

# APPLYING MICROSCOPIC PEDESTRIAN SIMULATION TO THE DESIGN ASSESSMENT OF VARIOUS RAILWAY STATIONS IN SOUTH AFRICA

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## ABSTRACT

The assessment of station designs by applying a pedestrian flow simulation model is addressed. In particular, station design issues pertaining to the way infrastructure items will influence pedestrian flow operations with levels of service and congestion are presented.

To examine these issues, pedestrian traffic operations for different station designs are evaluated with the VISSIM dynamic microscopic pedestrian flow model.

Insight into the behaviour of pedestrians and tools to predict this behaviour are essential in the planning and design of public pedestrian facilities such as railway stations. Pedestrian simulation models can now analyse the impact of station layouts, access gate numbers and locations on walking times and pedestrian comfort levels.

This paper shares some of the modelling techniques used in the micro simulation process, presents the lessons learnt during the assessment of several new and upgraded railway station designs in South Africa and introduces Virtual Reality for station assessment.

## 1. INTRODUCTION

The evaluation of new station architectural designs and upgrade proposals using a microscopic approach is a relatively new engineering field worldwide and has recently been introduced to South Africa.

Microscopic analysis allows 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. This was previously not possible using traditional macroscopic principles.

The purpose of this paper is to demonstrate the versatility of microscopic pedestrian modelling for station design assessment, to share lessons learnt from past modelling work and to introduce the potential of Virtual Reality as a station assessment tool.

The author/s have been fortunate to be involved in the transportation aspects of various new and upgrade railway station projects that are referred to in this paper.

The layout of this paper is organised as follows. Sections 2 and 3 highlight the basic pedestrian model development approach and parameters and identifies the assumptions and limitations of the VISSIM microscopic model. Section 4 presents the type of outputs

generated by the model and how these are used to assess station designs. Section 5 describes how the evacuation requirements of railway stations are calculated. Section 6 provides some of the lessons learnt through case study application of the microscopic model to the various station designs. In Section 7, Virtual Reality (VR) capabilities are briefly introduced and a concluding statement is made in Section 8.

## **2. PEDESTRIAN MODEL DEVELOPMENT**

### **2.1 Pedestrian Simulation Software**

The latest VISSIM module from the PTV Vision product line (used for traffic planning that realistically simulates interactions between pedestrian and vehicle flows) has been used as the software of choice. VISSIM is a microscopic simulation tool that simulates all vehicles and pedestrians as individual agents. The behaviour of pedestrians can now be defined individually, in the same way as before with vehicles. With the speed distribution, the VISSIM user can allocate each pedestrian an individual desired walking/running speed.

### **2.2 Approach to the Station Modelling Projects**

Appropriate station design involves testing not only the normal day to day operations during peak periods, and also ensures that the proposed station infrastructure can safely evacuate passengers (pax) within acceptable time limits. There are four distinct phases used in the pedestrian modelling process:

- Station infrastructure model development.
- Identification of peak 15-minute periods for assessment.
- Testing operational and evacuation scenarios.
- Evaluation of pedestrian assessment and documentation.

### **2.3 Identification of Passenger Demand and Assesment Scenarios**

Pedestrian assessments are normally undertaken for the operational scenario for a horizon year (usually a +20 year horizon) only. Scenarios tested include a morning and an afternoon 30-minute peak period.

Modelling results for the proposed station are provided over a minimum of 180 ten-second intervals for both AM and PM peak operational scenarios. A technical assessment for the evacuation event using macroscopic principles is also necessary as this can be critical and may require significant station design changes.

## **3. PEDESTRIAN MODEL PARAMETERS**

### **3.1 Assessment Code of Practice**

Station infrastructure sizing requirements are based on the minimum operational capacity determined according to the minimum acceptable Levels of Service; LOS D for stairways and LOS C for all other station elements. LOS criteria are adopted specifically from Mass Transit Guidelines (TCQSM, 1999) rather than HCM guidelines that is more suited to street walkways.

To determine the required number of turnstiles/access gates necessary to satisfy the demand, a queuing LOS C density standard is adopted (TCQSM, 1999). Previous pedestrian modelling experience has shown that turnstile/access gate demand needs to be lower than turnstile/access gate capacity to achieve acceptable levels of queuing service. Independent research conducted by the author/s has revealed that turnstile/access gate demand needs to satisfy a Volume/Capacity (V/C) ratio of between 0.74 and 0.80 to achieve a reasonable level of service (Hermant and De Gersigny, 2010).

