporated the semi-manual tracking of each pedestrian head from the moment they entered the measurement area until they exited.

With the assistance of the Computer Science Department at the University of Stellenbosch, software(*Headrecorder*)was produced over a four-month period in 2009.To measure the position of every pedestrian per selected frame, the software provided a target crosshair tool to follow the subject head and extract the screen XY coordinates upon a mouse click. The coordinates were automatically saved to a text file which could be repeated for every frame if so selected. To avoid occlusion at high densities, the head of each pedestrian was taken as the tracking point.

For each tracked pedestrian, the output is automatically exported to a text (".txt") file consisting of the following data:

- The total number of frames in the video file.
- The screen co-ordinates of the measurement area.
- The unique id of the pedestrian.
- The associated frame number.
- The location of the pedestrian head of the tracking (tracked) person(s) in terms of *x* and *y* screen co-ords or screen pixels.
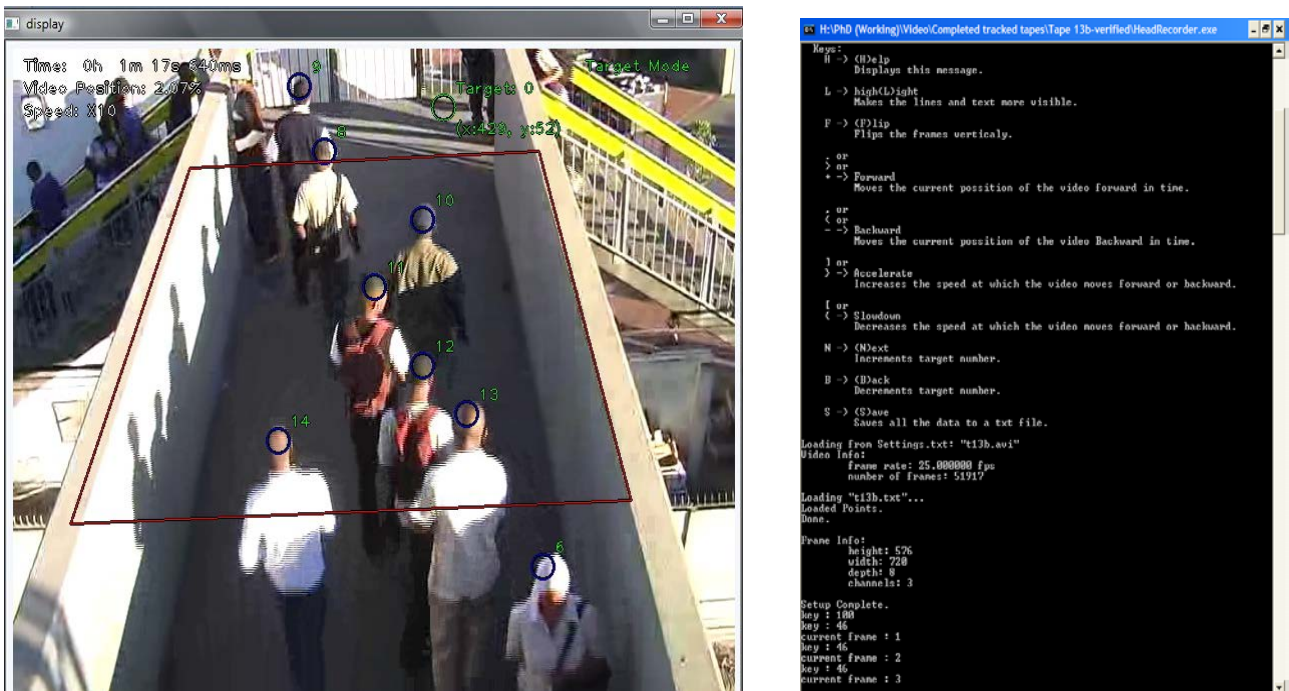


**Figure 2: Example of the "*Headrecorder*" tracking screen**

The process of tracking using "*Headrecorder*" could not automatically identify pedestrian attributes such as gender, disabilities etc. and so a second file was manually inputted for each pedestrian ID no. For each ID no., Gender, Age, Person size, Group size, Mobility and Movement type was manually inputted (by visual recognition) separately. Refer to Figure 2 for a sample of the "*Headrecorder*" interface screen.

