Assessing Evacuation Compliance in the MRT-3 Ayala Station: A Microsimulation Approach Through PTV Viswalk

Eren Karl T. MORTEL [a], Elmon Jr. M. BANDOJA [b], Andrea Jenn L. RIVERA [c]

[a,b,c] *College of Engineering, Polytechnic University of the Philippines, Sta. Mesa, Manila, 1016, Philippines*
[a] *E-mail: morteleren@gmail.com; erenkarltmortel@iskolarngbayan.pup.edu.ph*
[b] *E-mail: elmonbandojajr@gmail.com; elmonmbandojajr@iskolarngbayan.pup.edu.ph*
[c] *andreajennrivera@gmail.com; andreajennlrivera@iskolarngbayan.pup.edu.ph*

Abstract: Simulating pedestrian behavior represents an advanced method in evaluating and modeling emergency egress performance in transit stations. In this study, microsimulation was conducted using PTV Viswalk, implementing behavioral frameworks such as the Social Force Model (SFM), to evaluate pedestrian behavior and assess emergency egress compliance of the MRT-3 Ayala Station against local and international fire safety standards. The simulation model was constructed from field data collected during peak-hour operations. Behavioral parameters based on the SFM were calibrated through the Response Surface Methodology (RSM) framework and validated against an independent data set. Emergency egress was evaluated across nine simulation scenarios, incorporating baseline, worst-case, and projected ridership conditions, with sensitivity analyses on walking speed and pedestrian route choice. Results revealed consistent non-compliance with the NFPA 130 evacuation standard and life safety benchmarks across all scenarios, with implications for station emergency planning.

Keywords: Pedestrian Behavior, Evacuation Methods, Rail Transit System, PTV Viswalk, Transportation Safety, NFPA 130

1. INTRODUCTION

1.1 Background and its Context

Metro Manila is the most congested city globally, and this is caused by a misallocation of land use, including public transportation. As Aloc and Regidor (2017) describe, 80% of Manila's population uses road-based public transportation, yet 70% of the road space is taken by private vehicles. Since 2019, car and motorcycle ownership have increased constantly, and grown by 27% and 64% respectively, while public transportation like Public Utility Vehicles (PUVs) and Public Utility Buses (PUBs) have collectively decreased by 67%, and seem to have stagnated. At its current state, there comes a point where car-centric development becomes unsustainable, and thus, an alternative is proposed. The railway system, used by thousands of Filipinos on a daily basis, is important for a working and growing urban environment. It allows the city to expand, insofar as enabling its citizens to live farther and still access their jobs, services, and leisure (Zimmerman, 2005).

Many studies in recent years have devoted their attention to finding ways to make transportation systems safer, particularly in the railway sector, as a reaction to accidents and disasters that have negatively affected the industry in recent years (Evans 2021; Hadj-Mabrouk, 2021; Shojaei et al., 2023). It can be seen that, to facilitate metropolitan growth, it is essential to ensure that the systems and infrastructure of these services are able to keep up with the

increasing passenger demand. After all, lines like the MRT-3 contribute largely to the gross movement of passengers in and out of Metro Manila. More importantly, prioritizing human safety before casualties occur has been the main focus point in the design and operation of these systems. In the context of Metro Manila and the MRT-3, a case is presented where its systems and station limitations are constantly challenged.

1.2 Statement of the Problem

In emergency situations, passengers must also be able to evacuate the station efficiently; therefore, an unobstructed and reliable means of exit from the station—also known as egress—is essential. This topic has been unexplored in the Philippines, and virtually none in the MRT-3 System. This becomes a vulnerability as the MRT-3 system has a limit to what it can offer, how much, and for how long (Ganiron, 2015). It follows that an increasing reliance on the MRT-3 System necessitates an assessment of whether the infrastructure standards of that system meet the growing demand, particularly in passenger flow and emergency egress. This study therefore seeks to a) identify vulnerabilities in the spatial configuration of the stations, b) examine how passenger flow dynamics during normal and emergency egress are impacted by these vulnerabilities, and c) evaluate egress times to international standards for fire protection.

1.3 Objective of the Study

This study took the existing setup of the MRT-3 Ayala Station as a baseline, simulated the station's egress performance under normal and emergency conditions, and identified spatial or operational bottlenecks that may put stress on the system or compromise evacuation. This research aimed to analyze and quantify emergency egress time performance through three primary metrics: clearance/leave times from the i) platform, ii) concourse fare gates, and iii) station to street level. These metrics were evaluated across simulation scenarios that range from current baselines to worst-case and future projected conditions, and mediated through variable walking speeds, pedestrian volume, and route choice splits. The social force model (SFM) by Helbing et al. (2007) was used in this study for pedestrian microsimulation with PTV Viswalk.

2. LITERATURE REVIEW

Pedestrian dynamics structure the behavioral foundation for analyzing the patterns of evacuation movement within confined areas. The SFM fits this criterion, as it can accurately model pedestrian behavior through different forces acting on the pedestrian (Fariha et al., 2025; Helbing et al., 2000). It constitutes the driving force that describes pedestrians' movement towards a certain destination, the repulsive force that shows the distance between pedestrians to avoid collisions, and the obstacle force that influences the pedestrian movement as caused by physical barriers. Conveniently, the PTV software also follows the SFM algorithm to analyze pedestrian flow dynamics, which are governed by various parameters.

From a macroscopic perspective, Vanumu et al. (2017) underscore the variables constituting the Fundamental Diagram, which represents the empirical relationship between speed, flow, and density. While the Fundamental Diagram represents the relationships among the macroscopic variables describing the collective pedestrian movement, a necessary area to explore is how these aggregate patterns emerge from individual behaviors (Bode et al., 2019). In the context of metropolitan stations, pedestrian behavior is characterized by "batch arrivals" or rhythmic pulses of high-density crowds synchronized with train headways—accompanied by alighting and boarding of passengers—rather than a steady and continuous flow

(Boonsomparn, 2019). According to the level of service (LOS) framework, as the available space per person decreases, individual walking speeds decrease, and the crowd begins to behave as a collective fluid, leading to the formation of bottlenecks that significantly affect clearance times (Fruin, 1974). High densities cause smooth pedestrian flows to collapse, which leads to collective patterns of motion such as stop-and-go waves (Helbing et al., 2007).

