

TOWARDS APPROPRIATE BRT STATION DESIGN FROM A PEDESTRIAN SPATIAL UTILITY PERSPECTIVE

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ABSTRACT

In this paper, guidance towards the quantitative assessment of pedestrian spatial requirements within Bus Rapid Transit (BRT) stations is proposed. Currently, little quantitative guidance is offered regarding the internal design and spatial arrangements within BRT stations; and without guidance, engineers resort to rely upon macroscopic calculations based on average passenger demand to calculate spatial requirements.

This paper provides methodologies to assess BRT station pedestrian requirements in terms of corridor, turnstile and platform operations using case study assessments recently undertaken for the eThekweni and Msunduzi Municipal IRPTN¹ projects. Guidance is also offered regarding “run-off” length requirements between the turnstile battery and the ticket kiosk (within the typical BRT station typology as adopted throughout major South African cities).

An investigation into the sensitivity of undertaking the BRT station spatial assessments through microscopic² simulation techniques (using VISSIM³) is also compared against the results achieved using standard macroscopic⁴ methods.

The paper provides a greater awareness of the design considerations within industry and offers quantitative guidance towards providing appropriate spatial requirements within the generic BRT Station typology as evaluated in terms of required pedestrian Level-of-Service (LOS) criteria.

¹ *Integrated Rapid Public Transport Network*

² *The method of modelling used based on the dynamic behaviour of individual pedestrians rather than as an aggregate volume.*

³ *Verkehr in Städten - Simulation model (Microscopic modelling software)*

⁴ *The methodological term used to calculate spatial parameters based on an aggregate volume over a certain time interval.*

1. INTRODUCTION

The assessments presented in this paper provides methodologies towards calculating the pedestrian capacity of BRT stations based on acceptable pedestrian spatial operational requirements. The paper draws from the results of case study assessments recently undertaken for the eThekweni and Msunduzi Municipal IRPTN projects for a future operational 2025 scenario for both the CBD and Rural station typologies and are based on predicted peak hour boarding and alighting data.

Whilst there are numerous sources for guidance towards the operational design of stations externally, little design guidance is offered in available literature for internal station sizing arrangements (Hermant, 2012). Little quantitative guidance is offered in the “*Accessible Bus Stop Design Guidance*” (TfL, 2006) document, except to indicate that “*sufficient space should be provided for passengers*” without providing a technique or offering the required operational Level-of-Service (LOS).

The “*ACT Bus Passenger Station/Stop Design Guidelines*” (ACT, 2005) document does not offer quantitative guidelines, except to indicate that platform widths of major stations should be between 4.0 to 5.0 m wide.

The seminal “*Bus Rapid Transit Planning Guide*” (ITDP, 2007) guideline provides simple formulae for calculating station platform widths, it however does not allow for the direct calculation of pedestrian LOS, but required widths only. It assumes the designer can accommodate any platform width that the calculations provide, rather than offering a LOS for the available platform width (usually a restriction in urban environments). The formulae also utilises flow rate criteria (which has been shown to underestimate true LOS (Hermant, De Gersigny & Ahuja, 2010; Hermant, 2012)) and does not take counterflow effects into consideration.

This paper first presents the reader with a clear understanding of the operational criteria within which stations are intended to operate in terms of Levels of Service (LOS) criteria and defines the two station typologies assessed as case studies. This is followed by presenting the methodologies used towards calculating the generic BRT station spatial requirements for five different infrastructure components viz. corridor, turnstiles⁵, “*run-off*” lengths and platforms. Differences between macroscopic and microscopic results are also evaluated for corridor and platform calculations. The paper then summarises the findings of the report in the concluding chapter.

⁵ For the sake of consistency, reference to the term “turnstiles” will be made throughout this paper, although more recent terminology such as “access gates” or “ticket verification points (or TVP’s)” are also applicable.

2. CONTEXTUAL ASSESSMENT

2.1 Station Assessment

For the purposes of spatial assessments, passenger movement within stations can be divided into unique travel-link components as follows:

- Alighting onto a platform / or boarding and waiting on a platform;
- Walking onto or off the platform;
- Passing through the turnstiles;
- Walking on the sidewalk immediately outside the station;
- Evacuation (Emergency) scenario.