In addition to designing for the peak loads during normal operations, the evacuation time plays an important role in evaluating emergency infrastructure requirements and requires designing for the maximum possible evacuation load. Pedestrians within a station facility should be able to evacuate the platform and station building within four and six minutes respectively from the time the fire alarm is activated in line with international standards.

### 3.2 Pedestrian Composition

Research has shown that males walk faster than females (Willis et al, 2004) and their collective mixture also affects infrastructure capacities. To account for the various types of users i.e. gender, age or impaired, a stochastic walking speed profile is used ranging from 1.61 m/s to 0.72 m/s. For the purposes of modelling, the default population and associated walking speed profile is a 2:1 Man to Woman profile as shown in Table 3.2. This gender proportion is region specific.

<b>Table 3.2: Composition of Modelled Pedestrians</b>		
Description	Composition	Speed Distribution
Normal Male	67%	0.97 – 1.61 m/s
Normal Female	33%	0.72 – 1.19 m/s

In the table, speed refers to a walking speed in unhindered (or “free-flow”) conditions. Results of previous work (Goba, 2009a) that tested the impact of possible variations in the pedestrian composition showed that a greater Special Needs Passenger (SNP) proportion and/or females improves levels of service of the station for the duration of the simulation.

This is contrary to what is intuitively expected when one considers SNP’s in a pedestrian environment. The reason for the improvement in flow rate levels of service is the reduction in walking speeds of Special Needs Persons that spreads out the pedestrian arrival rate at infrastructure elements and thereby reduces the density and flow rate levels.

### 3.3 Modelling Assumptions and Limitations

To simplify the modelling process, the following assumptions are considered:

#### 3.3.1 *General Assumptions*

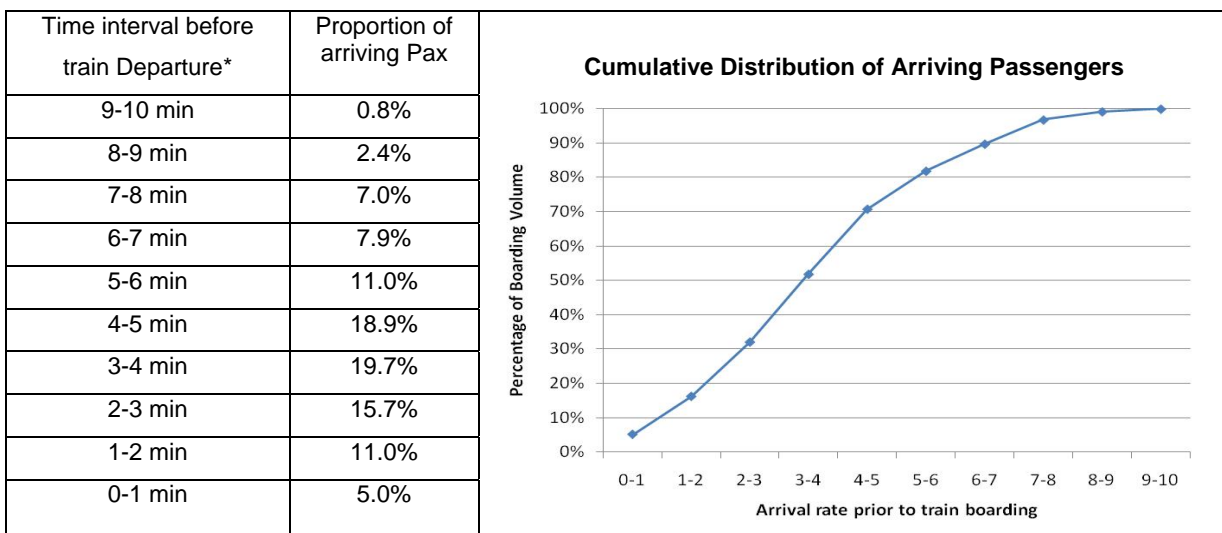
- Coach alighting rates of two seconds per passenger (TCQSM, 1999) are modelled assuming a nominal door opening width of 1.3m. Note that the two seconds alighting rate is an international average (USA and Canada only) for medium volume doorways and has not yet been calibrated for South African commuter conditions. Research is currently underway to examine boarding and alighting rates in South African stations.
- A High speed access gate (HSAG) capacity of 45 passengers per minute is used as the operational capacity used for modelling purposes for the higher capacity access “flap” gates. An unrestricted “open” flap gate capacity of 50 passengers per minute is used to

model the evacuation scenario. Since access gates are modelled as bottleneck gaps, throughput capacity is dependent on the local passenger mix.

