MICROSCOPIC ASSESSEMENT OF PEDESTRIAN SPACE REQUIREMENTS WITHIN RAILWAY STATIONS IN SOUTH AFRICA

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ABSTRACT

The station evaluation and assessment processes undertaken recently in South Africa have used innovative means of applying microscopic modelling such that the required longitudinal (time interval) outputs are obtained for analysis and assessment purposes. Through these case studies, microscopic pedestrian modelling software has been used to assess the impact of rail passenger flow increases on infrastructure designs.

A key output of the modelling process is to increase the level of pedestrian service through improved design as well as highlighting crowded conditions that add risk to the operations. An iterative design process incorporating microscopic modelling assists in mitigating against these factors while increasing the overall "safety" of the final design.

A method to determine the required pedestrian space in station buildings is presented using microscopic techniques. These include the assessment of walkway, foyer and concourse levels of service (LOS) in terms of density LOS parameters with staircase operational functionality expressed in terms of flow rate LOS. The required numbers of turnstiles (or access gates) have also been determined according to queuing densities rather than queue lengths. This paper presents innovative means of modelling railway stations developed by the author/s and applied to several station designs in South Africa.

1. INTRODUCTION

The increasing importance of rail travel and objectives of the rail authority has necessitated re-investment into stations and new stations buildings that together with technological advances in computing has led to the possibility of assessing new station designs and upgrade proposals using microscopic methods. Pedestrian microscopic assessment is a relatively new engineering field worldwide and has only recently been introduced to South Africa to evaluate station architectural designs.

A particular set of problems concern levels of congestion on stairways, passageways and Ticket Verification Points (TVP) or turnstile areas used by passengers. In Mass Transit Railway (MTR) stations, these spaces frequently suffer from bottlenecks and excessive queues. Areas subject to interactions between flows and queues of passengers waiting for service – such as foyers in front of TVP's are especially prone to congestion. The conceptual problem is that the current design procedure for rail stations determines space requirements according to broad macroscopic criterion of average space per person, instead of focussing on critical locations.

The purpose of this paper is to highlight current issues and aspects in station macroscopic design and suggest a focussed microscopic design process for assessing pedestrian space in railway terminals. The assessment is based on the longitudinal analysis of the fundamental flow, density and speed relationships of the measurement areas used by pedestrians in the facility.

Microscopic analysis permits detailed operational assessments of all public spaces to be undertaken including assessing the required number of stairwells, turnstiles, ticket sales booths and identifying widths of skywalks and staircases for any user specified time interval that was previously not possible using traditional macroscopic principles.

The layout of this paper is organised as follows. Section 2 highlights the current station design processes and problems. Section 3 highlights innovative modelling techniques recommended for the micro-simulation of railway stations. The paper offers a brief conclusion in Section 4.

2. RAILWAY STATION DESIGN

2.1 Current Station Design Practice in South Africa

The standard procedure for determining the space required for pedestrian areas in station building facilities uses basic macroscopic principles. Experience in reviewing design reports has shown that design practitioners modify these methods slightly, according to their judgement. The net result is the same: an overall amount of space is allocated to an activity sufficient to accommodate the pedestrian demand on average but not the micro peaks. Individual critical areas and smaller time intervals are not analysed at all.

Work carried out by Still (2000) provided evidence that crowd behaviour cannot be dealt with only using contemporary design guidance and is complex in nature. With technological advances in computing and software for MTR stations, the area of circulation design should consider incorporating more detailed quantified assessments of pedestrian movement.

2.2 Critique of Current Design Practice

Standard macroscopic design approaches suffer from a major defect with regard to analysing congestion that stems from a failure to realistically incorporate the highly variable stochastic pedestrian demand phenomenon common within MTR stations.

The general rules-of-thumb for determining peak passenger (pax) loads are inadequate and misleading for detailed design purposes. Average flows taken over the peak hour can be used as crude preliminary estimates of the overall requirements for space and of cost.

Focussing on averages can be erroneous as the local extremes will limit the performance of a facility. Identifying the design peak one minute pedestrian volume by dividing the peak 15 minute flow by 15 can be a common mistake. This practice does not capture the actual pedestrian dynamic and true one minute peaks may be significantly higher those calculated in this way. This is due to boarding and alighting patterns that vary greatly since boarding volumes can be distributed over a 10 minute period prior to train departure whilst alighting volumes are considered more of a “pulse load” and the distribution of passengers over time is purely a function of the pedestrian walking speed distribution.