Each of these travel-link components have their own capacities and the minimum capacity of the components identified above would therefore dictate the overall station capacity.

Level of Service Criteria.

The Level of Service (LOS) thresholds from the Transit Capacity and Quality of Service Manual (TCQSM), (TRB, 1999) were used in the assessments (refer to the Table 1 below). These differ to the thresholds provided in the HCM2000⁶ and older Fruin guidelines specifically to account for pedestrian movements within public transit areas, where conditions that are more crowded are to be expected and tolerated.

⁶ *Highway Capacity Manual*

Table 1 : TCQSM LOS Criteria (TRB, 1999)

LOS	Platform corridor Flow (pax/m/min)	Turnstile Queuing Area Density (m ² /pax)	Platform Walking Area Density (m ² /pax)
A	< 23	> 1.2	> 3.3
B	23 – 33	0.9 – 1.2	2.3 – 3.3
C	33 – 49	0.7 – 0.9	1.4 – 2.3
D	49 – 66	0.3 – 0.7	0.9 -1.4
E	66 – 82	0.2 – 0.3	0.5 - 0.9
F	> 82	< 0.2	< 0.5

Proposed spatial designs of stations are normally tested against Flow LOS criteria for platform bottlenecks (using TCQSM criteria) and Density LOS criteria for boarding queuing and alighting walking area platform requirements.

3. TYPICAL BRT STATION TYPOLOGY

Figure 1 shows the proposed internal arrangement of the ticket office kiosk in the two case study station typologies in relation to the turnstile battery and available corridor and platform widths. Details of the proposed turnstile battery and associated components are also shown in the figure.

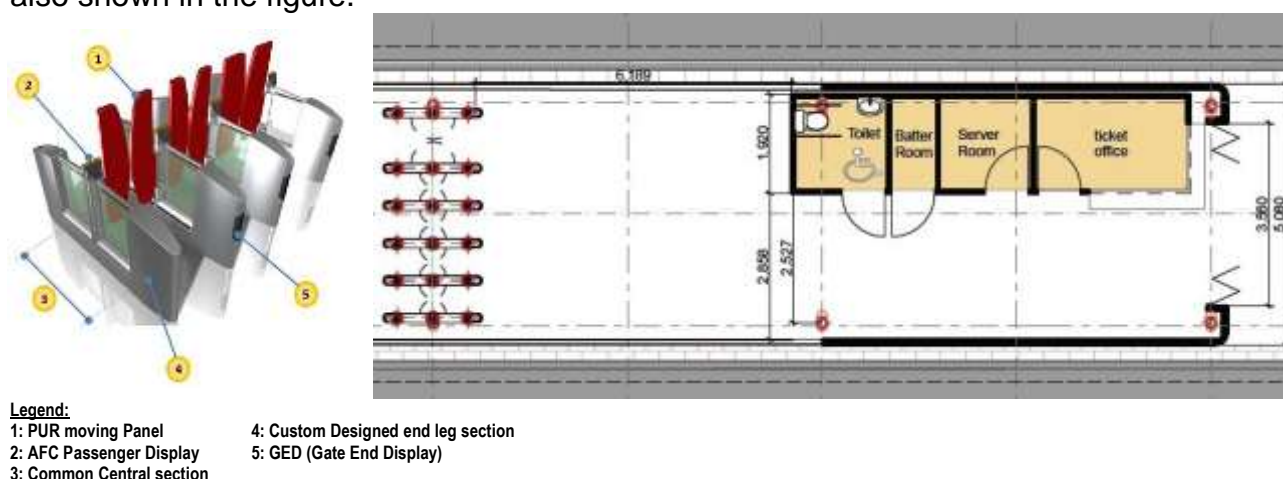


Figure 1: Typical Internal arrangement of a (Msunduzi) BRT Station (Goba, 2013)

Table 2 provides a summary of the more important component parameters of the proposed case study BRT station infrastructure.