- Uniform coach boarding distribution is normally assumed for modelling purposes and the full length of the platform is used for boarding purposes. To reduce modelling complexity, separate boarding and alighting profiling for the Metro Plus and Metro coaches is not modelled.
- Maximum Train dwell times of two minutes are used for modelling purposes throughout. Actual dwell times terminate after a five second interruption of boarding flow.

### 3.3.2 Passenger Arrival Rates

For modelling purposes, a variable passenger arrival rate of between five and ten minutes is applied depending on train schedule headways. A typical ten minute arrival profile is as follows:



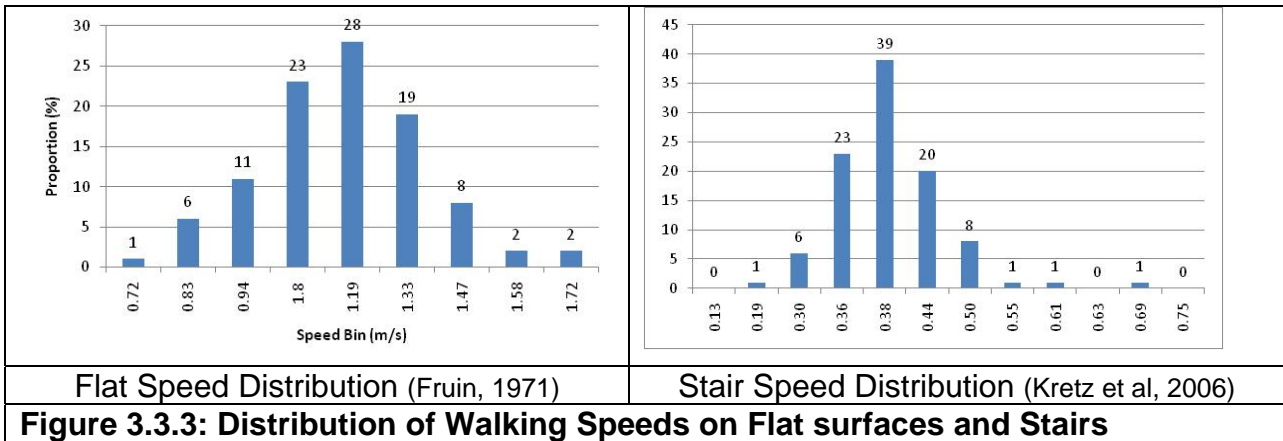
\*Note that train departure occurs at time  $t=0$

The passenger arrival rates are based on the same S-curvature of the cumulative passenger (pax) versus time graph presented in other literature (Tolujew and Alcalá, 2004). Results of recent preliminary arrival rate studies undertaken at Bonteheuwel Station by the author/s reveal a uniform rate of arrival that will be incorporated in future models.

### 3.3.3 Pedestrian (Infrastructure) Speed Distribution

The way pedestrians are modelled in the VISSIM microscopic model is entirely dependent on the infrastructure type the pedestrian use e.g. stairs, flat surfaces or ramps. Pedestrians tend to have higher average speeds on flat surfaces than when negotiating stairs and the corresponding densities also vary. Pedestrian movement on escalators is especially important as the speed distribution is dependent on the slope speed of the stair mechanism.

For flat surfaces and staircases, the Fruin and Kretz un-impeded speed distribution profiles are used, as shown in Figure 3.3.3.



