Analyzing Passenger Waiting Times of MRT-3 via Discrete Event Simulation

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Abstract— **The Philippine Metro Railway Transit-3 (MRT-3 is one of the most heavily used forms of public transportation yet is currently known to be ineffective in getting passengers quickly to their destination due to long passenger waiting times; especially during the morning and evening rush hours. In this study, we explore the operations of the MRT-3 during the morning rush hour by creating a model and simulating the passenger waiting times during this time frame as well as seeing the effect of certain actions on the system to the passenger waiting time. The study reveals two major factors that when improved, can decrease the passenger waiting time; increasing the number of trains, and increasing the speed at which the train travels.**

Keywords—discrete-event simulation; lightrail transit; simulation analysis

I. Introduction

The Institute for Transportation and Development Policy (ITDP) defines rapid transit systems as a form of public transportation with a fixed route having additional features that improve speed, capacity, reliability, and quality of the service [1].

One type of rapid transit system is the bus rapid system (BRT) having the characteristics of a rapid system. The bus rapid system is identified to have five general elements:

- physically separated lanes to avoid congestion
- stations and lanes at the center of the street to avoid being delayed by other vehicles
- Fares are collected off the bus
- Boarding is done at a platform level with the bus floor
- Bus priority is present at intersections to avoid delays

Another type of rapid transit transportation that is similar to the bus rapid transit is the light-rail transit (LRT). It is similar to BRT systems in that it has the similar elements in place that allow for efficient operations such as:

- exclusive line with right-of-way
- fares are also collected prior to boarding
- boarding is also done at a platform level with the floor of the train.

The Metro Railway Transit – 3 (MRT-3) line is one of the most commonly used public transportation infrastructure in Metro Manila. With its route which traverses EDSA, one Metro Manila's most traversed roads, it has a daily ridership count of around 300,000 people (based on 2019 Ridership data) [2]. While the MRT-3 contains the same elements listed in rapid transit systems, it is known that the train consistently has operational issues with ridership capacity, and service frequencies; with specific stations known for having very low service frequency due to the train being full upon arrival.

With this, the study will focus on creating a model to represent the MRT-3 that follows the same assumptions as rapid transit systems in general (either from BRT or LRT type transportation).

The objectives are:

- to be able to create a base model of the MRT Line 3, being able to track the waiting time of passengers at the different stations.
- To assess the impact of changes in the model to the different metrics measured, allowing for the formulation of actionable recommendations for improving the operations of the line.

By tracking the passenger waiting time throughout the trains operations, we are able to get a better understanding of which parts of the current MRT-3 system are mostly experiencing issues in the process that leads to the long wait-time of passengers in the system and by studying the impact of changing certain parameters in the model of the MRT-3 system, we are able to understand what actions can be taken to improve the passenger waiting time and how effective they are in doing so.

II. Review of Related Literature

A. *TRANSPORTATION MODELS AND SYSTEM PERFORMANCE*

Various studies have been published with the goal of being to simulate public transportation systems such as train stations, and bus rapid transit with the different models aimed at simulating different aspects of the operations of these systems from ticketing queue, passenger arrivals, train travel time, or even end-to-end model of the entire commuter journey within the different stations.

Acierno and Botte highlighted that there are multiple approaches to modelling transportation systems: two of which are (1) Analytical Approach, and (2) Simulation Approach [4].

i. Analytical Approaches

Analytical approaches focus on representing models through assuming different behaviors of the system follow certain equations while using approximations of equations to solve for a solution to the equations representing the behavior.

Rice proposed a queueing theory approach to modelling railway capacity through the use of stochastic and mathematical approximations to describe length of queue, delay, and relaxation time within the operations of the train station [3].

A study by Acierno and Botte proposed modelling a railway transportation system as a schedule-based system using the Merry-Go-Round (MGR) paradigm [4]. They proposed that certain transportation systems will have similar layouts and characteristics of a merry-go-round such has (1) having a closed-loop route where a train will traverse an inbound trip and a corresponding outbound trip after reaching the terminal station, (2) the seats (or horses) of a Merry-Go-Round represent the corresponding stations, and (3) the external spectators of a merry-go-round represent passengers who are queueing, and (4) the cycle time of a seat in the merry-go-round represents the time needed for a train to complete one trip across all stations . This approach also makes assumptions about operations of the railway system similar to a merry-go-round and uses a set of equations focusing on angular velocity to come up with figures regarding the train performance.

ii. Simulation Approaches

Simulation approach occurs when the model is measured by running the process which describes the model, also based on a set of equations, multiple times and recording the figures.