Table 2 : Proposed BRT Station Parameters (Goba, 2013)

Parameter Description	CBD Station	Rural Station
Eff. (Internal) Platform width	4,063 m	5,080 m
Internal Platform length	42,791 m	41,745 m
Platform Area (Single Stations)	174 m ²	212 m ²
Platform Area (Double Stations)	None	424 m ²
Bus Berths (both directions)	4	4
Optimal turnstile arrangement	4 (2 x extra wide)	5 (2 x extra wide)
Turnstile Battery width	3,750 m	4,470 m
Turnstile Battery capacity	140 pax/min	175 pax/min
Ticket Kiosk width	1,600 m	1,920 m
Platform Corridor width	2,080 m	2,527 m

4. ASSESSMENT OF BRT STATION OPERATIONAL CAPACITIES

4.1 Turnstile Battery Requirements

Through previous research undertaken by the author (Hermant, 2013), a volume/capacity (v/c) versus queue space-density (M) relationship profile was developed and plotted using microscopic modelling analysis techniques. The relationship (shown in Figure 2) is considered significant as it provides a simplified method of determining the required number of turnstile gates necessary for a particular demand flow and is applicable to all types of stations.

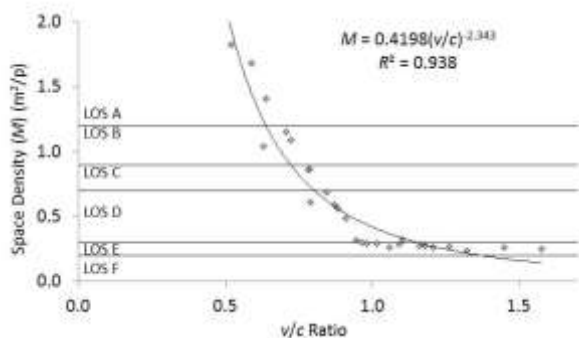


Figure 2: Turnstile M vs. v/c Operational Relationship

From this research, a simple power relationship is proposed between space-density (M) and the v/c ratio as follows:

$$M = 0.4198 \left(\frac{v}{c} \right)^{-2.343} \quad (R^2 = 0.938) \quad (1)$$

where M is the queuing space-density in m^2/pax , v is the demand in pax/min and c is the turnstile service flow capacity in pax/min . From the relationship developed in (1), the number of turnstiles (n) required for a particular pedestrian demand volume (v) can then be determined from:

$$M = 0.4198 \left(\frac{v}{n.c} \right)^{-2.343} \quad (2)$$

For example, if a LOS C/D⁷ turnstile boundary operating condition is required (viz. at $M = 0.70$ from Figure 2), then equation (2) can be written as:

$$1.67 = \left(\frac{v}{n.c} \right)^{-2.343} \quad (3)$$

From this relationship, the number of turnstiles can easily be calculated as shown in equation (4), bearing in mind that at least two turnstiles are always required as an absolute minimum (both to allow for breakdowns and/or to permit simultaneous bi-directional pedestrian movement); and that the overall evacuation capacity of the turnstile battery complies with the regulatory requirements.

$$n = \frac{1.24v}{c} \quad (4)$$

4.2 “Run-off” Lengths

No guidance regarding “run-off”⁸ length (indicated in Figure 3) is offered in either the ITDP or ACT documents. The London Underground “*Engineering Standard: Station Planning*” guideline document (LUL, 2005) specifies “run-off” lengths of 6.0 m between the turnstile battery and the street or staircase and 4.0 m between the turnstile battery and passageways).

The area required between the turnstile battery and the ticket office is called the “run-off” area and is necessary to allow passengers to walk without having to stop or change direction and should be free of any obstructions such as furniture or columns and should be provided on both sides of the turnstile battery.

⁷ Previous work by the author established that the turnstile operation needs to satisfy a volume/capacity (v/c) ratio of between 0.72 and 0.80 to achieve a reasonable queuing density level-of-service of LOS C.