# 3   SITUATIONAL EFFECTS ON OBSERVED WALKING SPEEDS

In the following sections, the results of a variety of personal, situational, and environmental factors on pedestrian walking speedsare presented. Results presented in this paper have been limited to Platform and/or Skywalk observations only.

## 2.1   Effect of Gender

Men walked, on average, faster than women. This difference (1.19 versus 1.01 m/s) was highly significant, tested with the Students t-testat a 5% significance level. Variability was slightly higher amongst males unlike the platform dataset, but walking speeds were normally distributed around the mean in both groups. Figure 3 shows the gender specific histogram of walking speeds for (a.) males and (b.) females for Skywalk data only.
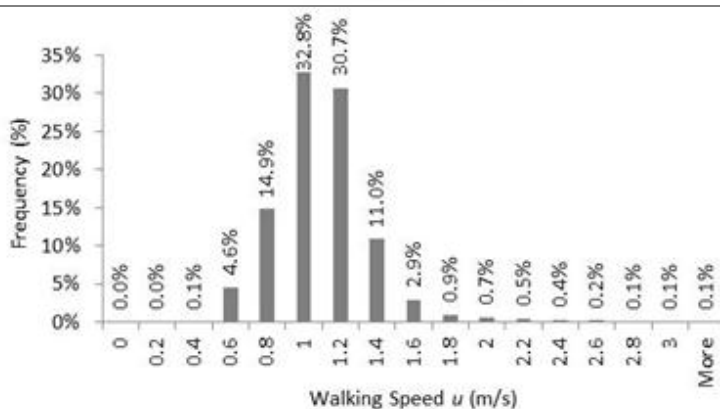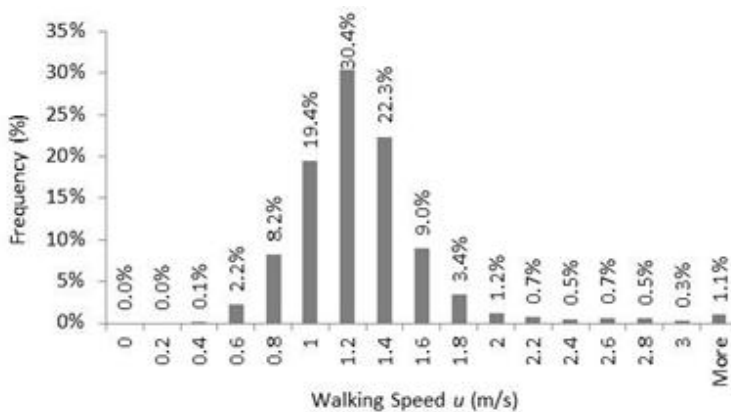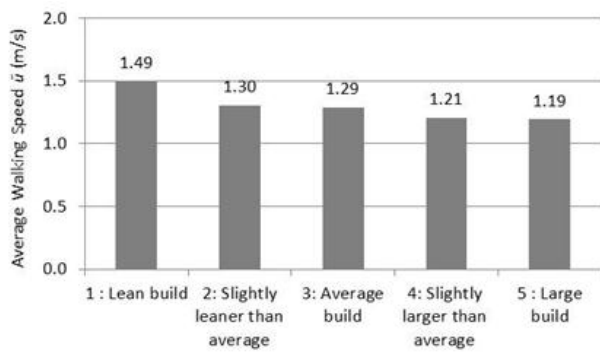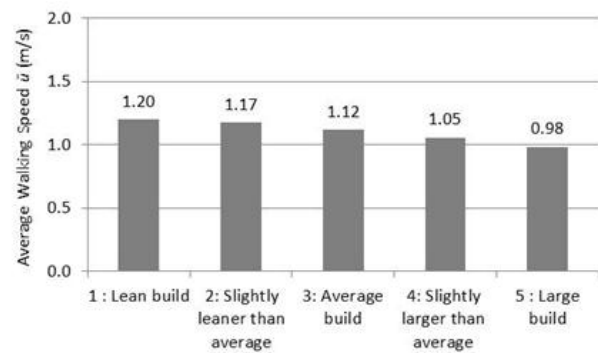


*(a.)Males:*
*Mean: 1.19 m/s, n = 7166*



*(b.)Females:*
*Mean: 1.01 m/s, n = 5325*

**Figure 3: Effect of Gender on walking speeds (Skywalk only)**

### a.   Effect of Person Size

The results of the analysis, isolating the "Person size" variable, is shown in Figure 4 (a.) for males and Figure 4 (b.) for females. The results clearly show a decreasing trend in average walking speed (for both genders) with increasing body size viz. identified from 1 to 5.