In the event of emergencies, Van der Wal et al. (2024) emphasized that evacuation response behavior is characterized by the way occupants interpret and respond to evacuation cues, allowing them to validate the condition of their environment and initiate preparation for evacuation measures. A critical factor affecting evacuation efficiency is the choice of exits (Zhu and Shi, 2016). Another phenomenon impacting evacuation is the 'faster-is-slower effect' where people try to move faster than normal to get through the exit because of impatience (Helbing et al., 2000). In terms of crowd saturation, the LOS framework by Fruin (1974) defines a highly dense crowd at LOS E, and especially at LOS F. This leads to the overall safety of the station, which is governed by specific time-based performance benchmarks, specifically for the Philippines. Two primary standards govern these requirements: the R.A. 9514, also known as the Fire Code of the Philippines, and the NFPA 130: Standard for Fixed Guideway Transit and Passenger Rail Systems of the National Fire Protection Association (NFPA).

In terms of the limitations of PTV Viswalk, it upholds complex and demanding modeling of pedestrians as public transport passengers where credible results greatly depend on the detail and accuracy of calibrating and representing passenger behavior using relevant parameters (Alexandersson & Johansson, 2013). Within this software, the use of the SFM's default parameters constitutes a limitation when applied to the Philippine transit context of MRT-3 Ayala Station. However, this limitation is directly addressable through empirical parameter calibration that localizes pedestrian behavior to the study context, an approach similarly employed in studies conducted in other countries (Boonsomparn, 2019; Fariha et al., 2025; Gaddam et al., 2022; Shrestha, 2025).

3. METHODOLOGY

3.1 Research Instrument

PTV Viswalk was used in the simulation aspect of this study. Made by the PTV Group, this software allows for the modeling of complex geometries integrated with a large number of modifiable pedestrians (Martén and Henningsson, 2014; Alexandersson and Johansson, 2013). Figure 8 showcases the overall process framework that will be applied in this study, and subsequent tasks will be further detailed in this chapter. For the SFM, the relevant parameters, their descriptions, default values and allowable value range are listed in Table 1.

3.2 Data Gathering

The process of data gathering began with obtaining primary and secondary data from the DOTr-MRT3 and the Freedom of Information (FOI) website, and conducting on-site surveys, interviews, and visits. Multiple requests were made in order to access data such as the as-built plan, emergency exit plan, and elevation plan of the Ayala station. A request was also made for the hourly ridership report of the line through FOI. Field visits were conducted to verify measurements of the as-built plans, along with other data sets, as detailed in Table 2.

Table 1. Parameters of PTV Viswalk

Parameter	Description	Default value	Range
Tau (τ)	Reaction time	0.40 (s)	0.05 - 1.00
Lambda (λ)	Field of vision	0.167	0.00 - 1.00
Noise	Random force of pedestrians	1	0 - 10
React to N	Force applied from n closest pedestrians	8	≥ 1
Grid size	Max distance up to which pedestrians influence each other	5	≥ 0
VD	Lateral evasion between two colliding pedestrians	3 (s)	≥ 0

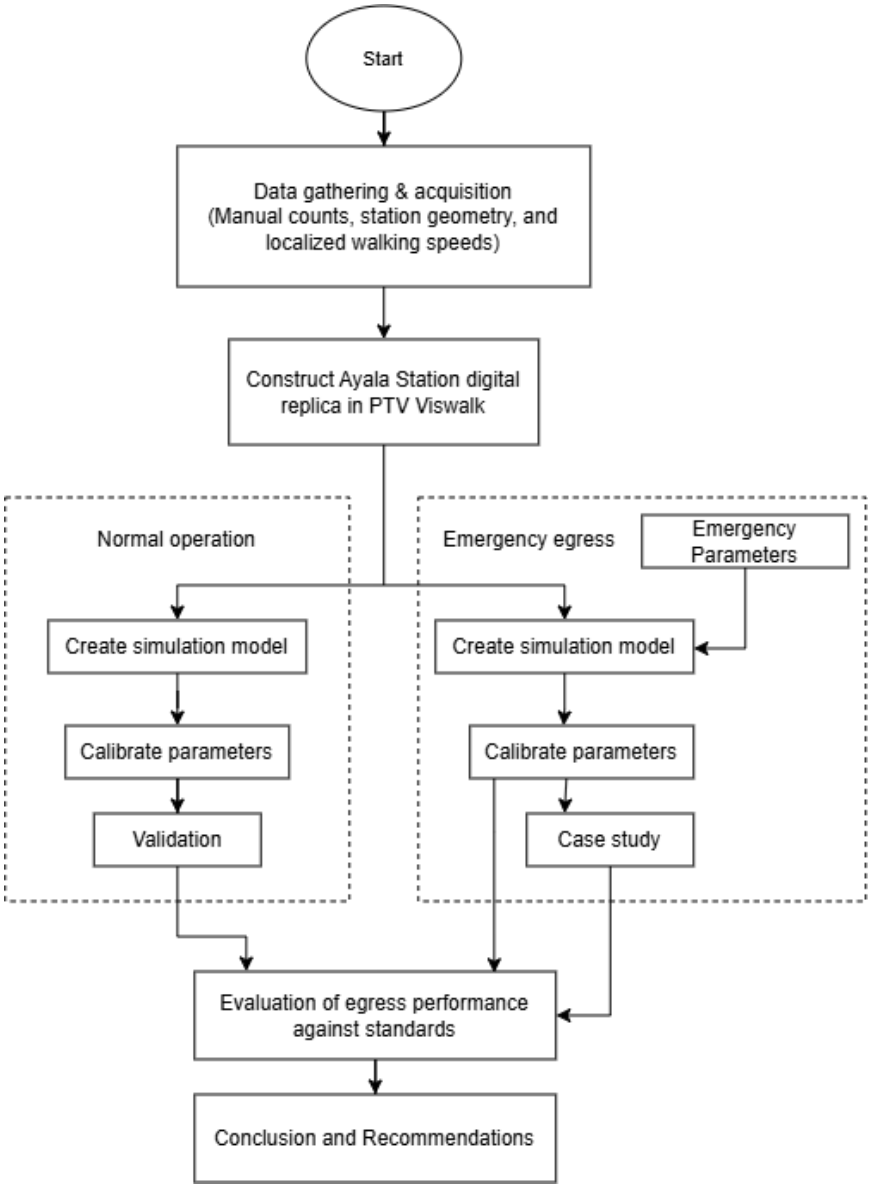


Figure 1. Process flowchart of the study (Adapted from Boonsomparn, 2019)