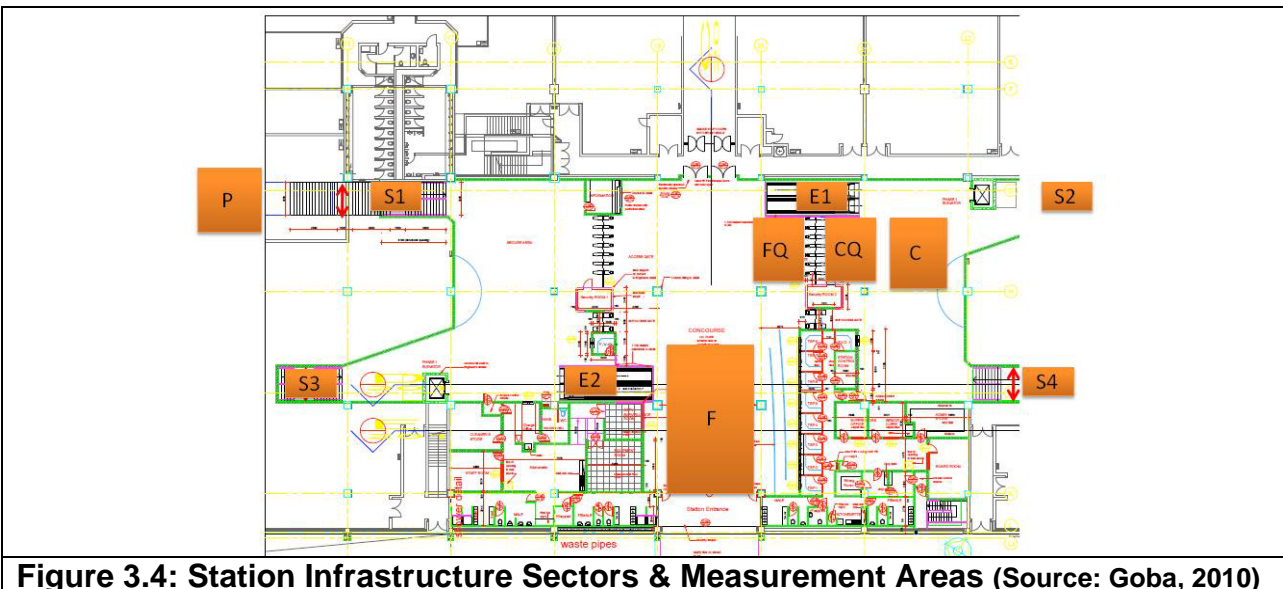
**Figure 3.3.3: Distribution of Walking Speeds on Flat surfaces and Stairs**

The selection of unimpeded speed distribution profiles appropriate to the particular infrastructure with attributes of the local people who are actually going to use the facility is important. Unfortunately local South African pedestrian speed profile attributes at stations are not yet available and speed distribution profiles determined from international research have been used.

### 3.4 Definition of Assessment Areas

The VISSIM simulation model requires the user to define measurement (or assessment) areas that will automatically accumulate data and write to a database for later analysis.

Figure 3.4 shows the naming legend used for each infrastructure sector for a typical station (Goba, 2010) as follows: Staircases (S1, S2, S3 and S4), escalators (E1 and E2), platform (P), concourse area (C), concourse queuing area (CQ), foyer queuing area (FQ) and foyer area (F).