*(a.) Males (n = 1431)*      *(b.) Females (n = 1352)*

**Figure 4: Effect of Person Size on walking speeds (Platform only)**

A Students t-test shows significant differences between body types 1 and 2 and all other body type walking speed averages at the 5% level of significance.

b. <u>Effect of Group Size</u>

Figure 5 shows the effect of group size on average walking speed. Single pedestrians walked faster (average at 1.22 m/s) than those walking with one or two companions (1.02 and 0.92 m/s respectively), with data for both populations falling normally about the mean. The difference in desired walking speed between singletons and groups of two was highly significant when tested with the Students t-test at the 5% significance level. Difference between the means was also determined to be significant between the walking speeds of groups of two and groups of three or more persons.
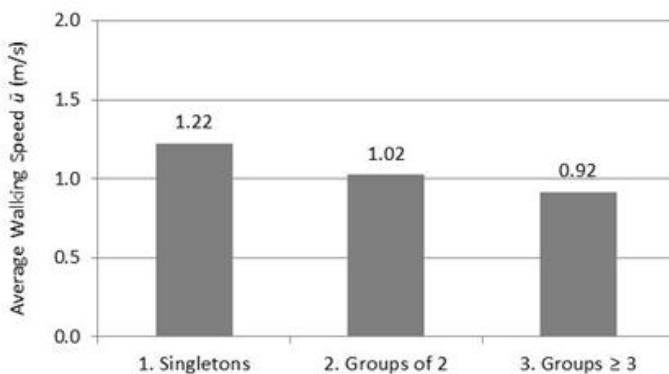


**Figure 5: Effect of Group Size on walking speeds (Platform only),** *n = 2783*

c. <u>Effect of Baggage on Mobility</u>

Figure 6 shows the effect of baggage on walking speeds. A Students t-test confirmed that unencumbered pedestrians ("Group 0") did not walk significantly faster than "Group 1", ie. the sample that walk with rucksacks with both straps engaged, in other words "Group 1" could be classified as unencumbered pedestrians. "Group 0" did however walk significantly faster on average, than Groups "2" and "3".
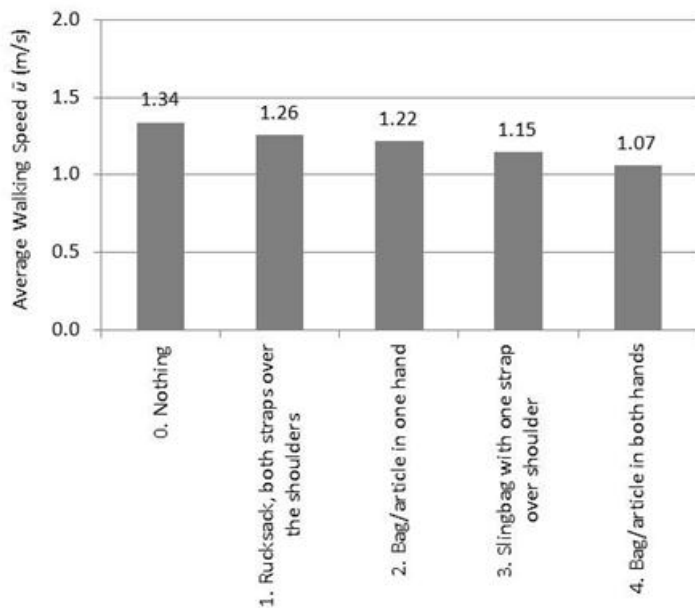
**Figure 6: Effect of Baggage on walking speeds (Platform only), *n* = 2783**

The overall conclusion of this particular observation reveals significant difference in walking speed between pedestrians not carrying (Groups 0 and 1) and carrying baggage (Groups 2 to 4), which is contrary to the findings by Fruin (1971), Whyte (1988), Young (1999) and Davis and Braaksma (1988). Our observations however collaborate the more recent findings of Knoblauch, Pietrucha and Nitzburg (1996) and Willis *et al.* (2004) where it was found that pedestrians carrying baggage have significantly slower walking speeds than pedestrians without baggage.