Table 2. Field survey methods

Task	Location	Method
Volume Count – Ingress	Turnstile, Concourse	CCTV and video recording
Volume Count – Egress	Mezzanine	CCTV
Speed Measurement	Corridor (4m marked section)	Stopwatch
Service Time	Ticket Counter, TVMs, and fare gates	Stopwatch
As-built survey	Station	Tape measurement
Interview	Whole station	Voice recording
Route Choice	Mezzanine A/B and concourse	Manual count and CCTV
Max dwell time	Platform	CCTV

Alongside manual counts, closed circuit televisions (CCTV) were also taken for data gathering, as it allowed for zoning, detection, and aggregation of large amounts of data (Caramuta *et al.*, 2017). The data gathering process was conducted for three separate days from midday to evening, with the last day being used for data validation. The data gathered from the speed measurement, the service time, and dwell time will be used to calibrate an optimal value for the set of parameters that was described in Table 1. The rest of the gathered data is applied to PTV Viswalk and to aid in the findings of pedestrian flow during peak-hour operations.

The station model is built with three (real) levels. i) The concourse level: consisting of three street entrances and two mall entrances, this level also allows for the sale of fare tickets and is separated between a paid and unpaid area; ii) the mezzanine level: separated into two vertically, although each area does not discriminate between platform sides and egress/ingress flows; and iii) the platform level: separated into two horizontally, each side services one train direction only. These levels and its 3D and 2D representation can be seen in Figure 1.

The pedestrian was made more accurate with the local context by scaling the 3D model to match the average height of a male and female Filipino of 1.63 m and 1.50 m, respectively (FNRI, 2013). The age group of the pedestrians, traveller type, and traveller behavior was not modelled in this study.

3.3 Calibration Framework

In order to find the optimal value for the relevant parameters seen in Table 1, the central composite design (CCD) in the response surface methodology was utilized. This methodology requires two input values and a response value. The former is derived from the values of the walking behavior parameters, tested by pairs (e.g., Tau and Lambda), and the latter describes the squared difference in error between the observed value in the field versus the simulated value in the model. The CCD helps by modeling a quadratic surface that can predict a pair of input values that outputs the smallest response, in the least number of runs as compared to alternative calibration frameworks (Montgomery, 2001).

In this study, one design was conducted per parameter pair, yielding a total of 13 runs. The number of runs is given by the i) four factorial points, ii) four axial points, and iii) five center points. The distance of the axial points from the center and the number of replicates is important, as both directly affect the properties of the experimental design.

Table 3. Tau and Lambda CCD runs

Run	Code	Tau (x_1)	Lambda(x_2)
1	(-1, -1)	0.1	0.1
2	(1, -1)	0.4	0.1
3	(-1, 1)	0.1	0.9
4	(1, 1)	0.4	0.9
5	(0, 0)	0.25	0.5
6	(0, 0)	0.25	0.5
7	(0, 0)	0.25	0.5
8	(0, 0)	0.25	0.5
9	(0, 0)	0.25	0.5
10	(+α, 0)	0.4	0.5
11	(-α, 0	0.1	0.5
12	(0, + α)	0.25	0.9
13	(0, - α)	0.25	0.1

The range is mediated by the realistic and technical limits of the parameter being calibrated. A CCD uses five levels of ranges: negative alpha (-α), minimum (-1), center (0), maximum (+1), and positive alpha (+α). Usually, , but a face-centered design utilizes α=1. Meaning that axial points no longer have the same radius as factorial points, rather, they coincide with the midpoint of each factorial point. The center points are used to make the data more reliable, by which reason it has five replicates.

For example, Tau and Lambda informs the speed at which pedestrians will move. In Viswalk, every generated pedestrian has an inherent desired speed, how they move around below this speed is dictated by the values of Tau and Lambda. Thus, it is important to define a range that still falls within the realistic limits of the model. The different pairs of input values and their run number is detailed in Table 3.

Five simulations are given for each run, and the mean is taken for the calibration criteria, which in this case, is the walking speed (m/s). With the field data of the calibration criteria, the objective function's squared error (SE) can be derived. Penalizing greater errors compared to smaller ones, this formula is given by

$$SE = (x - y)^2 \tag{2}$$

where,

x : field survey result of calibration criteria, and

y : simulation result of calibration criteria (see Table 5).

The resulting values are then plotted using RStudio, and the resulting ANOVA table from this response model can then be evaluated. After verifying the model's robustness, an optimized parameter is chosen based on the predicted response value that is closest to zero.

For emergency parameters, this study utilizes the same calibrated parameters in normal egress. Reason being the absence of local empirical data from which the parameters for emergency egress can be derived. In its stead, urgency during emergencies was operationalized mainly through walking speed adaptation, different design scenarios, and manual staircase movement penalties. This is consistent with the scope of this study, which evaluates egress times against international fire safety standards rather than modelling the phenomenon of panic.

3.4 Evaluation Criteria

In addition to the standards and limitations set by the NFPA 130 (2019) when informing scenario designs, criteria can be set to evaluate the performance of evacuating pedestrians. According to the NFPA 130, as cited by the IRR (2019), evacuation times from the station platform should be four minutes (4 min) or less (§ 10.2.19.2(C1)). Evacuation to a point of safety from the platform shall be done in six minutes (6 min) or less, and a point of safety is described as one of the following: i) exit leading to a public way or any safe location outside the station, ii) an at-grade point beyond the station, or iii) any other approved location (§ 10.2.19.2(C2a-c)). For these standards, this study sets three criteria for measuring egress capacity. t_1 details the time the last occupant leaves the station platform, t_2 is the time to pass the fare gates on the concourse, and t_3 is the time to reach a point of safety at the street level outside the station. t_2, as the unpaid concourse, can be a valid point of safety, provided that an engineering analysis determines the concourse to be safe from the effects of a train fire (§ 10.2.19.2(C3a-b)). The street-level point for Ayala station is chosen by its proximity to the fare gates, which, in this case, were the two southbound escalators and stairways. This is applied to PTV Viswalk using area measurements and 'Leave time,' a data attribute that measures the point in time at which all pedestrians leave a specified area.