One study by Gunawan, modelled a bus rapid transit (BRT) system using discrete event simulation. The model was simplified while still featuring all the important subsystems present in a BRT system namely the (1) departure of buses from the starting station; where all buses originate, (2) arrival and departure events of buses at each of the succeeding stations, (3) the travel time of the bus from one station to another; with the estimation of headway for passenger who will board the arriving buses [5]. The simulation assumes the following flow for the rapid transit system: (1) First, the bus departs from its origin, (2) the bus arrives at the first station, (3) the bus stays at the station for a certain amount of time to pick up passengers, and then proceeds to the next station, (4) the bus drops off passengers who will alight the station and pick up another set of passengers within a certain amount of time. This process is repeated (e.g., the bus makes a trip to all stations (which are all visited in a continuous flow) until the operating hours of the bus ends. These flows of events have corresponding parameters assigned to them which have their own corresponding distributions to allow for the generation of the time taken for each of the processes as well as the flow of passengers.

Another study by Dantas et al. modelled a Bus Rapid Transit system using a Stochastic Petri Net, as a way to model and evaluate the performance of the BRT system by monitoring different metrics namely, Mean System Size, Mean Queue Size, Mean Queue Time and Utilization [6]. The study also allowed for sensitivity analysis, by identifying the effect of various factors on the different metrics of the system; allowing for an evaluation of the effect on performance of the rapid transit system.

Another study by Chua modelled the Light Railway Transit Line 1 (LRT-1) in the Philippines through the use of both a standard queue model, and a swarm intelligence model with the assumption that on-boarding activities will not always happen at all station [7]. The study showed that improvements were made to the waiting time on average in the swarm intelligence model when loading of passengers did not occur at all of the stations.

Another study by Poomrittigul et al., focuses on modelling only the queue of the train ticket system of the Bangkok Rapid Transit train [8]. The researchers mainly used models derived from queueing theory with assumptions on parameters like the average waiting time, service rate, and customer arrival time. The model was run using Python with different simulations being conducted based on different scenarios, namely single queue and multiple queue assumptions. Then, the metrics of arrival rate and queue length were measured.

Author	Study	Transporation System	Model Approach	Specific Method
Pecundo	**(Current Study) Analyzing Passenger Waiting Times of MRT-3 via Discrete Event Simulation**	**Metro Railway Transit - 3 (MRT 3)**	**Simulation**	**Discrete-Event Simulation**
Rice	A Queueing Theory Approach to Railway Capacity in Urban Commuter Railways	London Transport Type Railway	Analytical	Queueing Theory with Mathematical Approximations
Acierno and Botte	Railway System Design by Adopting the Merry-Go-Round (MGR) Paradigm	Unnamed Metro Line	Analytical	Merry-Go-Round paradigm representation
Gunawan	Design and Implementation of Discrete-event Simulation Framework for Modeling Bus Rapid Transit System	TransJakarta BRT	Simulation	Discrete-Event Simulation
Dantas	Sensitivity Analysis in a BRT System	Brazil BRT System	Simulation	Stochastic Petri-Net
Chua	Feasibility improvement of transportation for light rail train system	Light Railway Transit - 1 (LRT - 1)	Simulation	Discrete-Event Simulation with Swarm Intelligence Model
Poomrittigul et al.	The Simulation of Queuing Model for Bangkok Rapid Transit Train Ticket System Using Python	Bangkok Rapid Transit - Ticket Queue only	Simulation	Discrete-Event Simulation

Table 1. Summary of Related Literature

III. METHODOLOGY

A. ASSUMPTIONS OF THE MODEL

The model of the train station operations will be based on a similar flow used by Gunawan [5] in representing the TransJakarta BRT, given that the BRT system and LRT or Train System have multiple similarities in operations; with some modifications in the form of removal of certain aspects of Gunawan's model that are not necessarily applicable to a model representing the MRT such as presence of intersections, or stoplights.