2.5    Different Movement Types

Figure 7 shows that boarding passengers walked significantly faster on platforms (at an average of 1.54 m/s) than alighting passengers (1.24 m/s) and waiting passengers (1.04 m/s).By way of definition, "alighting" passengers are defined as all passengers tracked after train arrival walking towards the staircases en route to the concourse. "Boarding" passengers are defined as all passengers tracked on the platform arriving from the staircases onto the platforms once a train visibly enters the station. "Waiting" passengers are defined as being similar to "boarding" passengers, but before the train visibly enters the station.
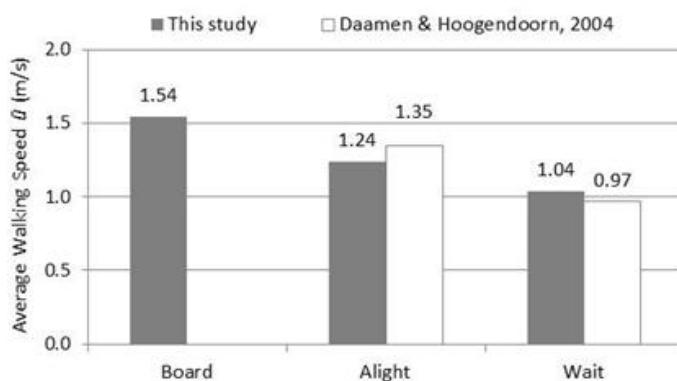


**Figure 7: Effect of Movement Type on Mobility (Platform only), *n* = 2783**

In our study, an average boarding (waiting) speed of 1.04 m/s and alighting speed of 1.24

m/s is calculated, a difference of 19.2%. The "Waiting" speed comparison between our data and the data collected by Daamen and Hoogendoorn (2004) is very similar with only a 6.7% difference between the average speeds.

## 2.6 Cross Correlation of Factors

The cross factor influences on average walking speeds was evaluated in the original research. It was found that the female population was biased towards the larger body frame categories when compared to the males who were more normally distributed about the normal body frame size. Average walking speeds nevertheless decreased with increasing body size when isolating genders. It was also found that almost 20% of females walked in groups of 2 or more when compared to only 9% of males. Again, for both genders, walking in groups resulted in a lower walking speed although the difference was smaller for females.

In terms of mobility constraints, 78% of the female population were found to carry a slingbagor large handbag compared to only 39% of the male population. Also 26% of males were not encumbered with any luggage compared to less than 2% for females. Again, despite the bias of females to carry slingbags or large handbags, the speed differences between males and females across all categories ranged between 3.17% to 19.35%, with males always exhibiting the higher speed.

## 2.7 Passenger Arrival Rates

For modelling purposes, it is necessary to identify the passenger arrival rates (PAR) of the boarding passengers assigned to a particular train. Due to the operational nature of Bonteheuwel Station as a transfer station, the Passenger Arrival Rate (PAR) analysis is influenced by transferring passengers from other platforms.

Only staircase data could be used to derive PAR as the video angle for this dataset allowed for observation of train arrivals and departures. Figure 8 shows the PAR for each one minute period up to ten minutes prior to train arrival. The data is derived from a sample of 2872 arriving passengers catching 14 trains for both AM and PM periods.
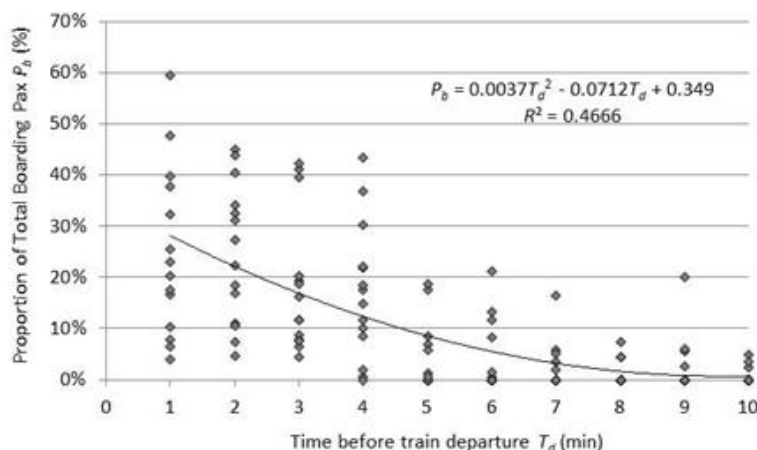