2.2.1 Microscopic versus Macroscopic Flow Rate Assumptions

This section provides some insight into the differences between the average one-minute flow rate (termed the macroscopic flow rate) and the true microscopic flow rates. Table 2.2.1 shows the AM peak period volume details taken from the Langa Station assessment (Goba, 2009b). The average peak one-minute volume is based on dividing the peak 15-minute (determined from Rail Census data) flow by 15.

Table 2.2.1 : AM Peak Period volumes (Source: Goba, 2009b)

Description	Volumes
Peak AM period volume* (x)	3634 pax per 15 min
Peak AM 1-min vol (uniform distribution) [A=x/15]	243 pax per minute(solid red line)
Peak 1-min vol (from micro model) [B]	316 pax per minute (occurring at t=1000)
B / A Micro peaking Factor	**1.30**

**Determined from Rail Census Boarding and Alighting volumes*

Figure 2.2.1 below plots the microscopic flow rates per ten second interval over the peak 15 min (900 sec) period identified as the yellow block within the 30 minute analysis period. The measurement area is taken at the concourse level of the station.

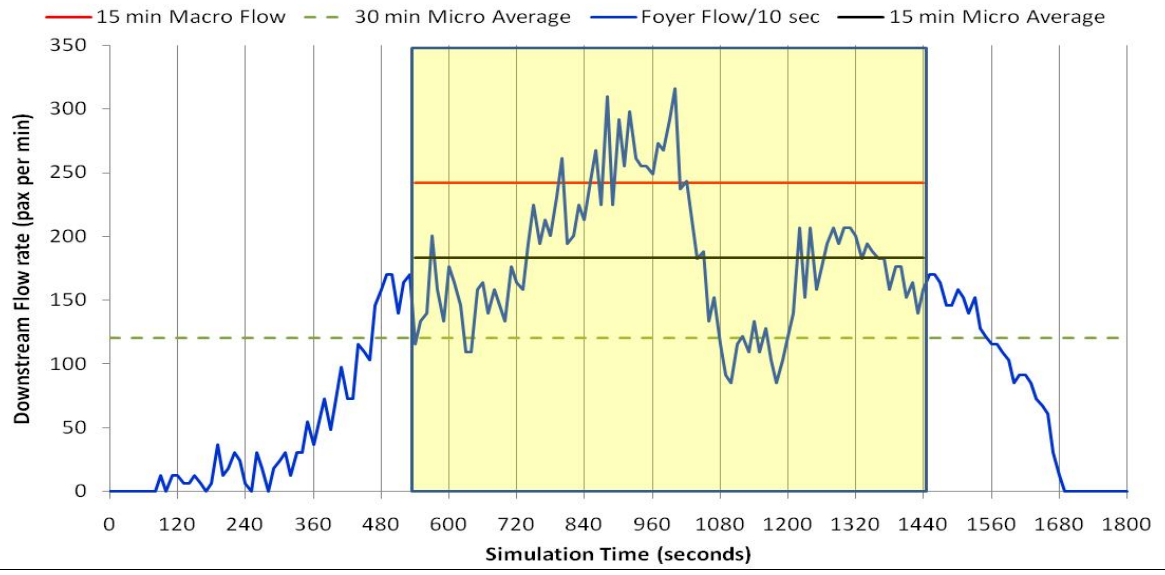

Figure 2.2.1: Comparison between Macro and Micro Flow rates (Source: Goba, 2009b)

From the graph above, the peak 15 minute average (uniform) macroscopic flow rate is represented by the red line with the average 30 minute microscopic flow rate represented by the dotted line with values plotted every 10 second intervals. The actual design peak one-minute flow in this case is 1.30 times greater than the uniform flow calculated over the peak 15-minute period (i.e. the red line) using Rail Census boarding and alighting data. This peaking effect occurs around the t=960 time period.

The selection of the uniform one-minute flow rate as the design volume is thus lower than the true peak one-minute flow rate by up to 30% and lasts for approximately three minutes in duration. This analysis highlights that average flow rates may misrepresent the flows that will actually occur by a wide margin; 50 to 100% being entirely possible (de Neufville and Grillot, 1982) and therefore the average flow should not be used for the design of specific facilities. Maximum peaking factors of 1.52 and 2.54 over a 15-minute period (for platform occupancy) for two separate platforms was identified during the modelling of the North Melbourne station (Laufer, 2008).