Aside from that, the model will be further simplified by having the following assumptions:

- The MRT-3 will be represented by a total of 14 trains and 26 stations; in reality this is represented by 13 stations having a separate Northbound and Southbound side. The 2019 article [9] mentions that there are around 15 trains operating but for this study it will be brought down to 14 to allow to allow for an equal split across 2 station routes.

- Since there are two directions in which the trains go, the 14 trains will be split into 2 sets of 7 trains with each set originating from different terminal stations, namely North Edsa – Southbound, and Taft – Northbound.

- The simulation will represent the passenger arrivals during the morning rush hour (6am to 9pm) for one day; meaning passengers arriving within 3 hours at the morning rush hour rate.

- Passengers arriving at the station are ready for boarding; meaning they have already passed the stage of queueing for a ticket or already have stored-value cards. The model will only measure the queueing for onboarding the train.

- All trains will start at either one of the two terminal stations; North Edsa – Southbound or Taft - Northbound.

- Trains will depart in a certain order; for the first trip, the trains will depart from the initial station only after the train before it leaves.

The train will follow 2 possible routes, depending on their origin station.

Station Name	Station Order (North Edsa - Southbound Origin)	Station Order (Taft - Northbound Origin)
North Edsa - Southbound	1	14
Quezon Ave - Southbound	2	15
GMA Kamuning - Southbound	3	16
Cubao - Southbound	4	17
Santolan - Southbound	5	18
Ortigas - Southbound	6	19
Shaw Blvd - Southbound	7	20
Boni - Southbound	8	21
Guadalupe - Southbound	9	22
Buendia - Southbound	10	23
Ayala - Southbound	11	24
Magallanes - Southbound	12	25
Taft - Southbound	13	26
Taft - Northbound	14	1
Magallanes - Northbound	15	2
Ayala - Northbound	16	3
Buendia - Northbound	17	4
Guadalupe - Northbound	18	5
Boni - Northbound	19	6
Shaw Blvd - Northbound	20	7
Ortigas - Northbound	21	8
Santolan - Northbound	22	9
Cubao - Northbound	23	10
GMA Kamuning - Northbound	24	11
Quezon Ave - Northbound	25	12
North Edsa - Northbound	26	13

Table 2. Station Route of Trains in MRT-3

B. MODELLING THE FLOW OF THE STATION

For modelling the flow of the station operations, the following actions will occur at a station:

- Passengers will arrive at the station ready to board the train; if they train is present and has capacity, then the passenger will board the train.

- Once the operating hours of the station within the simulation is over, it will not accept any more passengers arriving. However, the train operations will still continue until all passengers reach their destination (e.g., all trains are empty)

The following diagram will be used to show the events occurring at the train station.

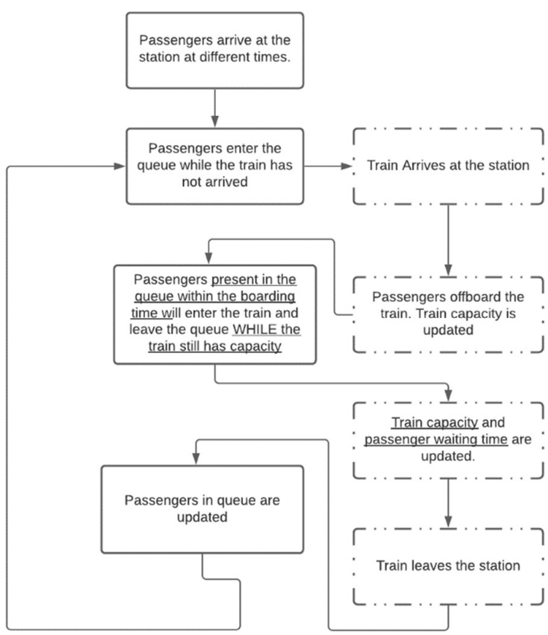

Figure 1: Flow diagram of station activity

C. MODELLING THE FLOW OF THE TRAIN

For modelling the train, the following actions will be taken by the train:

- Every time the train arrives at a station, a percentage of passengers will be offboarded.