The chart shows the equation $P_b = 0.0037T_d^2 - 0.0712T_d + 0.349$ with $R^2 = 0.4666$. The x-axis is labeled "Time before train departure $T_d$ (min)" and the y-axis is labeled "Proportion of Total Boarding Pax $P_b$ (%)".

**Figure 8: Passenger Arrival Rate at Bonteheuwel Station (AM and PM Period)**

The graph shows a greater proportion of passengers (> 10% per minute) arriving on the platform between 0 to 4 minutes prior to train arrival with fewer passengers arriving (< 10% per minute) arriving after the five minute waiting period.

# 4   PEDESTRIAN FLOW PARAMETERS AND RELATIONSHIPS

The scatter plots of the relationships between pedestrian flow, density, and speed were drawn for the skywalk and stair facilities and will be shown and discussed in the following sub-sections.

## 2.1   Flow-Density Relationship by Facility

A general observation of the resultsis that pedestrian flow rate gradually decreases with increasing density, as shown in Figure 9, but for the stairs, the speed–density relationship peaks at a much lower flow rate.A second-order polynomial regression equation was fitted to the data points. Note the reduced variation in flow rate observations for LOS E and F density categories. This is attributable to the reduced opportunity for pedestrians to select their free speed at higher densities**.**
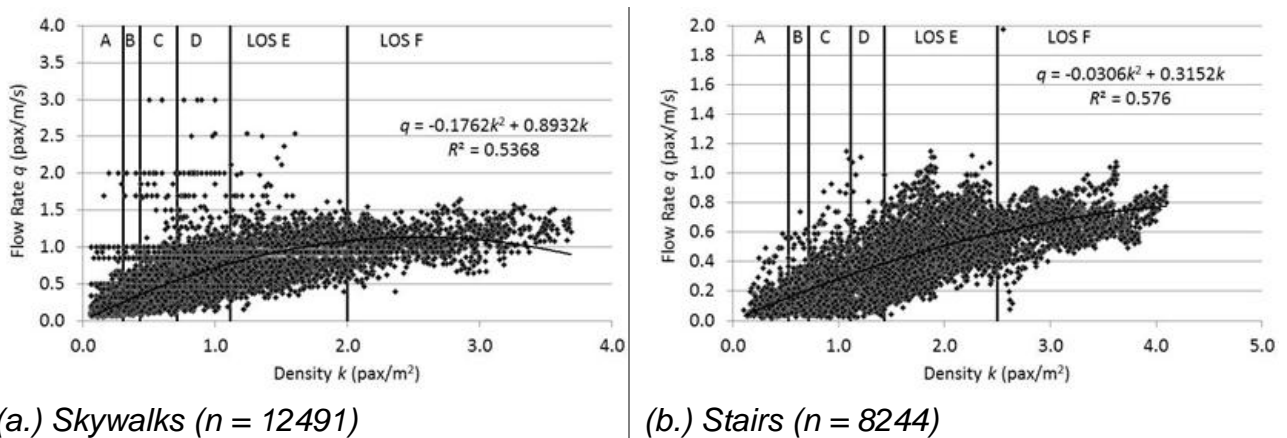


(a.) Skywalks (n = 12491)          (b.) Stairs (n = 8244)