⁸ “Run-off” areas are to be provided at stations to allow passengers to walk clear of critical areas such as ticket counters, lifts, stairs etc. without having to stop or change direction. Provision of “run-off” areas reduce the risk of circulation being impeded due to passengers stopping to orient themselves or take decisions immediately beyond. (Source: Ross, 2000)

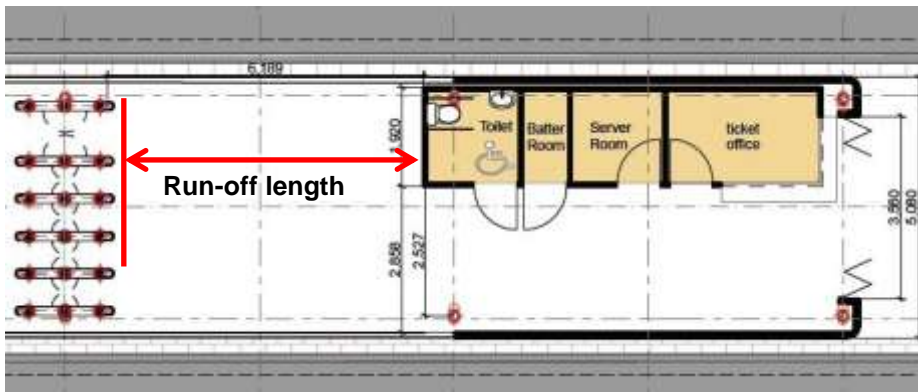
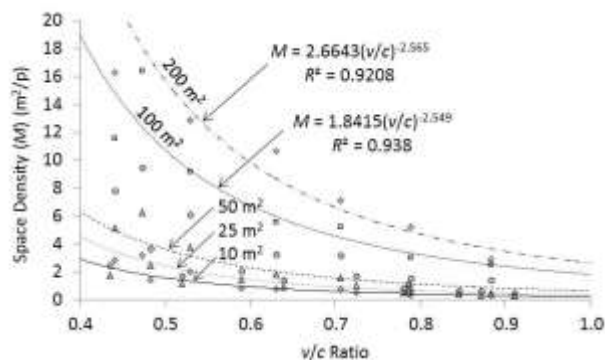


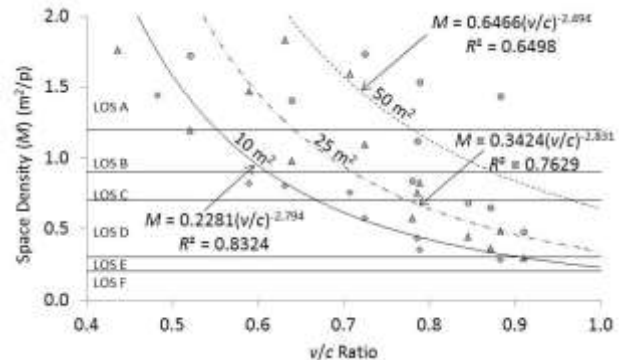
Figure 3: Typical BRT Station layout showing “run-off” length

Determining the optimum “run-off” length is neither descriptive nor prescriptive, but for the purposes of calculating this distance at the proposed case study stations, the spatial LOS queuing requirements upstream of the turnstiles (as discussed in Section 4.1) was used as the basis for calculating “run-off” length.

Independent research work undertaken by the author (Hermant, 2013), revealed through a microscopic simulation exercise, that an area of approximately 25 m² is required upstream of turnstiles to allow for a design LOS C/D queue space-density (M) operation (at $v/c = 0.8$). Figure 4(a.) shows the results of the exercise for 10, 25, 50, 100 and 200m² confined upstream spaces and Figure 4(b.) shows the results for the range $M < 2.0$ m² indicating the space-density LOS bandwidths.



(a.) M vs. v/c ($0 < M < 20$ m²/pax)



(b.) M vs. v/c ($0 < M < 2.0$ m²/pax)

Figure 4: Relationship between M and v/c for various turnstile upstream spaces (Hermant, 2013)

From the relationships derived, it is evident that, in order to maintain a (turnstile) operational queuing LOS C/D (at $v/c = 0.8$), that a minimum “run-off” length of 5.0 m and 6.0 m is required for the Rural and CBD Stations that have platform widths of 4.06 m and 5.09 m respectively.