4. FIELD SURVEY RESULTS

4.1 Study Area

This study was conducted in the Ayala Station of the DOTr-MRT3, located along EDSA, in Makati, Philippines. The station was selected for its unique multi-level design, complete with an underground platform and an elevated concourse. The concourse has direct access to One Ayala and SM Makati on the southbound side, and street exits on the northbound side.

As-built survey results showed that the concourse-level escalators had an actual width of 1.00 m. While NFPA 130 does not prescribe a minimum width for escalators, it prescribes a minimum stair width of 1.12 m (44 in.) as a valid means of egress (National Fire Protection Association, 2019). For escalators, NFPA 130 permits escalator use in egress provided that they are made of noncombustible materials (§ 5.3.5.7(1)) and that those running in the direction of egress are allowed to remain operating (§ 5.3.5.7(2)). All stairways and exit corridors are able to meet the minimum requirement. In total, the station has 11 escalators, 14 stairways, 3 elevators, 9 fare collection gates, 4 swing gates, 26 columns, and 2 ticket vending machines (TVMs).

4.2 Passenger Volume

Passenger volume survey results showed that the 15-min peak interval occurred between 17:15 and 17:30, where 1,395 pedestrians entered the station. Southbound trains recorded the most alighting passengers, with 210 passengers during the 17:30 to 17:45 interval, compared to 77 passengers for the northbound trains in the same interval. Average train headways were 267 seconds for the northbound trains and 278 seconds for the southbound trains.

4.2 Walking Speed

The free-flow walking speed survey (N = 200) showed that the local pedestrians exhibited an overall mean of 1.10 m/s (SD = 0.205). The pedestrian flow rate at the concourse area averaged 7.58 ped/min/m across all intervals, corresponding to Level of Service A (LOS A) at the measurement area.

4.3 Route Choice

Passenger route choice survey results showed that 79.98% of entering passengers proceeded directly to the fare gates, 17.64% to ticket counters, and 2.37% to TVMs. After passing through the fare gates, passengers were nearly equally split between Mezzanine A (48.65%) and Mezzanine B (51.35%). From Mezzanine A, 54.60% proceeded to the northbound platform and 45.40% proceeded to the southbound platform; from Mezzanine B, 90.35% proceeded to the northbound platform, and 9.65% proceeded to the southbound platform.

4.4 Service Time

The passenger service time survey results showed that the average service times at ticket counters, TVMs, and fare gates were 14.77 s (SD = 7.68), 34.00 s (SD = 17.94), and 3.56 s (SD = 1.01), respectively. Queue observation confirmed the formation of queues at TVMs, ticket counters, security x-ray gates, and fare collection gates at the concourse level, and at stairways on the platform level during train arrivals.

5. DISCUSSION

5.1 Parameter Calibration

5.1.1 Tau and Lambda

The ANOVA results for calibration of Tau (τ) and Lambda (λ) are presented in Table 6. Both the 2-Factor Interaction (2FI) and CCD models were statistically significant. However, the CCD lack-of-fit test was also highly significant ($p < 0.001$), indicating that the quadratic terms did not adequately describe the data, making the simpler 2FI model the more appropriate choice. There are two parameters identified that affect the walking speed in the model — Tau and Lambda. A 2-Factor Interaction (2FI) model with center points was used initially to test for curvature in the response. The ANOVA results indicate that Tau and Lambda affect each other significantly ($p = 0.001$) and that the linear model adequately describes the response surface ($p = 0.079$) (Table 6). To further refine the search, axial points were added to form a Central Composite Design (CCD) that could capture whether the relationship between the parameters and the response shows curvature. This model and its lack-of-fit test were both significant ($p = 0.027$, $p < 0.001$, respectively), showing that the additional quadratic terms failed to

meaningfully explain the data. Therefore, the simpler 2FI model was retained as the more appropriate model to describe the calibration surface.

Table 6. ANOVA summary: p-value comparison for Tau and Lambda

	p-value	
2-3 Source Component	2-Factor Interaction (2FI)	Central Composite Design (CCD)
Model	0.001147	0.027356
Curvature	0.078713	—
Lack of Fit	—	0.000020

The response surface plot for Tau (τ) and Lambda (λ) is shown in Figure 2. The optimal values, Tau = 0.2 and Lambda = 0.8 (SE = 0.007), were therefore adopted as the calibrated values.

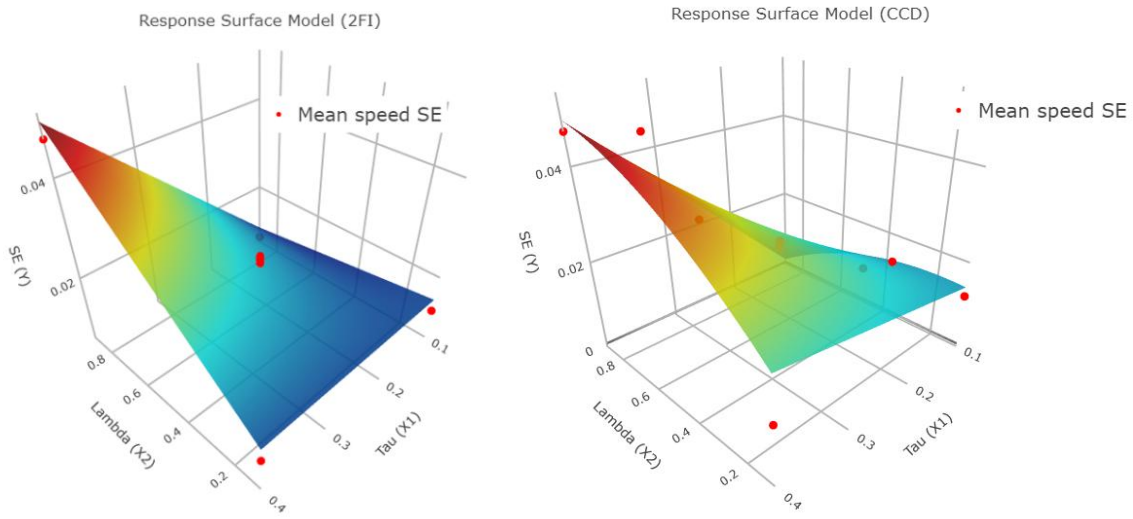


Figure 2. Response surface plots for Tau (τ) and Lambda (λ).