**Figure 9: Flow Rate vs. Density Relationship**

## 2.2   Speed-Density Relationship by Facility

From the results shown in Figure 10, speed decreases linearly with increasing density as expected, but stair speeds decrease quicker at twice the rate of the flat walking surface.
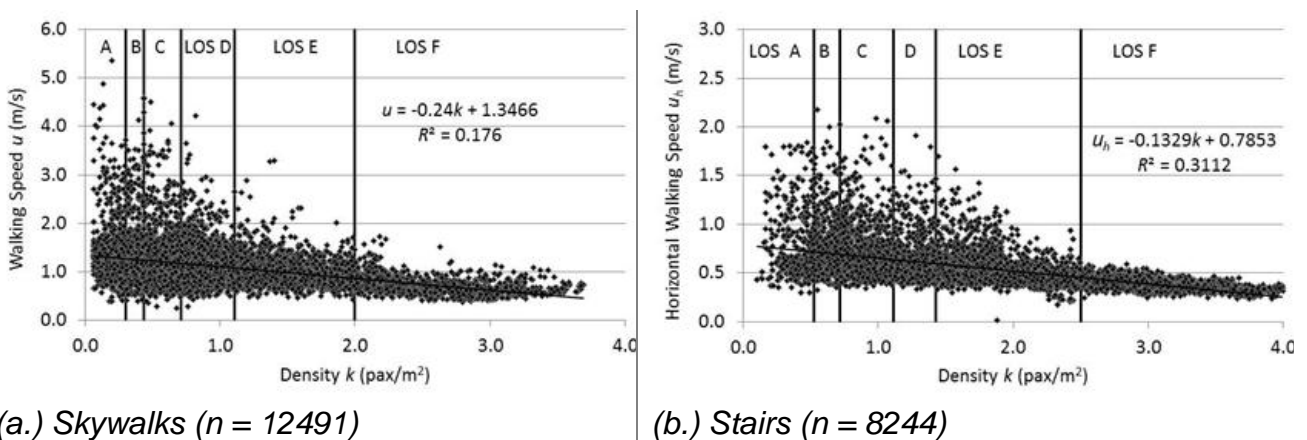


(a.) Skywalks (n = 12491)          (b.) Stairs (n = 8244)

**Figure 10: Speed vs. Density Relationship**

The high variability observed at low LOS is as a result of the pedestrians' ability to select their preferred free-flow walking speed.Although the fitted linear equation displays poor $R^2$ values, the linear relationships arenevertheless statistically significant at the 5% level of significance (i.e. P-value < 5%).

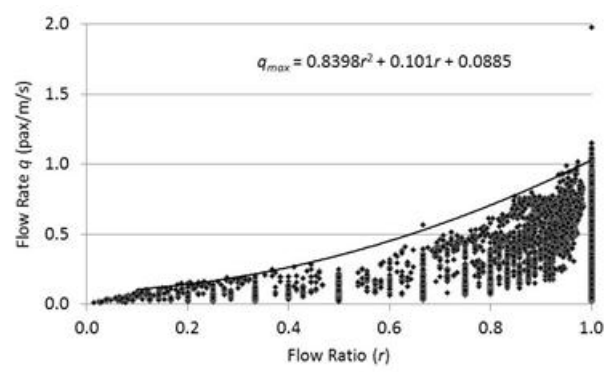### 2.3    Impact of Flow Ratio Flow Rates

The flow ratio parameter (*r*) is defined as the passenger volume in one direction divided by the volume in both directions for a particular time interval. In this research, flow ratios were calculated for every pedestrian observed. The relationship between flow ratio and pedestrian flow rate was explored individually according to the time interval that the target person was within the measurement area.

From the results of the observations (see Figure 11), the lower flow ratio of the skywalk gives lower maximum flow rate values over all densities. This correlates to research which revealed that lower flow ratiosresult in lower capacities (Blue and Adler 1999; Cheung and Lam 1997; Lam *et al.* 2003; Wang and Liu 2006 and Hoogendoorn*et al.*2007).)

Each data point in Figure 11 represents a pedestrian identified by the flow ratio they are in viz. either in the minor or major flow together with the overall flow rate observed.
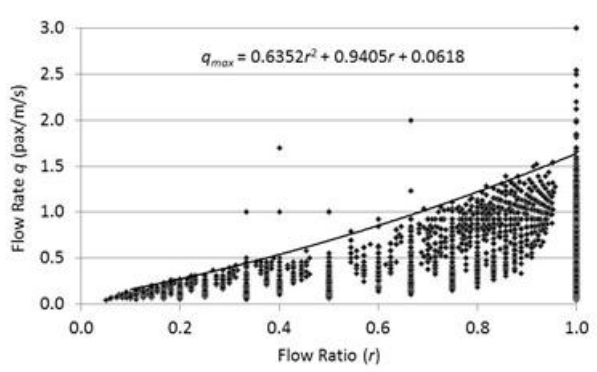


*(a.)Skywalks (n = 12491)*                    *(b.) Stairs, both directions (n = 8244)*

**Figure 11: Impact of Flow Ratio (*r*) on Flow Rates (*q*)**

From the skywalk graph, we observe a maximum flow rate drop from 1.6 pax/m/s at $r = 1.0$ to around 0.2 pax/m/s at $r = 0.1$, an 87.5% drop in the particular uni-directional flow rate. Similar results were obtained by Blue and Adler (1999) who reported a 90% drop at $r = 0.1$.