The analysis and investigation shows that using a “design peaking factor” to obtain the actual one-minute flow rates should be used with caution as they are largely influenced by train scheduling and whether there are large alighting volumes.

2.3 Proposed Station Design Method using Microscopic Principles

The proposed spatial assessment method using microscopic simulation techniques consists of five fundamental steps to be applied to any station infrastructure evaluation. The five steps of analysis are as follows:

1. Identify the ultimate design year (+20 year) peak 15 to 30 min pax loads.
2. Determine the train schedule including occupancy, boarding and alighting (B&A) volumes per train and project to the assessment horizon. (Base B&A data usually obtained from Rail Census data for an existing station).
3. Construct the simulation infrastructure model.
4. Identify appropriate measurement areas for assessment per infrastructure type.
5. Run the simulation model and evaluate the measurement area LOS.

The first three steps are considered straightforward and whilst the last two steps are described and illustrated in the following sections. The novelty of the approach is the way a spectrum of techniques are combined for assessment purposes. It is important to note that the modelling uses European default values and the results are therefore not calibrated for South African conditions. Calibration of local pedestrian attributes is subject to ongoing research by the main author.

3. MICROSCOPIC MODELLING INFRASTRUCTURE ASSESSMENT

This section forms the main scope of the paper and highlights innovative methods for microscopic railway station modelling.

3.1 Measurement Area LOS Assessment Criteria

Level of Service (LOS) thresholds from the Transit Capacity and Quality of Service Manual (TCQSM, 1999) are used as the evaluation criteria for pedestrian flow and density within public transit areas. Table 3.1 provides a summary of these criteria.

Table 3.1: Level of Service Criteria (Source : TCQSM, 1999)

LOS	Skywalk	Stairways	Queuing areas	Walkways
	Flow (p/m/min)	Flow (p/m/min)	Density (m^2/p)	Density (m^2/p)
A	<23	<16	>1.2	> 3.3
B	23-33	16-23	0.9-1.2	2.3-3.3
C	33-49	23-33	0.7-0.9	1.4-2.3
D	49-66	33-43	0.3-0.7	0.9-1.4
E	66-82	43-56	0.2-0.3	0.5-0.9
F	>82	>56	<0.2	< 0.5

LOS is a dynamic output as flows and density vary over time, and should be identified for a specific time period or provided over smaller intervals for the assessment period. As indicated earlier, an average LOS calculated over the peak 15 minute period is not considered an acceptable means for station infrastructure assessment as a measurement area could be empty during one minute but heavily crowded during the next due to a train arrival. A 10 second interval during the peak 15 minute period is recommended for LOS calculations for station assessment.

Station infrastructure sizing requirements adopted in South Africa are based on the minimum operational capacity determined according to the minimum acceptable LOS D for Stairs and LOS C for all other station elements (incl. queue areas) (SARCC, 1997).

Passengers become impatient and more reckless when they have to wait for more than 30 seconds (Hoogendoorn et al, 2007) and the recommendation is that densities worse than the minimum acceptable LOS lasting for a period longer than 30 seconds should be considered unacceptable and the particular infrastructure should be amended (e.g. widening of stairs) to bring the LOS into acceptable levels such that the LOS criteria is within tolerable limits.

3.2 Assessment of Stairways

Staircases are a key area of evaluation in station modelling, as stairways often provide a limiting factor to the level of pedestrian flow from the platform onto the concourse. A crowded staircase also has potential safety implications.

The major issue with staircase modelling is removing pedestrian conflict on stairways that can easily result in delay or gridlock. Simulated pedestrians moving on staircases will not naturally arrange themselves, as they do on flat surfaces, as they are restricted in their horizontal movement along the steps and therefore do not avoid opposing pedestrians as effectively. Only five pedestrians opposing the major pedestrian flow direction can have a significant detrimental effect and there are specific measures that be implemented to avoid pedestrian conflict (refer to Hermant et al, 2009).