**Figure 3.4: Station Infrastructure Sectors & Measurement Areas (Source: Goba, 2010)**

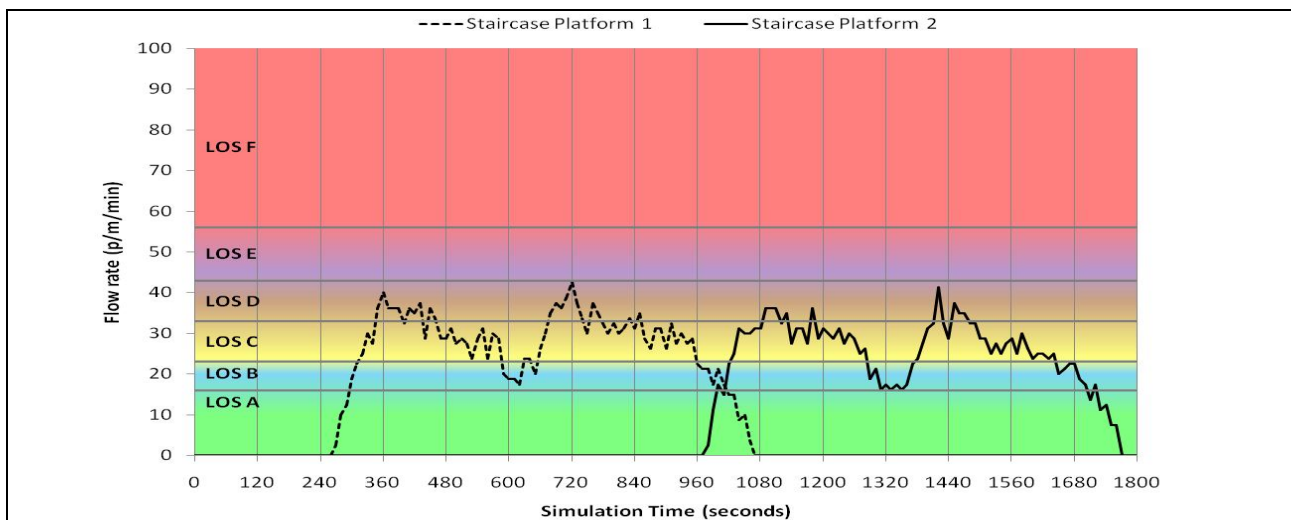
## 4. MODEL OUTPUTS

The VISSIM model allows the simultaneous output of speed, flow or density in any selected time interval for the defined measurement areas.

For the purposes of station evaluation, all assessments are based on density criteria except stairways where a flow criterion is used. This is because the VISSIM model is unable to collect density criteria on complex sloping infrastructure. For assessment of stairs, a flow rate criterion is determined from a user positioned virtual line on the stair landing between the lower and upper flights of stairs.

### 4.1 Stairways

Figure 4.1 shows a typical time scale output of flow rates (pedestrians per metre per minute) for staircases. Note that the flow rate outputs are in p/m/min and the data interval is 10 seconds.

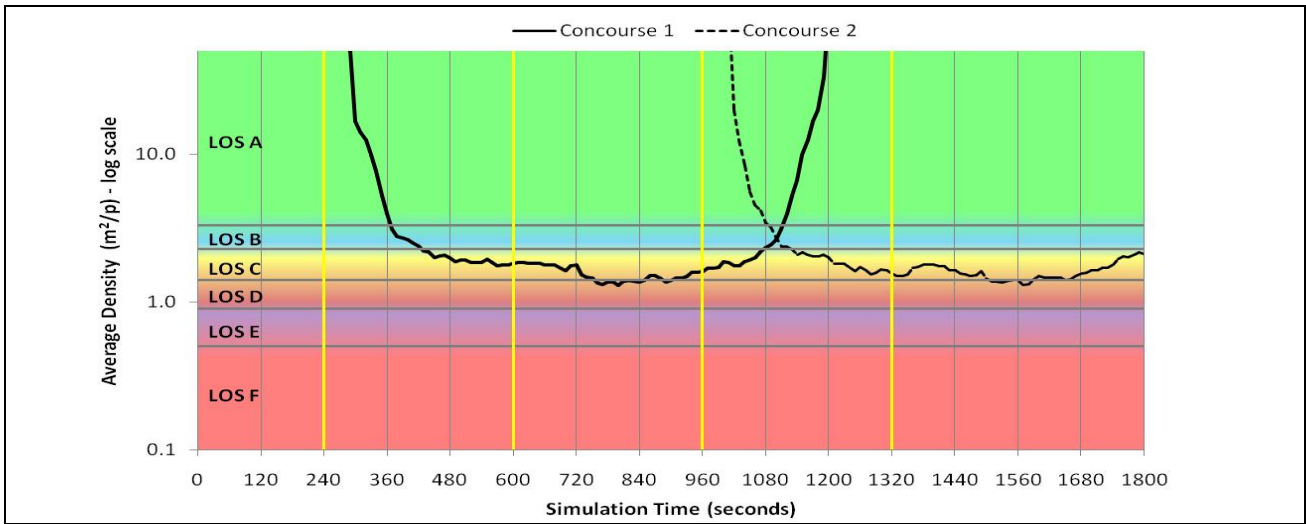


**Figure 4.1: Example of a Platform-Concourse Staircase Flow Rate LOS (Source: Goba, 2009c)**

From Figure 4.1, both sets of staircases on either platform 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 at their operational capacity in terms of the LOS criteria. Note that operational capacity is the maximum flow rate used for station designs and this is normally set at LOS D. Jam capacity (LOS F) occurs when flow reduces to zero. The preference is to design according to a density LOS parameter since flow rate does not give any indication of the “crowding” effect. The possibility also exists for both LOS A and LOS F to occur for the same flow rate. VISSIM is unable to provide density results on staircases.

### 4.2 Walkways including Platforms, Concourses, Foyers and Skywalks

Figure 4.2 below shows a typical time scale output of the density parameter ( $m^2$  per pedestrian) for the concourse. Two measurement areas have been used as the concourse leads to two separate stairs and platform groups.