## 5    BOARDING AND ALIGHTING RATES

A plot of cumulative boarding and alighting (B&A) passenger (pax) volumes against cumulative boarding and alighting times per single train coach door is shownin Figure 12. A limitation of the study was that on-board passenger volumes could not be observed, but as the surveys were conducted during peak periods, the coaches were consistently between 80 to 100% of carrying capacity.
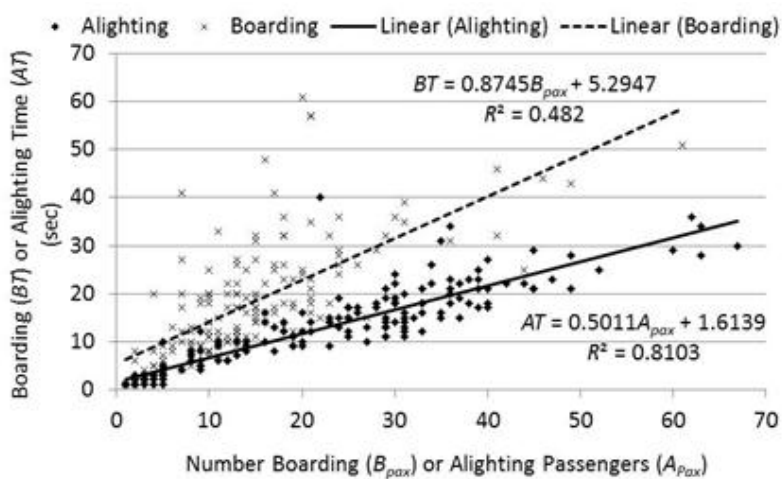
**Figure 12: Cumulative B&A Times for various Pax volumes (per coach door)**

From the data and graph, the following can be determined:

- Despite the limitation identified above, both linear relationships were found to be significant with the P-value less than the 5% level of significance.
- Boarding times are always slower than alighting times, for all passenger volumes. The reasons suggested for this is because boarding activity is influenced to a certain extent by the existing coach occupancy (which was not observed) and/or that there is less urgency in the boarding process.
- The variance of the alighting times is much smaller than the boarding time variance with the result that the correlation coefficient for alighting is good i.e. $R^2 = 0.81$ when compared to a $R^2 = 0.48$ for the boarding passenger data. The fact that the $R^2$ for the boarding rates is lower when compared to the higher $R^2$ for the alighting data suggests that the on-board volume influences the boarding rate to a greater extent than the alighting rate.
- Boarding time appears to require about twice the amount of time for all passenger numbers than alighting time for the same passenger volume. For example 40 alighting passengers take about 20 seconds to alight whilst 40 boarding passengers take 40 seconds to board the train.

## 2.1 Comparison of Door Capacities

Figure 13 shows individual alighting and boarding rates observed from international studies compared to the local study. For the purposes of the plot; only reported data is shown; i.e. if only ranges only are reported, then the mean (red line) is not plotted and vice versa.

From graph, the average alighting rate (0.64 s/pax) observed in this study was found to be the lowest of the international B&A dataset reviewed. The alighting rate data range observed in this study is similar to the range observed by Harris and Anderson (2006) with the average rate only slightly lower than the alighting rate of 0.7 s/pax calculated for a 30 cm vertical clearance (using a linear relationship) from the Daamen *et al.* (2008) data.

The local boarding data appeared to be well within the ranges observed internationally. We note very high rates for the TCQSM data (TRB, 1999), particularly those associated with steps, but it is not clear if the data is associated with commuter travel or longer distance travel passengers.