- After passengers are offboarded, passengers planning to board the train can board, assuming there is still capacity.

- For the certain stations, it will be assumed that no passengers will be boarding the train given how close they are to the final station. This will be elaborated later on.

- After the time allotted for boarding, the train will leave the station. Travel from one station to another will assume a duration of 9 minutes, within the average headway of MRT published in a 2019 article [9].

- Trains will continue to run until there are no more passengers onboard any of the trains. Even if the time in system goes beyond the 3 hours of the rush hour, the trains will continue to operate and pick up and take passengers from station to station. Only passenger arrivals will strictly stop within the 3 hours allotted in the simulation.

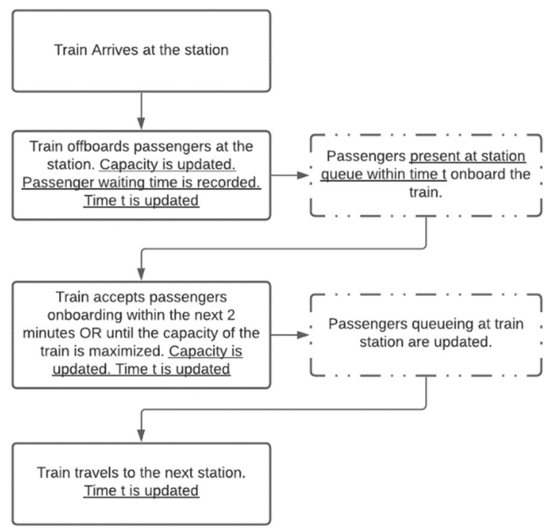

Figure 2: Flow diagram of train activity

D. SIMULATION SET UP

The simulation will follow the process flow presented and will be run using a discrete-event simulation coded entirely on Python. To be able to set up the simulation, the code will feature the creation of 2 classes to describe and measure the behavior of the 2 main aspects of the train model, namely the Train, and the Station; both of which will be represented by classes each with its own functions that will execute the various activities happening within the station and within the train.

i. The Train Class

The train class will mainly be used to track the entire journey of the passengers from the different stations that will be traversed as well as (1) provide information on the passengers onboard at a given time, and (2) the time of the day.

The train class will have the following operations to simulate the different activities described within the flow diagram of the train station activity.

- **Onboarding –** the onboarding function will allow the train to look at the queue of passengers present during a given time when it reaches a station and allow all possible passengers onboard provided that the train has capacity. This operation also updates the number of passengers the train is carrying, which will be represented by an array of the arrival times at the station of each passenger.

  If the train is full by the time it reaches the station, it will still wait for a certain amount before departing. The assumption here is that the onboarding process will take 2 minutes; calling this function will also add 2 minutes to the current time elapsed.

  The average train capacity is assumed to be 1240 passengers. This is derived from an article [10] claiming that the train operating at 30% capacity will be able to carry around 372 passengers. Hence, the train carrying at 100% of its capacity will have 1240 passengers.

- **Offboarding** – the offboarding function will allow the train to randomly select a certain number of passengers to depart from the train; based on the designated percentage rate of offboarding determined by the station the train is at. This operation also updated the number of passengers the train is carrying, which will then affect the remaining capacity determining how many passengers can still onboard.

  Offboarding assumes that the process will take 1 minute; calling this function will also add 1 minute to the current time elapsed. There are certain stations with assumed 0% rate of offboarding given how close they are to the initial station. For these stations, the offboarding function will not be called and no time will be used up for offboarding.

- **Travel –** the travel function will signify the train leaving the current station and moving to the next one. The travel process assumes that it will take the train 9 minutes to reach the next station (based on the headway from the article [9]); calling this function will also add 9 minutes to the current time elapsed.

The entire process flow of the train will continue until there are no more passengers left on any of the trains.

ii. Station Class

The station class will be created to track the events occurring at the train station, described earlier in the methodology section. The events will mostly be used for tracking the (1) number of passengers arriving at the station to board the train, (2) the time they arrive at the station, and (3) the number of passengers that will board the train (and leave the station queue) when a train arrives.

The station class will have the following operations which will simulate the different activities occurring at the train station.