5.1.2 Noise/React to N and Grid Size/VD

The first-phase 2FI model was significant, while the CCD model was not statistically significant, as shown in Table 3. The optimized values were found to be Noise = 3 and React to N = 7 (SE = 0.003). As for Grid Size and VD, ANOVA results showed that both phases produced insignificant models (p = 0.996), and the response surface was flat, as shown in Figure 3. Therefore, default values were retained for this parameter set. Following the same sequential calibration approach described in 4.2.1, the Noise and React to N were the parameters affecting the time spent by pedestrians in bottlenecks. The ANOVA results, shown in Table 7, indicate that both parameters and their combined effect were significant ($p < 0.05$). Moreover, the subsequent CCD model was not statistically significant ($p > 0.05$), indicating that the added quadratic terms offered no meaningful improvement over the 2FI model and were therefore unnecessary. The optimal values, Noise = 3 and React to N = 7 (SE = 0.003), were accordingly adopted.

As for Grid Size and VD, this pair describes the flow of pedestrians in the model. The ANOVA results, shown also in Table 7, produced a different outcome since both the 2FI and CCD models were insignificant (p = 0.996), indicating that neither Grid Size nor VD produced

a meaningful effect on mean speed SE within the tested range (Fig. 3). Since neither model produced a defensible calibration point, the default Viswalk values for Grid Size and VD were retained.

Table 7. ANOVA summary: p-value comparison for Noise/React to N, and Grid Size/VD

3-4 Parameter Pair	Source Component	p-value	
		2-Factor Interaction (2FI)	Central Composite Design (CCD)
Noise and React to N	Model	0.013679	0.9960357
	Curvature	0.347239	—
	Lack of Fit	0.655394	0.9980019
Grid Size and VD	Model	0.996036	0.9960357
	Lack of Fit	0.998002	0.9980019

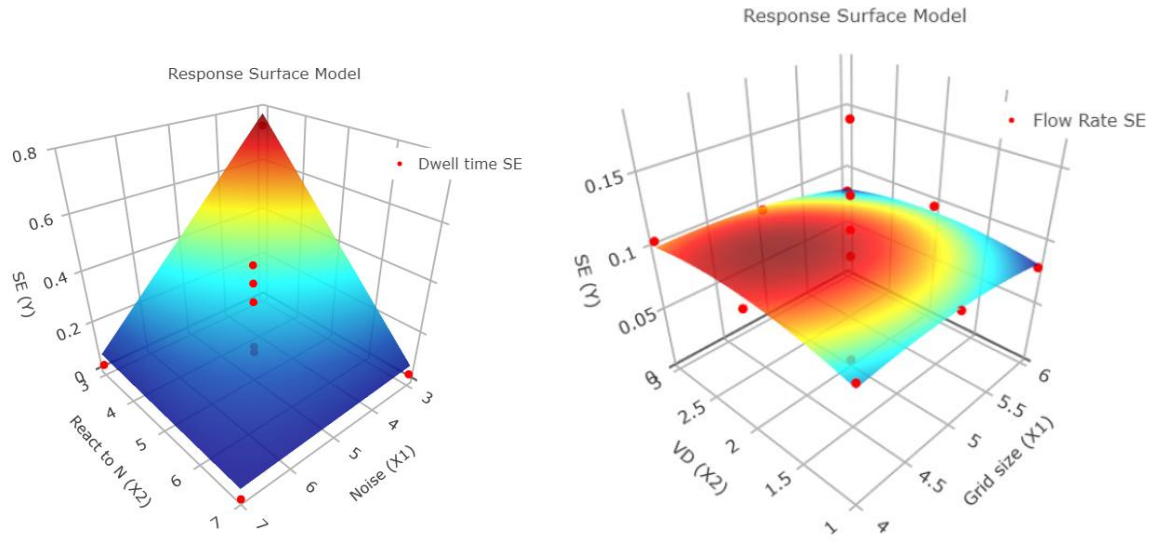


Figure 3. Response surface plot for Noise/React to N and Grid Size/VD

5.2 Validation of Parameters

Temporal validation was performed using Day 3 field data withheld from the calibration process, with RPE and an acceptance threshold of ±10% as the accuracy metric. Four parameter sets were compared: the PTV Viswalk default values, representing generalized pedestrian behavior not specific to any transit context; MRTA (2016) and Boonsomparn (2019), both simulation-based studies of pedestrian-focused behavior calibrated for Bangkok transit stations; and the calibrated values of this study. Results are presented in Table 8.

Table 8. Comparison of RPE across parameter sets and validation criteria

Validation Criteria	Default Values	MRTA (2016)	Boonsomparn (2019)	Calibrated Parameters (This Study)
Speed (m/s)	-20.041%	-17.015%	-17.015%	-6.977%
Max Dwell Time (s)	34.803%	16.027%	19.988%	3.043%
Flow (ped/min/m)	7.718%	13.094%	9.590%	7.718%*

*Flow rate RPE for calibrated parameters reflects retained default values.

This comparison highlights the importance of localized parameters given that each set was developed under differing contexts, methodologies, and pedestrian populations. The calibrated parameters presented in Table 8 consistently achieved the lowest RPE across all three validation criteria. For walking speed, the calibrated parameters achieved the lowest average RPE at -6.977%, outperforming the default values (-20.041%), MRTA (2016) (-17.015%), and Boonsomparn (2019) (-17.015%). Similarly, for bottleneck dwell time, the calibrated parameters achieved an average RPE of 3.043%, the lowest among all compared sets. For pedestrian flow rate, however, default values were retained in this study, yielding the lowest RPE (7.718%), followed by Boonsomparn (2019) at 9.590% and MRTA (2016) at 13.094%. Overall, the average RPE across all three criteria for the calibrated parameters was 3.04%, confirming the reliability of the localized parameter set for Filipino pedestrian behavior in a transit station context.