The average boarding door capacity was found in this study to be 1.34 ± 0.78 sec/pax, similar to the overall average door capacity ranges and averages observed by Harris *et al.* (2006) and Zhang *et al.* (2008) respectively. The data ranges shown by Daamen*et al.* (2008) in the graph are narrow as the values plotted refers to the average rate observed over a range of vertical gaps and the sensitivity in vertical clearance in this case (ie. from 20 to 60 cm) is not that sensitive.

A limitation of the B&A observations in this study was that no record of passengers carrying luggage was taken, nor was the crowding levels on-board the train at the time of the boarding or alighting activity identified. Due to lack of B&A research worldwide, we further note that the results in this study are only compared against the results of first world countries, and our conclusions should be viewed within the context of this limitation.
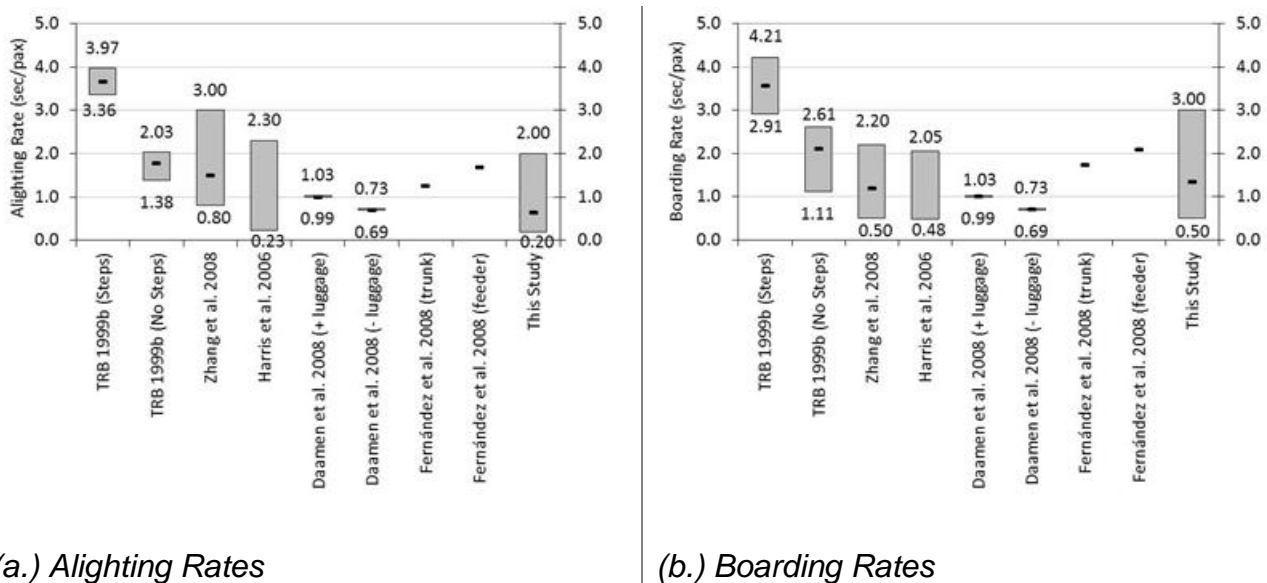


(a.) Alighting Rates    (b.) Boarding Rates

**Figure 13: Comparison of B&A Rates with other International Sources**

## 6   DISCUSSION

The findings presented in this paper indicateseveral factors that influence pedestrian movement behaviour within the railway station environment. The results should prove useful both to designers of railway stations and to pedestrian modellers by providing the situation specific default parameters required by the pedestrian models.

This study describedseveral of the most fundamental elements of movement behaviour that may be used by modellers to assign realistic values to each modelled pedestrian according to a range of simple parameters(for example, the walking speed histogram).

Which factors affect the values of these parameters also provide an insight into how a realistic distribution of values might be chosen for a particular environment: eg. different walking speed distributions for various infrastructure types.

Our results should also prove useful not only in the calibration of movement parameters by planners and modellers of pedestrian spaces, but also in highlighting a number of behavioural phenomena that might be expected to emerge from any realistic model of individual movement behaviour. One example isthe impact of bi-directional flow on infrastructure capacity or boarding and alighting rates.

A more comprehensive understanding of how pedestrians negotiate spaces is essential to the development of models that aim to help in the design of effective pedestrian space, and this researchshouldproveofbenefittoplanners, policymakers, andmodellers interested in creating more pedestrianfriendlyspaces.

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