- **Passenger Arrival** – the station class will have a function generate a random number of passengers, based on a Poisson process with a pre-defined average rate, that will arrive for the whole allotted time of the simulation. The passengers will be represented by their arrival time, and the queue will represent a list of passengers (represented as arrival times).

  Since all the arriving passengers will be generated at the start of the simulation, the different functions that will determine whether they get to board the train or whether they are currently present in the queue at a given time will take into account the current time of the system; so even if the passengers are already generated, they will not be considered present for the different functions if their time of arrival is not lower or equal to the current time of the system. This is a way of representing whether the passenger has actually arrived or not.

- **Record Waiting Time** – the station class will also have a function to record the number waiting time of each passenger to determine the performance of the system in terms of minimizing waiting time before onboarding the train.

  This function will execute every time the train begins to onboard passengers at a station. Waiting time is calculated as the difference between the time of onboarding and the time of passenger's arrival at the station.

iii. Dataset and Parameter Assumptions

The dataset used was the September 2019 daily ridership data of the MRT-3 found on their website [2]. Since the objective of the model was to understand the average waiting time experienced by passengers during the morning commute, the boarding rates used the average of the boarding rate (expressed in number of people per minute) from 6am to 9am on weekdays. This average was taken from the monthly figures of weekday ridership rates and expressed as daily passenger rate per minute.

For passenger onboarding rates, the following assumptions were made due to lack of certain details in the ridership data:

- Passengers would have 0 onboarding rate at the last 2 stations; given how close they are to the final destination.
- For stations in between the first 2 and last 2 stations, the onboarding rate of the northbound and southbound side of the stations were assumed to be 50% each of the stated boarding rate of the station.

For passenger offboarding rates, the figure was expressed as a percentage (%) of the passengers present in the train given that using the exit rates, as its absolute number, would not be as accurate in representing the offboarding behavior due to the rate of passenger offboarding being expressed as a per minute rate and not necessarily based on per departure of the train (which is not per minute). The offboarding percentages were assumed based on the rate of exit in comparison to the other stations, with stations that have larger exit rates having larger assumed percentages of offboarding.

The following other assumptions were made regarding the passenger offboarding:

- Passengers would have 0% offboarding rate within the first 2 stations as it is assumed that passengers who board these stations are planning to depart somewhere else farther than just one station from the 1st station.

- All passengers present on the train have an equal chance of departing the station they are arriving at; there is no higher likelihood of passengers offboarding if they onboarded from an earlier station.

With all the assumptions stated, the onboarding and offboarding, the final rates used were as follows (with **stations in bold representing the first 2 and last 2 stations of either Northbound or Southbound side**):

Station Name	**Passenger Arrival Rate (per minute)**	**Percent Offboarding Rate**
North Edsa - Southbound	**88**	**0%**
Quezon Ave - Southbound	**20**	**0%**
GMA Kamuning - Southbound	5.5	5%
Cubao - Southbound	8.5	20%
Santolan - Southbound	3	10%
Ortigas - Southbound	3.5	20%
Shaw Blvd - Southbound	11	20%
Boni - Southbound	9	10%
Guadalupe - Southbound	11	10%
Buendia - Southbound	2	10%
Ayala - Southbound	5.5	15%
Magallanes - Southbound	**0**	**10%**
Taft - Southbound	**0**	**100%**
Taft - Northbound	**63**	**0%**
Magallanes - Northbound	**18**	**0%**
Ayala - Northbound	5.5	15%
Buendia - Northbound	2	10%
Guadalupe - Northbound	11	10%
Boni - Northbound	9	10%
Shaw Blvd - Northbound	11	20%
Ortigas - Northbound	3.5	20%
Santolan - Northbound	3	10%
Cubao - Northbound	8.5	20%
GMA Kamuning - Northbound	5.5	5%
Quezon Ave - Northbound	**0**	**10%**
North Edsa - Northbound	**0**	**100%**

Table 3. Passenger Onboarding and Offboarding Rate by Station

iv. Simulations Conducted

For this study, 4 simulations (1 baseline + 3 other simulations) will be conducted to highlight the standard average waiting time of passengers of the MRT-3 during the regular weekday morning schedule, and present the impact of different possible changes to the MRT-3 operation to the waiting time of the passengers (e.g., sensitivity analysis).