4.3 Corridor Capacity

No guidance regarding corridor width (indicated in Figure 5) is offered in either the ITDP or ACT documents. The reduced platform corridor created by the ticketing office, toilet and storage facility, effectively narrows the overall platform width considerably, with implications on passenger throughput and overall station capacity. Note that bi-directional (or counter flow) volumes, will further influence the effective capacity of the corridor.

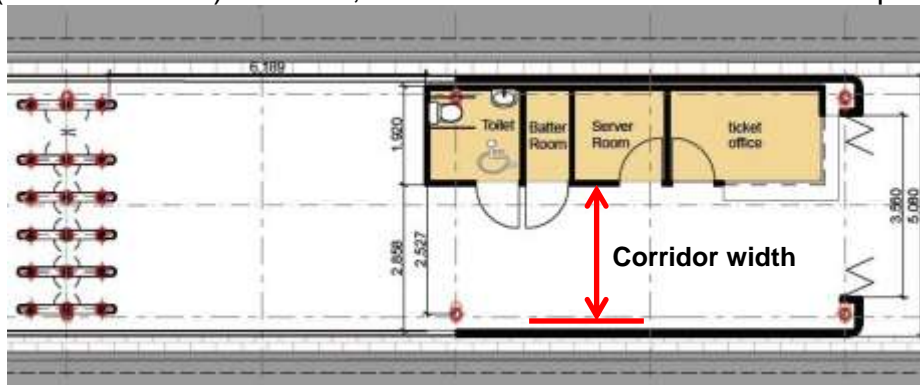


Figure 5: Typical BRT Station layout showing Corridor Width

Figure 6 below shows the results of the microscopic simulation exercise undertaken for the case study stations and shows the 2.0 m and 2.5 m corridor width capacities for a LOS C/D operational specification, dependant on boarding and alighting passenger volumes. The relationship shown below is for 1-minute bus headways only.

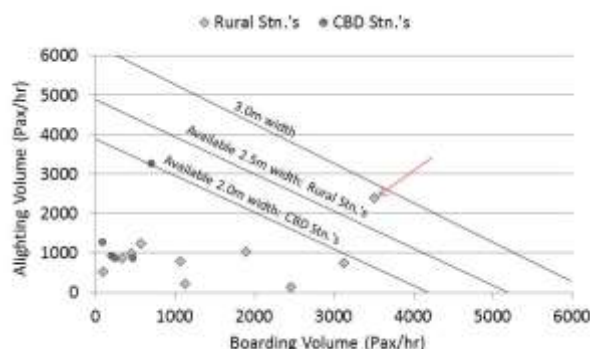


Figure 6: Typical BRT Station LOS C/D Corridor Width Capacities

From the graph, it can be seen that the capacity of the CBD stations (with a 2.0 m corridor width) have capacities of around 4,000 total passengers per hour and around 5,000 total passengers per hour for Rural stations.

It can also be seen that one case study station (indicated by the red arrow) has a total passenger volume of 5,896 passengers per hour, which requires a slightly wider corridor width to satisfy the required LOS C/D density operation.

The graph also shows that the higher (singular) boarding volumes can be accommodated than alighting (singular) volumes for the same corridor width. This is because boarding follows a uniform arrival rate that is less impactful on corridor densities than the “Pulse-like” loading of alighting passengers.

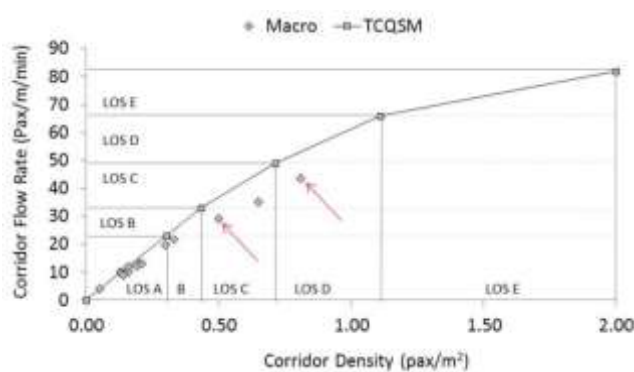
5. MACROSCOPIC VERSUS MICROSCOPIC STATION EVALUATION

Whilst it can be argued that the analysis of large and complex station layouts using microsimulation methods are usually warranted, the same argument is perhaps not applicable to the standard BRT station typologies used throughout South Africa that have simple layouts. This chapter aims to identify the differences between using these two types of assessment techniques when assessing two spatial parameters viz. corridor widths and platform areas using the proposed 15 Msunduzi BRT stations as case studies.