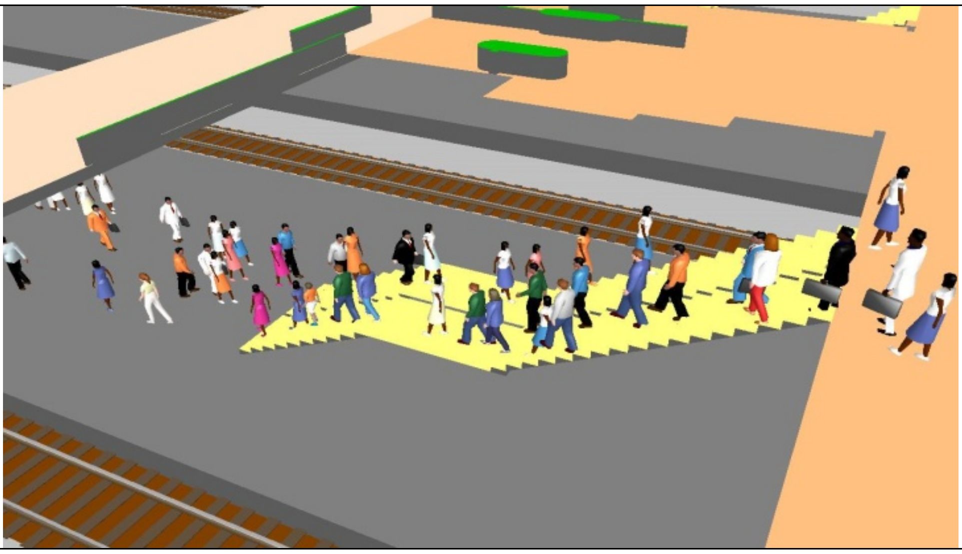

Figure 3.2.1: Staircase modelling **(Source: Goba, 2009a)**

Figure 3.2.2 provides a time scale output of the staircase landing area in flow rates (pedestrians per metre per minute) for a typical set of staircases as shown in Figure 3.2.1.

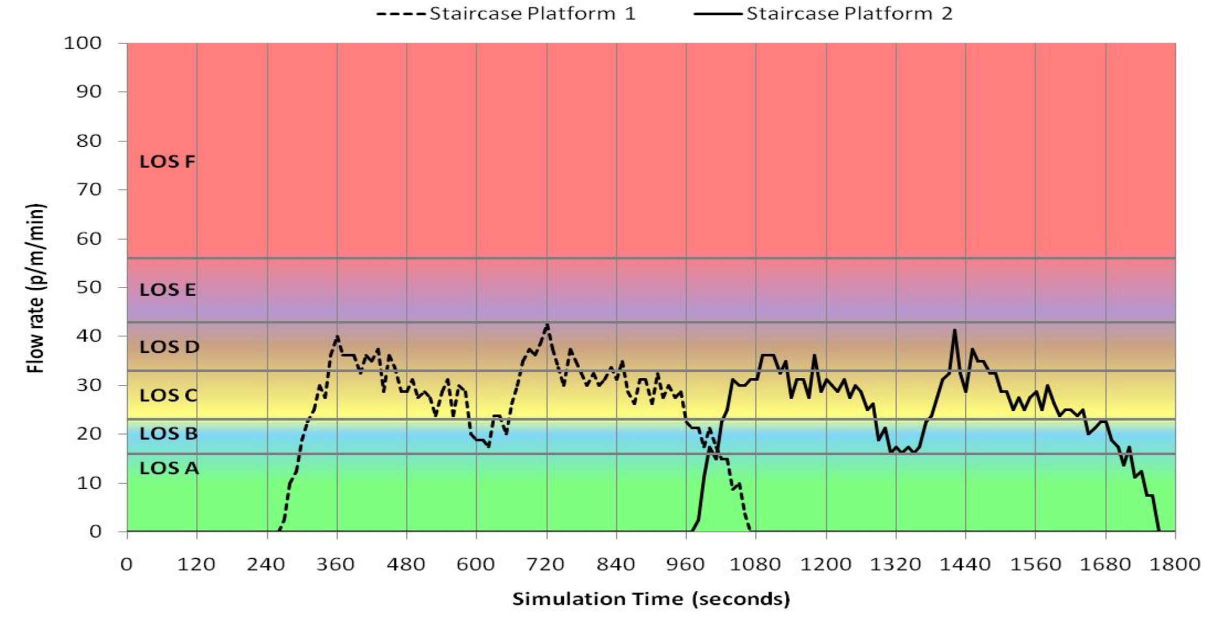

Figure 3.2.2: Example of Platform-Concourse Staircase Flow Rate LOS **(Source: Goba, 2009c)**

From Figure 3.2.2, both sets of staircases on either platform (viz. Platforms 1 and 2) operate within the required LOS D threshold with the Platform 1 staircases operating for a total of just under four minutes in this zone. The staircases are thus considered to be operating within the operational capacity of the design guidelines.