5.3 Application

Table 9 presents the maximum evacuation times for each criterion (t_1, t_2, and t_3) across nine simulation runs, evaluated against NFPA 130 thresholds of 4 minutes for t_1 and 6 minutes for t_2 and t_3.

Table 9. Maximum leave time of all cases

No.	Scenarios	15-min peak occupant load	Route split (fam./emerg.)	Desired speed (m/s)	Platform leave time (t_1)	Fare gate leave time (t_2)	Station leave time (t_3)
1	Base case	1074	100/0	1.231	**2:28**	**5:47**	6:57
2	Worst case	3997	100/0	1.231	6:17	10:31	11:53
3				0.628	12:05	18:53	19:50
4*				0.628	14:45	21:20	22:20
5				0.981	7:38	13:22	14:23
6				1.481	6:08	10:39	11:40
7			80/20	1.231	4:44	9:19	10:32
8			50/50	1.231	**3:41**	7:45	8:43
9	Future worst case	4976	100/0	1.231	6:46	11:06	12:25

Thresholds: t1 ≤ 4:00 (platform clearance), t2 and t3 ≤ 6:00 (point of safety)
*NFPA compliance—two opposing escalators per level were not traversable during simulation

Among nine simulation runs, only the Base Case (Run 1) and the Worst Case scenario, which has a 50/50 route split (Run 8), satisfied the NFPA 130 platform clearance requirement (4 minutes). More significantly, none of the simulations or scenarios met the 6-minute point-of-safety threshold for t_2 or t_3. Evacuation times varied widely across runs, from 57 s over the threshold in the Base Case (6:57 vs. 6:00) to over 16 minutes in the NFPA-speed worst case with escalator restrictions (Run 4, 22:20 vs. 6:00).

5.4 Discussion

5.4.1 RSET-ASET comparison

The most significant finding of this study is that the MRT-3 Ayala Station does not provide evacuees with sufficient time to complete a full station evacuation before hazardous conditions are expected to develop, even under current, non-emergency peak-hour conditions. The Base Case (Run 1) recorded a Required Safe Egress Time (RSET) of 6 minutes and 57 seconds for full station evacuation (t_3). This exceeds the 5-minute Available Safe Egress Time (ASET) established for underground railway stations (Könnecke and Schneider, 2007), which applies to the below-street-level platform configuration of the Ayala Station. This implies that even under the current peak ridership and station layout, passengers may not be able to complete a full station evacuation before life-threatening emergencies occur. This condition is not limited to emergency or unusual scenarios, since it was tested with the current operating state.

Across all nine simulation runs, RSET exceeded ASET without exception. The gap widened progressively with increasing occupant load and decreasing pedestrian speed, reaching a maximum RSET of 22 minutes and 20 seconds under NFPA-speed worst case with escalator restrictions (Run 4). The RSET-ASET deficit, therefore, represents a structural deficiency of the station's egress configuration, not an artifact of extreme or unlikely conditions.

5.4.2 Bottleneck behavior and congestion dynamics

The field survey results confirmed that the concourse corridor operated at LOS A during peak hours, with free-flow walking speed and flow conditions at that measurement point. This finding, however, does not reflect the station's overall egress performance. Queue formation observed at stairways, fare gates, x-ray security gates, and TVMs during train arrivals indicates that the station's overall performance is governed by localized bottleneck behavior rather than corridor-level density. This pattern is consistent with observations from Boonsomparn (2019) and Samson *et al.* (2017). In the simulation results, congestion at the stairway access point was identified as the primary structural constraint on evacuation time across all scenarios.

5.4.3 Simulation results and sensitivity analysis

The evacuation simulation results revealed a consistent pattern of non-compliance with NFPA 130 standards across all but two runs (Run 1 and 8). The primary drivers of extended evacuation times, ranked by their observed effect on t_3, were pedestrian walking speed, occupant load, and route familiarity.

Walking speed exerted the largest influence. The NFPA-standardized speed scenarios (Runs 3 and 4, at 0.628 m/s) produced the longest evacuation times of all runs, with t_3 values of 19:50 and 22:20—exceeding the 6-minute threshold by more than 13 and 16 minutes, respectively. The faster-speed sensitivity run (Run 6, at 1.481 m/s) reduced t_3 by only 13 seconds relative to the standard worst case (Run 2, 11:40 vs 11:53), showing that increased walking speed alone does not significantly shorten evacuation time, especially when the occupant loads were high. Non-compliance persisted across all three speed variants in the sensitivity analysis (Runs 2, 5, and 6), indicating that the finding holds regardless of the assumed walking speed. The Thai-derived scaling factor used to estimate Filipino emergency walking speed can therefore be considered a defensible approximation for this study, as the non-compliance outcome remained consistent across the full range of speeds tested.

The most effective mitigation identified in the simulation was the redistribution of evacuating passengers to emergency egress exits. The 50/50 route split scenario (Run 8) was

the only worst-case scenario that satisfied the 4-minute platform clearance threshold (t_1 = 3:41). This finding indicates that the current physical infrastructure of MRT-3 Ayala Station cannot accommodate peak occupant loads within the prescribed evacuation time when passengers are concentrated on familiar egress routes alone. This necessitates direct intervention of staff-directed evacuation to improve egress performance.

The future worst-case scenario (Run 9), projecting a 10-year ridership growth of 8% per year, recorded t_1 = 6:46, t_2 = 11:06, and t_3 = 12:25—the worst platform clearance time among the non-speed-restricted runs. As the station's ridership continues to grow without corresponding improvements in the infrastructure elements, evacuation times are expected to worsen further. These results have direct implications for station operations, emergency planning, and Philippine mass transit safety standards.