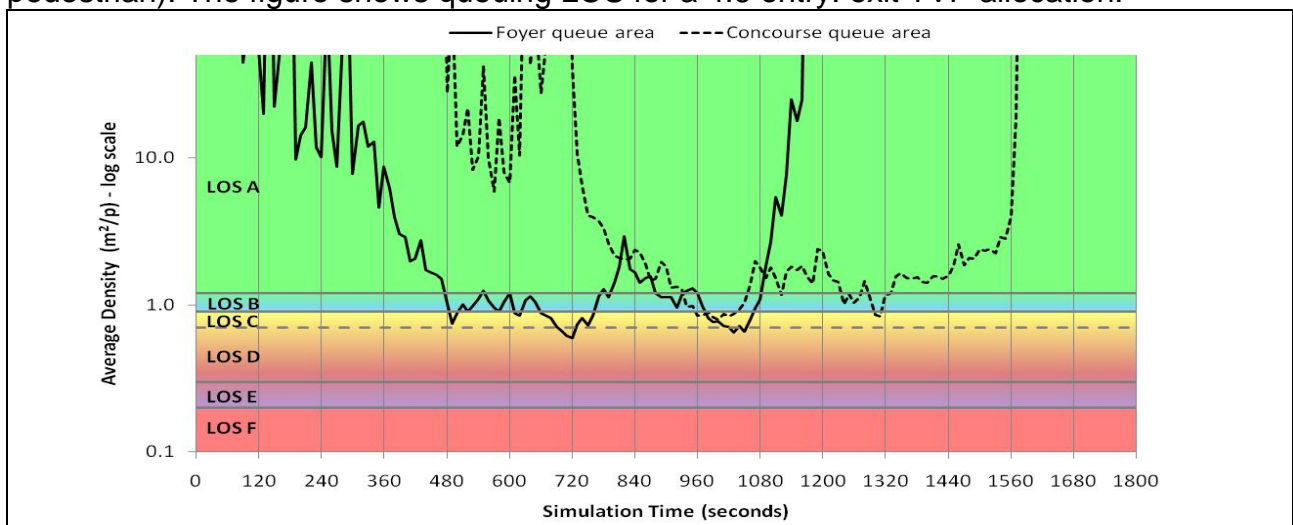
**Figure 4.2: Example of a Concourse Density LOS (Source: Goba, 2009e)**

The two concourse measurement areas, each 10.3m x 13.2m, indicate the congestion levels on the concourse. From the graph, Concourse 1 can be seen to operate briefly in LOS D for 90 seconds that 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 of the station. Note that, according to the rail authority, the LOS C is the governing operational capacity for all areas apart from staircases. This is to allow for additional space for Special Needs Passengers (SNP's).

### 4.3 Ticket Verification Points (TVP's)

Queuing at TVP's is modelled by density upstream of the access gates rather than queue length due to the tendency of pedestrians to crowd competitively close to access the batteries rather than queue in a linear fashion.

Figure 4.3 provides a typical time scale output of the queue density parameter (m<sup>2</sup> per pedestrian). The figure shows queuing LOS for a 4:6 entry: exit TVP allocation.



**Figure 4.3: Density output for a 4:6 entry: exit gate ratio (Source: Goba, 2009c)**

For this arrangement, the TVP queuing levels of service should remain at LOS C or better for the duration of the peak 15-minute period. From the graphs, there is an equal entry and exit LOS for access gates at t=960 where a 4:6 entry: exit TVP allocation is necessary to maintain adequate levels of service. In this case, 10 access gates are considered adequate.

## 5. EVACUATION ASSESSMENT

For the purpose of testing evacuation requirements, the 4-minute NFPA Test 1 and 6-minute NFPA Test 2 (NFPA 130, 2003) is the standard method used as follows:

Test 1: Evacuate *Platform Occupant Loads* from Platforms in 4-minutes or less.

Test 2: Evacuate *Platform Occupant Loads* from Most Remote Point on Platforms to a Point of Safety in 6-minutes or less.

The 4-minute test (viz. Test 1) computes the time required to clear the platforms. In this test, the entire platform occupant load must clear the platform in less than 4 minutes. The 6-minute test computes the total time required to exit the station from the most remote point on the platform and accounts for delays experienced at obstacles (e.g. stairs or doors).