3.3 Assessment of Walkways including Platforms, Concourses, Foyers and Skywalks

Figure 3.3.1 below provides a time scale output for the density parameter (m^2 per pedestrian) for a typical station concourse.

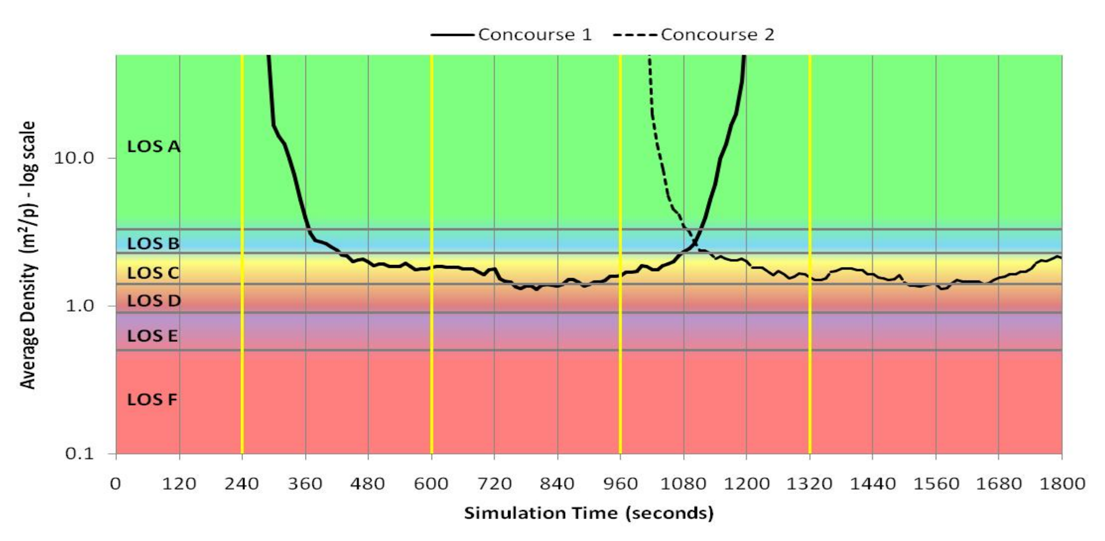

Figure 3.3.1: Example of Concourse Density LOS **(Source: Goba, 2009c)**

The two concourse measurement areas, each 10.3m x 13.2m, give an indication of the congestion levels on the concourse. From the graph, Concourse 1 can be seen to operate briefly in LOS D for 90 seconds which can be considered acceptable.

From the profile of the graph, the concourse cannot accommodate further passenger loading without operating in an unacceptable LOS D environment. The graph confirms that the input volume can be considered as the peak operational capacity for this station.

3.4 Access Gate / TVP Modelling Methodology

The queuing process that typically occurs at Ticket Verification Points (TVP's) in train stations is due to transients peaks of traffic that rarely attain steady-state. The textbook formulas for calculating lengths of queues in such conditions are thus generally not applicable for station facilities (de Neufville and Grillot, 1982).

To determine the required number of turnstiles/access gates necessary to satisfy the demand, a queuing LOS C density standard is adopted (TCQSM, 1999). Access gates are modelled as a bottleneck gap rather than as separate access gates. The size of the gap is determined by the number of access gates and the specific design throughput flow rate of each of those access gates e.g. five access gates each with a throughput of 45 pax per minute is modelled as a gap that provides a throughput of 225 pax per minute.

Related research (Hermant et al, 2009) has indicated that the size is the gap is linearly proportional to the throughput generated (refer to Figure 3.4.1 below) and is also dependant on the characteristics of the local population type served. The throughput is also influenced by the length of the gap or bottleneck that then introduces additional friction factors.