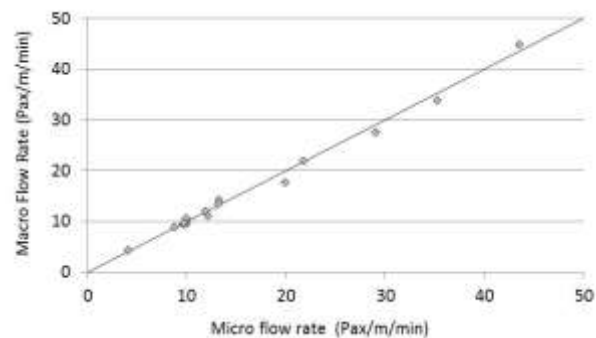
5.1 Corridor widths

Figure 7 (a.) shows the plot of the microscopic corridor flow rate vs. density relationship. The graph includes the TCQSM LOS bandwidths (TRB, 1999) as well as the density and flow rate results from the microscopic assessment plotted as points on the graph for each of the individual stations.

It is observed that the LOS density criteria is more critical than the flow rate criteria (refer to the data points indicated by the arrows: For both these data points, the density result is a LOS category lower than the Flow Rate LOS. This is attributable to the “LOS – mismatch”⁹ phenomena, corroborating with earlier work by the author. As a result, the more critical density criteria should always be used for design purposes.



(a.) Micro Density vs. Micro Flow Rate



(b.) Micro vs. Macro Flow Rate

Figure 7: Relationship between Macroscopic and Microscopic Modelling Results

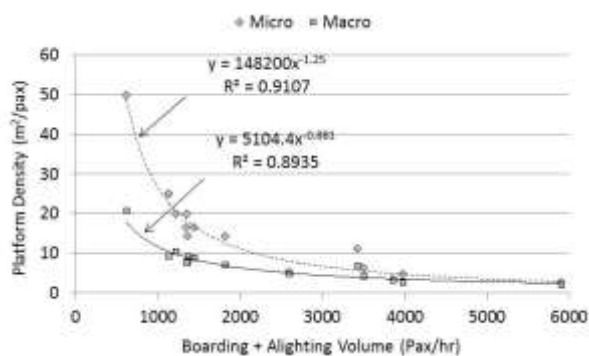
Figure 7(b.) shows the plot of the macroscopic flow rate calculation vs. the microscopic flow rate calculations. The results of this plot reveal that the macroscopic calculations are less conservative (i.e. calculate lower flow rate results) by an average factor of 0.99x for the 15 case study stations. The difference is however marginal and insignificant when tested with the students t – test at the 5% level of significance; ($t\text{-statistic} = 0.76 < t_{1-\alpha/2, n-1} = 2.776$).

It is concluded that despite the fact that there are insignificant differences between the macroscopic and microscopic flow rate calculations, the station designer should be aware that the flow rate result may lead to conservative LOS values (due to the “LOS-mismatch” phenomena) and should rather use corridor density results from microscopic analysis wherever possible.

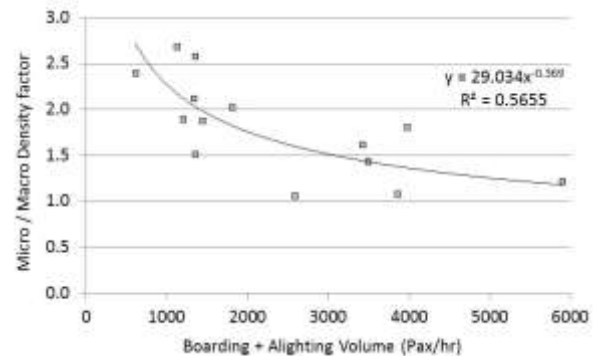
⁹ The phenomena where, for a particular pedestrian observation interval, discrepancies in LOS results occur depending on the criterion used, viz. either flow, speed or density (Hermant, 2012).