For the other simulations, 3 factors will be considered in isolation to see the impact on the passenger waiting time; these are (1) increasing the number of trains operating, (2) increasing the travelling speed of the train, and (3) allowing train to skip stations.

- For the 1st non-baseline simulation ("Sim 1"), the number of trains operating will be increased from 14 to 22 in total.
- For the 2nd non-baseline simulation ("Sim 2"), the travel time of the train will be decreased from 9 minutes to 5 minutes.
- For the 3rd non-baseline simulation ("Sim 3"), the trains will skip either the 1st (North Edsa – Southbound or Taft- Northbound) or 2nd (Quezon Ave – Southbound or Magallanes – Northbound) station whenever the train reaches full capacity in any of those stations. If the train reaches full capacity by the first station, it will skip the station after that. The train that succeeds the train which reached full capacity within the first station will then skip the first station and go directly to the second station to pick up passengers which the train prior to it skipped. This concept is similar to the comparison done by Chua [7] but less complex in the conditions required for skipping stations.

The baseline model will use figures taken from the dataset of MRT [2], publicly available news articles [9] [10], and some assumptions for cases where information will not be available. The parameters used for the base model are summarized in the table below.

Train Parameters	**Baseline Model**	**Sim 1**	**Sim 2**	**Sim 3**
Travel Rate (in minutes)	9	9	5	9
Offboarding Rate (in minutes)	1	1	1	1

Onboarding Rate (in minutes)	2	2	2	2
Passenger Capacity (in count of passengers)	1240	1240	1240	1240
Number of Trains	14	22	14	14
Skip Stations	No	No	No	Yes

Table 4. Comparison of Parameters used for baseline model vs other simulations

All other parameters and factors will remain the same for the 3 scenarios outside of the base model.

IV. RESULTS AND DISCUSSIONS

A. Baseline Model

The baseline model was run with the assumptions and parameters specified above had an overall average waiting time of 66 minutes. The following average waiting times were observed per station:

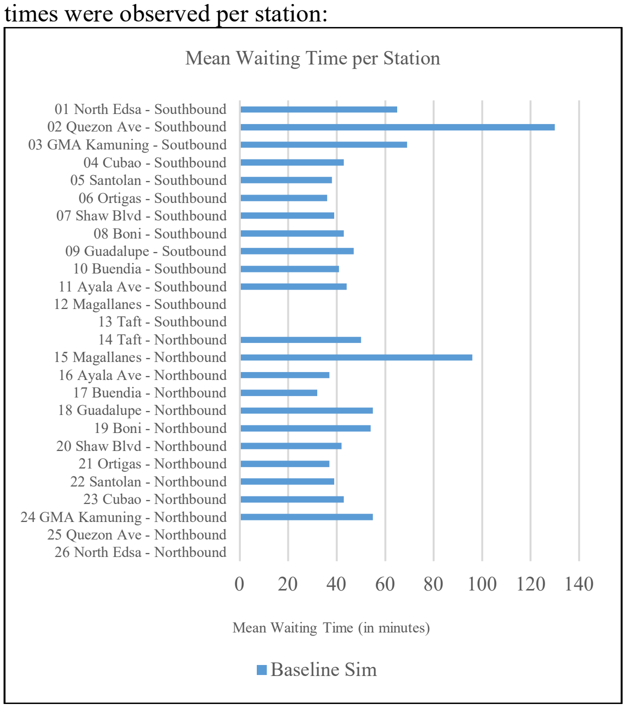

Figure 3: Mean Waiting Time of Passengers per Station – baseline model.

For the baseline model, we see that the largest waiting times occur at the 2nd station of each direction. Looking into the simulation results, we see that this is driven by scenarios wherein the train is full after boarding passengers from the first station which leads to passengers at the 2nd station not being able to board the train and need to wait at least another 9 minutes for the next train to arrive, assuming that train is no full as well.