### 5.1 Evacuation Assessment Matrix

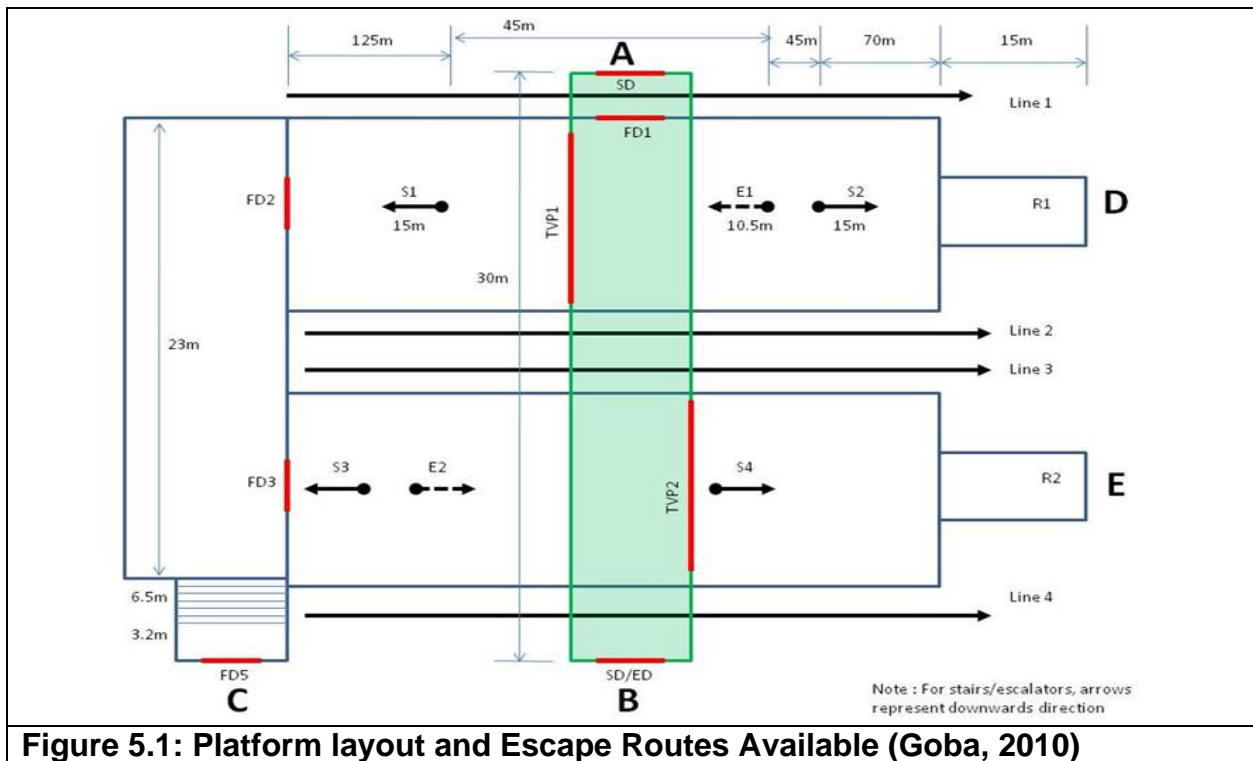
To assess the evacuation capacity of the station, an evacuation assessment matrix is developed for both tests that shows evacuation scenarios and route capacities. An example of a Test 1 assessment matrix is shown in Table 5.1 (Goba, 2010). The matrix allows for a range of evacuation scenarios to be tested against the 4-minute requirement using the egress routes available (viz. A through to E) identified in Figure 5.1. The 6-minute Test 2 assessment matrix is not shown.