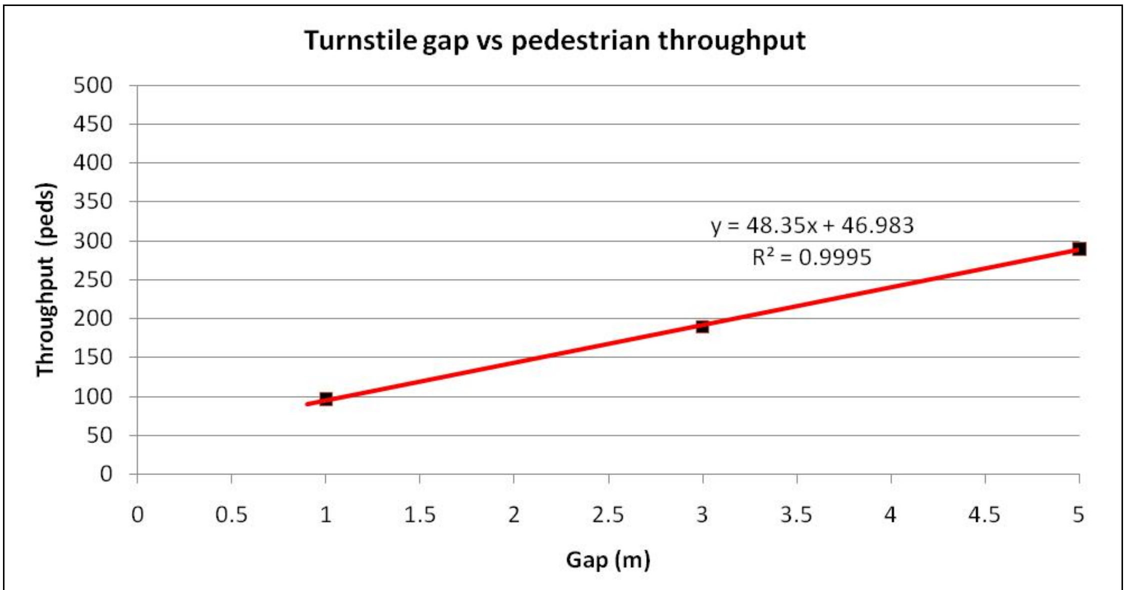

Figure 3.4.1: Relationship between Access Gate throughput and Bottleneck "Gap" width

Queuing has been modelled in terms of density immediately upstream of the access gates rather than queue length because of the tendency of pedestrians to crowd competitively close to access the turnstiles/ access gates rather than queue in a linear and orderly fashion (refer to Figure 3.4.2).

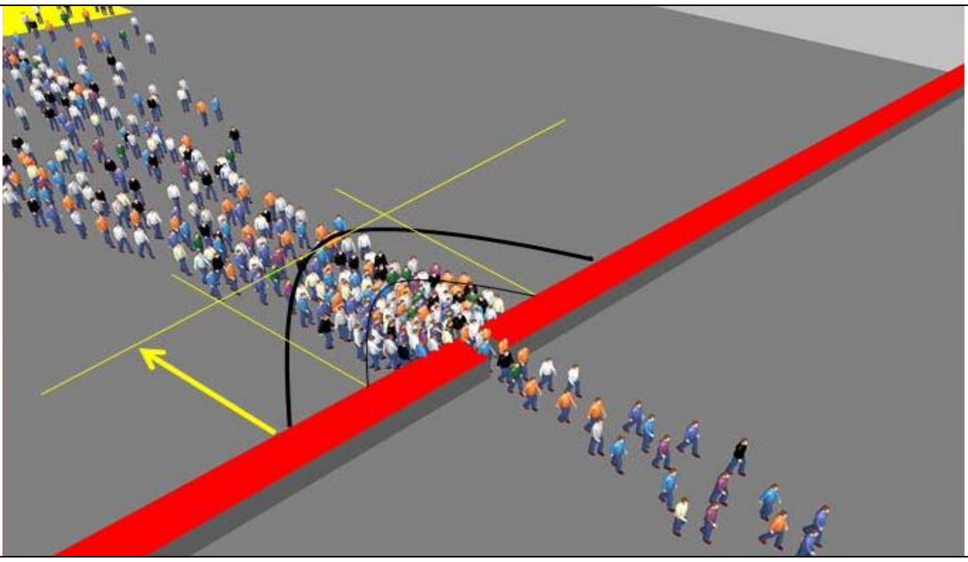

Figure 3.4.2: Pedestrian Queuing Dynamic Upstream of a Bottleneck

A volume to capacity (V/C) versus queue density relationship profile has been developed that determines the required number of turnstiles/access gates necessary for a particular demand flow. The profile is shown in Figure 3.4.3.