5.2 Platform Areas

For the macroscopic calculation, Platform Space densities (M) was calculated using combined boarding and alighting (BA) volumes over the peak hour, whilst the microscopic calculation used the actual dynamic boarding and alighting profile over the peak hour with the results plotted as points in the figures below. Figure 8 (a.) below shows the results of the assessment for BA volumes up to 6000 pax/hr and Figure 8 (b.) shows the Space Density factor differences between the macroscopic versus the microscopic results.



(a.) Space Density (M) vs. BA Vol.



(b.) Space Density factor vs. BA Vol.

Figure 8: Relationship between Boarding and Alighting Volumes and M

The analysis reveals that, for calculating the Space Density (M) parameters, the macroscopic calculations are (counter-intuitively) more conservative (i.e. calculate lower densities) than the microscopic calculations by an average factor ranging from 2.5 to 1.1 for BA Vol.'s ranging from 600 up to 6000 Pax/hr. The difference is significant for all values when tested with the students t – test at the 5% level of significance; (t -statistic = $3.97 > t_{1-\alpha/2, n-1} = 2.776$). The differences in results are largely due to the “pulse-like” nature of alighting that is not taken into account in the macroscopic calculation.

In conclusion, the station designer should be aware that macroscopic calculations are more conservative than the microscopic calculations. Accordingly, a factoring scale could be applied (as per Figure 8 (b.) to macroscopic results to better represent the dynamic nature of pedestrian movement.

6. CONCLUSIONS AND RECOMMENDATIONS

The research undertaken in this paper has contributed towards developing methodologies for quantitatively assessing the pedestrian spatial requirements and capacities of BRT stations in terms of turnstile, “run-off” length, corridor width, platform area requirements. These guidelines were used in helping ensure that the Msunduzi and eThekweni BRT stations conformed to the spatial requirements.

It is recommended that the number of turnstiles be calculated using the simplified queue density vs. v/c power relationship described in the paper, bearing in mind that at least two turnstiles are always required as an absolute minimum and that the overall evacuation capacity of the turnstile battery complies with the regulatory requirements.

Note that the simplified queue density vs. v/c power relationship is not valid for bi-directional flow and further research and empirical observation is required in this regard.

Previous work on spatial requirements upstream of turnstiles (to accommodate turnstile queuing) has been used in this paper towards calculating “run-off” lengths. It is recommended that the upstream space-density (M) vs. v/c relationships derived for various floor areas (viz. 10, 25, 50, 100 and 200 m²) be used to calculate the “run-off” lengths.

From the microscopic assessment undertaken to assess corridor widths, the results show that higher boarding volumes can be accommodated than alighting volumes for the same corridor width. It is assumed that this is because boarding follows a uniform arrival rate that is less impactful on corridor densities than the “Pulse-like” loading of alighting passengers.

The sensitivity assessment identified insignificant differences between the macroscopic and microscopic corridor flow rate calculations. The station designer should be aware that the flow rate result may lead to conservative LOS values (due to the “LOS-mismatch” phenomena) and should rather use corridor density results from microscopic analysis wherever possible.

The sensitivity analysis for calculating platform areas reveal that the macroscopic calculations are (counter-intuitively) more conservative (i.e. calculate lower densities) than the microscopic calculations by an average factor ranging from 2.5 to 1.1 for *BA Vol.*'s ranging from 600 up to 6000 Pax/hr. The difference is significant for all values when tested with the students t – test at the 5% level of significance and is attributed to the “pulse-like” nature of alighting that is not taken into account in the macroscopic calculation.

In conclusion, the station designer should be aware that macroscopic calculations for platform areas are more conservative than the microscopic calculations and that a factoring scale could be applied as described in the paper to better represent the dynamic nature of pedestrian movement.

It is stressed that no calibration or validation of the observed modelled LOS results described in this paper has been done with empirical field surveys, and is a shortcoming requiring further research. Furthermore, no evaluation of the evacuation requirements is presented in this paper and in certain instances may in fact govern the design, particularly when considering the limited evacuation potential of turnstiles.

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