6. CONCLUSION

This study aimed to evaluate pedestrian flow dynamics and emergency egress performance in the MRT-3 Ayala Station with emphasis on compliance with established standards that define safety and efficiency. Through simulation-based analysis, key findings highlight the limitations of the current infrastructure, particularly under high-density and emergency conditions. The following conclusions summarize the critical insights derived from the study:

1) Transit design must prioritize life safety; therefore, egress capacity must be evaluated as congestion renders the current infrastructure unsustainable, given its annual growth rate.
2) The application of PTV Viswalk, utilizing a Social Force Model (SFM) calibrated through RSM and SE calculations, effectively reflects real-life evacuation dynamics within the MRT-3 Ayala Station. By establishing a behavioral baseline from localized field data, this study provides a defensible framework for evaluating pedestrian flow and estimating evacuation performance in high-density, multi-story transit facilities.
3) The total evacuation times recorded across the worst case and future worst case scenarios fail to meet the NFPA 130 platform evacuation threshold of 4 minutes, with only the base case scenario and the worst case scenario under a 50/50 familiarity route split complying with the standard.
4) The RSET of 6 minutes and 57 seconds exceeded the ASET of 5 minutes, indicating that the existing station configuration presents a safety compromise even under current, non-emergency peak-hour conditions. Bottlenecks identified at the staircase areas suggest that the current egress infrastructure may be insufficient to support timely evacuation during peak demand or emergency events.

7. RECOMMENDATION

Before beginning with recommendations, it must be said that modeling does not replace judgment. Pedestrian evacuation simulation can prevent high-stakes decisions based on a single drill or an assumed pedestrian behavior profile. Modeling also provides a structured way to test improvements before investments or policy changes are enacted.

7.1 Recommended Actions of Key Stakeholders

To address the identified gaps in evacuation performance and ensure compliance with safety

standards, it is essential to outline targeted actions for key stakeholders. These recommendations focus on improving egress efficiency, strengthening operational strategies, and aligning institutional policies with established safety benchmarks. Thus, the following recommendations are given:

1) Institutionalize the alignment of the Revised IRR (R.A. 9514) with internationally recognized standards, such as the NFPA 130, to provide better frameworks for the verification of fire safety in transit systems.
2) Adopt performance-based criteria for all evaluations of platform and point-of-safety egress, prioritizing metrics like ASET, total evacuation time (TET), occupant flow rates, and stairway and corridor exit capacity during peak-hour conditions.
3) Integrate ten-year ridership growth projections into fire safety planning, ensuring egress capacity and safety interventions remain effective along future peak-hour demand.
4) Reconfigure existing egress routes along areas where egress modeling indicates that ASET exceeds RSET.
5) Operationalize station-specific crowd management protocols that train staff and personnel to aggressively redirect more than 50% of evacuating passengers in the platform toward emergency exits to optimize station clearance times (t_3).
6) Assess the technical and structural feasibility of installing additional vertical egress components, like stairs or escalators, to account for increasing ridership and its impact on life safety.

7.2 Improvement Areas of the Study

While the study provides valuable insights into pedestrian dynamics and evacuation performance, certain methodological and scope-related limitations present opportunities for further refinement. These areas highlight potential enhancements in data collection, model calibration, and future research directions to strengthen the overall reliability and applicability of the findings. The following are recommendations for future researchers:

1) The duration of the survey should be lengthened to increase the reliability of the data. Although the calibrated parameters are suitable and replicable in train stations in the Philippines, further studies should validate various pedestrian behavior parameters on their own accord. Furthermore, the calibrated parameters should be included in three or more levels, and queue lines at the platform level.
2) It may also be considered to include the area outside the paid concourse, such as, but not limited to, both mezzanine levels, the areas near shops, and the areas near station street-level exits. The software version of PTV Viswalk may also be considered; the version used for this study was PTV Vissim 2026 (SP 06).
3) For future studies, the unique characteristics of the pedestrians, if resources permit, could consider the variations of age, pedestrian carrying capacity, and persons with disabilities (PWDs).
4) Also, the recalibration of parameters for evacuating pedestrians can be considered. As one could argue that the pedestrian behavior on normal operations might be different in evacuation situations. Between the two scenarios, the study only differentiated between desired mean speed, pedestrian volumes, and route choice.
5) It may also prove useful for researchers to pursue local emergency evacuation studies to eliminate dependence on foreign factors, and to extend this given framework and methodology to other high-volume MRT-3 stations, particularly Cubao, Taft, and North Avenue.

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APPENDICES

APPENDIX A: Design Load Calculations

This section details the calculation of the 10-year projected occupant load. The methodology assumes that growth applies only to the entraining load, while the maximum train occupancy remains a static physical constraint of the rolling stock. The following values were derived from the field surveys conducted during the peak 15-minute flow period ($PHF = 0.93$), and a compound growth rate is applied to the entraining load to account for urban development over a ten-year horizon:

Table 11. Train Passenger Metrics and Analysis Parameters

Parameter	Value
Peak 15-minute Flow Rate	1,395 passengers
Maximum Train Occupancy (O_{max})	3,152 passengers (two 4-car trains)
Base Entraining Load (E_{base})	845 passengers
Base Train Occupancy	229 passengers
Annual Growth Rate (x)	0.08 (8%)
Analysis Period (t)	10 years

The projected occupant load (L_{proj}) is calculated using the following formula:

$$L_{proj} = E_{base} \times (1 + x)^t$$

The following table summarizes the scenarios based on the entraining and occupancy parameters.

Table 12. Summary of calculated occupant load scenarios

Scenario Description	Value (passengers)
Base Case (Existing conditions)	1,074
Worst Case (Existing Entraining + Max Occupancy (O_{max}))	3,997
Projected 10-Year Design Load (Max Occupancy + Growth)	**4,976**

APPENDIX B

Table 12. Validation of speed parameters across studies

	Field survey	Default values	MRTA (2016)	Boonsomparn (2019)	Calibrated parameters (this study)
Times	Speed (m/s)	Error %			
5:00 - 5:15	1.012	-19.436	-15.774	-15.774	-3.567
5:15 - 5:30	1.084	-21.981	-18.969	-18.969	-9.277
5:30 - 5:45	1.084	-22.028	-19.416	-19.416	-10.308
5:45 - 6:00	1.037	-16.719	-13.902	-13.902	-4.754