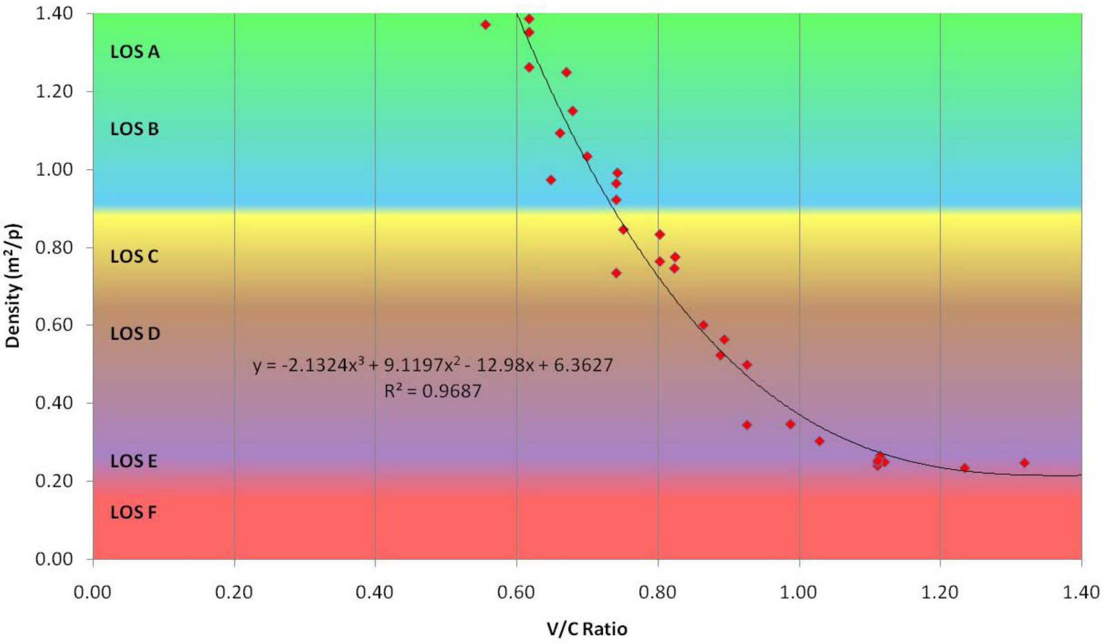

Figure 3.4.3: V/C versus Density Relationship and LOS bandwidths.

From the relationship determined above, a V/C ratio of between 0.74 and 0.8 is required to achieve a LOS C queue density standard. This relationship provides an initial idea of the required number of access gates.

When determining the size of the queuing area upstream of the access gates, the method employed was to match the width of the queue measurement area to the total gap (total access gate width excluding obstacles) that exists in the station design. This means that the width of the queue area is likely to be greater than the width of the modelled gap.

Figure 3.4.4 provides a time scale output for the queue density parameter (m^2 per pedestrian) upstream of the TVP battery per 10 second interval. In this scenario, the results for the TVP queuing area use an eight access gate arrangement with a measurement area of 65m^2 (5.0m x 13.0m).

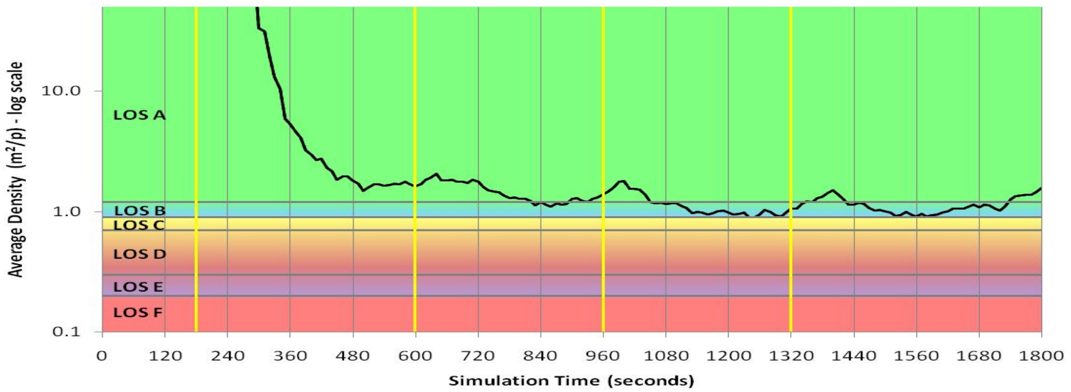

Figure 3.4.4: Example of Concourse TVP Queue Density LOS (Source: Goba, 2009c)

The figure shows that the queuing LOS for an eight TVP allocation is within the LOS B criteria and is therefore acceptable. Additional analysis undertaken revealed that a seven TVP allocation would not conform to even the minimum LOS C requirement and therefore the eight TVP allocation is recommended for this situation.