No	Exits un-available	Exits available	Possible Exit Routes	Platform Exit Capacity	Time (secs) to Clear Platforms ( <i>W1</i> )		
					2020 load	10M train	8M train
1	A	B, C, D and E	FD2→FD5→C	265 ppm	1.70	1.87	2.25
			(S1+S2+E1)→(TVP1+TVP2)→SD/ED→B	535 ppm			
			R1→D	267 ppm			
2	B	A, C, D and E	FD2→FD5→C	265 ppm	1.70	1.87	2.25
			(S1+S2+E1)→(TVP1+TVP2)→FD1/SD→A	535 ppm			
			R1→D	267 ppm			
3	C	A, B, D and E	(S1+S2+E1)→(TVP1+TVP2)→FD1/SD→A	535 ppm	2.25	2.50	2.99
			(S1+S2+E1)→(TVP1+TVP2)→SD/ED→B				
			R1→D	267 ppm			
4	D	A, B, C and E	(S1+S2+E1)→(TVP1+TVP2)→FD1/SD→A	535 ppm	2.25	2.50	2.99
			(S1+S2+E1)→(TVP1+TVP2)→SD/ED→B				
			FD2→FD5→C	265 ppm			
5	A and B	C, D and E	FD2→FD5→C	265 ppm	3.39	3.75	4.51*
			R1→D	267 ppm			
6	B and C	A, D and E	(S1+S2+E1)→(TVP1+TVP2)→FD1/SD→A	535 ppm	2.25	2.50	2.99
			R1→D	267 ppm			
7	A, D and E	B and C	(S1+S2+E1)→(TVP1+TVP2)→SD/ED→B	535 ppm	2.25	1.50	2.99
			FD2→FD5→C	265 ppm			

\*Platform Ramp End width is limiting capacity.



From Table 5.1, all reasonable evacuation scenarios comply with the 4-minute evacuation standard, except Scenario 5 for a crush loaded 8M train where an extra 30 seconds over the four minutes is required to clear the platform. As a result of this analysis, the recommendation was to widen the platform ramp ends (R1 and R2) from 3.0m to 3.75m to comply with the evacuation requirements for an 8M train. Sufficient holding area needs to be allowed for at the platform sides or ramp ends to cater for an evacuation event. The Evacuation Assessment Matrix provides a simple tabular format to test any additional evacuation scenarios.



**Figure 5.1: Platform layout and Escape Routes Available (Goba, 2010)**

## 6. SOME LESSONS LEARNT FROM MICROSCOPIC MODELLING OBSERVATIONS

During the simulation of the various station design assessment projects, valuable qualitative understanding could be gained by visualising the circulation flows and making judgements on pedestrian comforts. The following provides a few lessons learnt from the microscopic simulation runs:

- The location of structural columns close to stairs and/or turnstiles significantly impacts on these infrastructure throughputs.
- A certain amount of congestion occurs at the base of the stairs. This is partly attributable to persons adjusting their gait to ascend and partly due to the friction of pedestrians wanting to access the stairs from the sides.
- To reduce the inter-personal friction at tops of platform stairs that is sometimes exacerbated by the right-angle change in direction, it was found that the introduction of a short divider (or guardrail) to separate the two movements before merging significantly reduced friction. This is known as providing a “run-off area” (Ross, 2000), where pedestrian areas are limited to one activity at a time to reduce the risk of circulation being impeded or stalling (that would be dangerous at the tops of stairs) due to passengers stopping to orient themselves or making movement decisions immediately beyond.

- Friction is created wherever pedestrians negotiate sharp corners in the station building. As seen at many international station termini, a curved transition around these corners and bends is suggested to reduce the buildup of friction and smoothen the flow.

## 7. INCORPORATION OF VIRTUAL REALITY

Over the past few years, virtual reality (VR) in micro simulation has provided a valuable tool to evaluate complex infrastructure proposals. VR provides realistic visualisation and reflects detailed engineering aspects.

VR was used in both the Cape Town station upgrade (Goba, 2009d) and Bridge City evaluation (Goba, 2010) in Ethekweni. VR provides a unique platform to integrate micro simulation, urban design and existing infrastructure that demonstrates the functionality of the proposed environment before implementation to decision makers.

VISSIM output data (Pedestrian Protocol / Vehicle Data record) is processed using an advanced 3D VR Processor (SVR Bridge V5.1) that then links this data with the objects created and designated in 3DS max that then behave exactly the same as modelled in VISSIM. The data is an aesthetic tool and maps pedestrian behaviour realistically.

Typical examples of three dimensional VR render outputs are shown in Figure 7.



**Figure 7: VR Output sample taken off AVI video file (Goba, 2010)**

## 8. CONCLUSION

Until very recently, pedestrian microscopic modelling has not been incorporated into the design of railway stations in South Africa. The recent developments in computer technology and microsimulation software described in this paper have led to the incorporation of such modelling to confirm spatial designs for high pedestrian volume environments. Microscopic simulation provides beneficial value for modelling interactions between conflicting pedestrian flows.

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