Table 13. Validation of dwell time parameters across studies

	Field survey	Default values	MRTA (2016)	Boonsomparn (2019)	Calibrated parameters (this study)
Times	Max dwell time (s)	Error %			
5:00 - 5:15	22.910	16.630	-8.424	27.368	7.551
5:15 - 5:30	19.410	29.830	38.073	21.896	9.531
5:30 - 5:45	23.170	61.502	36.815	30.686	-2.374
5:45 - 6:00	22.080	31.250	-2.355	0.000	-2.536

Table 14. Validation of flow parameters across studies

	Field survey	Default values (this study)	MRTA (2016)	Boonsomparn (2019)
Times	Flow (ped/min/m)	Error %		
5:00 - 5:15	22.910	16.630	-8.424	27.368
5:15 - 5:30	19.410	29.830	38.073	21.896
5:30 - 5:45	23.170	61.502	36.815	30.686
5:45 - 6:00	22.080	31.250	-2.355	0.000

APPENDIX C

Table 15. Calibration results for walking speed

Run	Code	Seed	X1	X2	Simulation Number					Walking speed, m/s		Error	Error Squared
					1	2	3	4	5	Sim. Mean	Field Mean		
1	(-1, -1)	42	0.1	0.1	0.984	1.002	0.995	0.999	0.994	0.995	1.105	-0.11	0.012
2	(1, -1)	42	0.4	0.1	0.864	1.021	1.027	1.025	1.025	0.992		-0.112	0.013
3	(-1, 1)	42	0.1	0.9	1.023	1.028	1.019	1.028	1.021	1.024		-0.081	0.007
4	(1, 1)	42	0.4	0.9	0.887	0.892	0.887	0.89	0.887	0.889		-0.216	0.047
5	(0, 0)	42	0.25	0.5	0.944	0.948	0.946	0.951	0.948	0.947		-0.157	0.025
6	(0, 0)	2	0.25	0.5	0.949	0.953	0.946	0.949	0.951	0.95		-0.155	0.024
7	(0, 0)	12	0.25	0.5	0.951	0.953	0.945	0.951	0.959	0.952		-0.153	0.023
8	(0, 0)	22	0.25	0.5	0.946	0.94	0.947	0.961	0.94	0.947		-0.158	0.025
9	(0, 0)	32	0.25	0.5	0.948	0.935	0.952	0.946	0.964	0.949		-0.156	0.024
10	(+α, 0)	42	0.4	0.5	0.875	0.881	0.876	0.877	0.877	0.877		-0.227	0.052
11	(-α, 0)	42	0.1	0.5	1.009	1.018	1.012	1.015	1.01	1.013		-0.092	0.008
12	(0, + α)	42	0.25	0.9	0.955	0.962	0.958	0.964	0.958	0.959		-0.145	0.021
13	(0, - α)	42	0.25	0.1	0.928	0.935	0.934	0.93	0.926	0.93		-0.174	0.03

Table 16. Calibration results for dwell time

Run	Code	Seed	X1	X2	Simulation Number					Max. dwell time, *s*		Error	Error Squared
					1	2	3	4	5	Sim. Mean	Field Mean		
1	(0, 0)	42	5	5	22.675	22.000	24.200	21.675	22.000	22.510	21.893	0.618	0.381
2	(-1, -1)	42	3	3	20.850	20.900	22.225	19.950	21.250	21.035		-0.857	0.735
3	(1, -1)	42	7	3	20.350	24.575	23.375	20.575	21.350	22.045		0.153	0.023
4	(-1, 1)	42	3	7	21.600	22.000	22.950	20.775	21.300	21.725		-0.168	0.028
5	(1, 1)	42	7	7	20.875	23.825	22.975	20.475	21.175	21.865		-0.027	0.001
6	(+α, 0)	42	7	5	20.125	22.525	23.075	20.450	20.825	21.400		-0.493	0.243
7	(-α, 0)	42	3	5	20.725	22.825	21.650	20.525	21.500	21.445		-0.447	0.200
8	(0, + α)	42	5	7	20.500	20.200	22.425	24.000	21.475	21.720		-0.172	0.030
9	(0, - α)	42	5	3	20.350	21.250	23.875	20.075	21.150	21.340		-0.553	0.305
10	(0, 0)	2	5	5	22.425	21.700	23.925	21.400	21.625	22.215		0.322	0.104

11	(0, 0)	12	5	5	22.560	22.100	24.325	21.775	22.050	22.562		0.670	0.448
12	(0, 0)	22	5	5	21.500	21.375	23.350	20.800	20.650	21.535		-0.358	0.128
13	(0, 0)	32	5	5	21.275	20.275	21.250	21.075	22.800	21.335		-0.557	0.311

Table 17. Calibration results for flow rate

Run	Code	Seed	X1	X2	Simulation Number					Flow rate, ped/m/min		Error	Error Squared
					1	2	3	4	5	Sim. Mean	Field Mean		
1	(-1, -1)	42	4	1	7.880	7.886	7.759	7.859	8.048	7.886	7.583	0.303	0.092
2	(1, -1)	42	6	1	7.857	7.900	7.731	7.848	8.003	7.868		0.285	0.081
3	(-1, 1)	42	4	3	7.902	7.925	7.770	7.900	8.035	7.907		0.323	0.105
4	(1, 1)	42	6	3	7.870	7.912	7.777	7.750	8.032	7.868		0.285	0.081
5	(+α, 0)	42	6	2	7.898	7.912	7.747	7.868	8.046	7.894		0.311	0.097
6	(-α, 0)	42	4	2	7.896	7.912	7.759	7.857	8.030	7.891		0.307	0.094
7	(0, + α)	42	5	3	7.886	7.912	7.761	7.868	8.032	7.892		0.309	0.095
8	(0, - α)	42	5	1	7.864	7.916	7.722	7.848	8.073	7.885		0.301	0.091
9	(0, 0)	42	5	2	7.896	7.912	7.738	7.866	8.019	7.886		0.303	0.092
10	(0, 0)	2	5	2	7.889	7.991	8.014	7.779	7.907	7.916		0.333	0.111
11	(0, 0)	12	5	2	8.126	8.012	7.912	7.873	8.128	8.010		0.427	0.182
12	(0, 0)	22	5	2	7.823	8.096	8.005	7.829	7.998	7.950		0.367	0.135
13	(0, 0)	32	5	2	7.588	7.403	7.451	7.684	7.458	7.517		-0.067	0.004

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