3.5 Measurement Areas and the "LOS Mismatch" Phenomenon

The choice of measurement area and criteria can have a direct impact on the output results. LOS for skywalks can either be assessed in terms of the flow or density criteria. The relationship between flow and density measurements on LOS was determined for each 10 second interval at Nyanga Station in Cape Town (Goba, 2009a) and is shown in Figure 3.5 with each dot representing a data point for a 10 second interval.

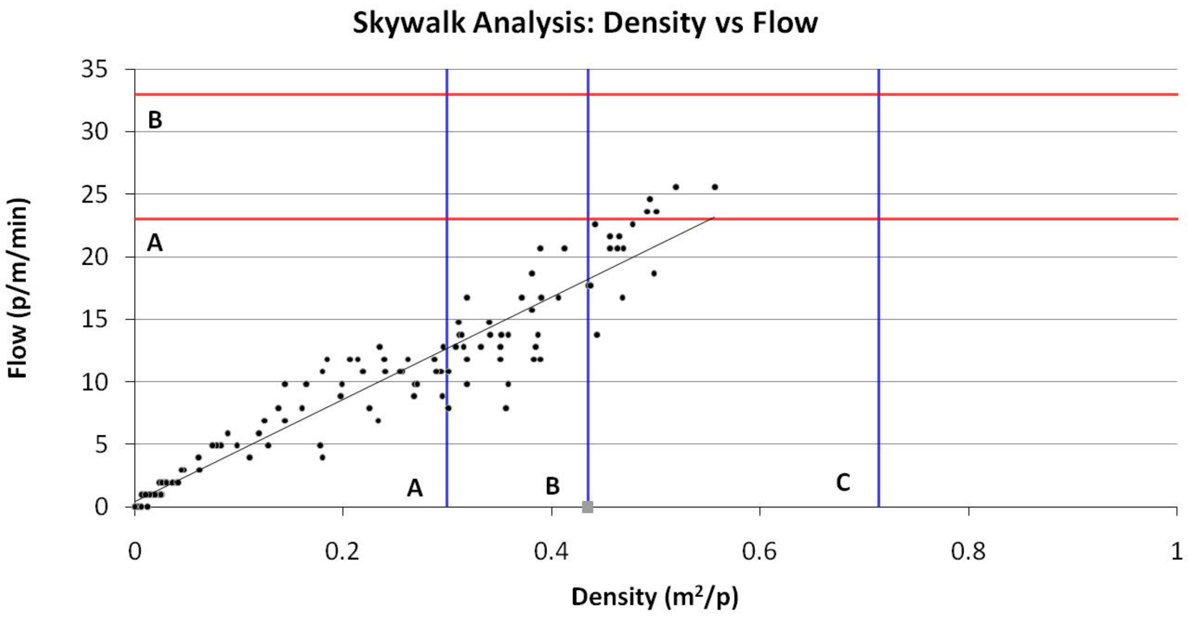

Figure 3.5: Relationship between flow and density LOS (Source: Goba, 2009a)

As can be seen from the above graph, the data points follow the fundamental (q vs k) relationship although the graph shows that the same measurement area can deliver a conclusion of LOS A using flow criteria and LOS C using density criteria. This is because the q vs k fundamental relationship will always be dependent on a variety of extraneous conditions (i.e. population, culture, temperature or gender mix) and will vary from situation to situation.

Assessments should therefore be based on passenger density, since speed and flow are usually not applied to pedestrian traffic (Fruin, 1971 and Hoogendoorn et al, 2007). The reason for this is that flows, used as base measure in road traffic, are not as suitable unless the prevailing speed or density data is available to determine whether there is congestion.

4. CONCLUSION

This paper has highlighted numerous modelling techniques that have been developed by the author/s during their pedestrian assessments of railway stations in South Africa. Although innovative techniques have been presented, this paper is by no means a definitive guide to modelling railway stations and rather a starting point for discussion and further research.

It is important to note that the modelling results presented in this paper have been based on European default pedestrian characteristics and have not been calibrated, nor has the model been validated for local South African conditions. Calibration of the fundamental pedestrian characteristics for local conditions is the subject of ongoing research by the main author and will provide further confidence in the use of such models in future.

The techniques described above are subject to the opinion of other researchers and may not necessarily present the optimal solutions to railway station modelling.

5. REFERENCES

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