B. Comparison of Other Simulations with Baseline Model

For the other models, we see the following waiting times generated in comparison to the baseline model:

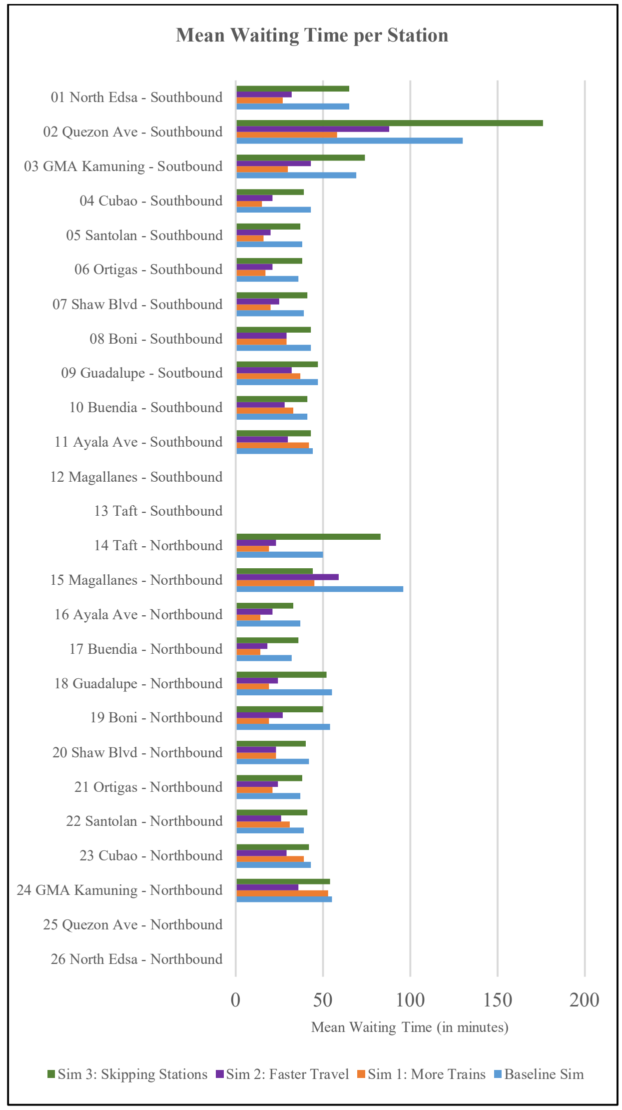

Figure 4: Comparison of Mean Waiting Time of Passengers per Station – baseline model against other simulations.

For the first simulation that involves increasing the number of trains running in the system from 14 to 22, all other factors held constant, the average waiting time of the passengers overall decreases to 32 minutes; 50% lower than the baseline. This decrease in waiting time is seen across all the stations. This decreases the waiting time as there are less times within the simulation where the stations are empty due to the entire set of trains (either Northbound or Southbound) leaving the station and the next set of trains requiring more gap time before arriving at the station.

For the second simulation that involves increasing the travel time of train from 9 minutes to 5 minutes, all other factors held constant, the average waiting time of the passengers overall decreases to 44 minutes; 32% lower than the baseline. This decrease in waiting time is seen across all stations. This decreases the passenger waiting time as trains will travel faster to the station thus increasing the arrival frequency of trains within the same span of time as the baseline model.

For the last simulation that involves allowing stations to alternately skip onboarding on the first 2 stations, the average waiting time overall of the passengers is 68 minutes; 8% higher than the baseline. For the first two stations, while we see an improvement in the waiting time of the 2nd Northbound station (Magallanes – Northbound), we see that the 1st Northbound station (Taft – Northbound) increases. As for the 1st 2 Southbound stations (North Edsa – Southbound, and Quezon Ave – Southbound), there are no improvements seen in the waiting time. The last simulation shows that although allowing skipping stations may save on some time with regards to unnecessary stopping at the station, there is no overall improvement in effect within the system as this just ends up decreasing waiting time for one station but increasing waiting time for another.

V. Conclusions and Recommendations

Overall, the study confirms that two major factors that can help improve the operations of the train station will be to either increase the number of trains operating in the system, or increase the speed at which the trains operate as well as the extent to which they are able to improve the passenger waiting time.

While the increasing the number of trains may be an expensive action to take, the simulations show us that even simpler actions such as increasing the speed of the train will yield almost as good of an improvement as increasing the number of trains in terms of reducing the passenger waiting time. Although this may still occur some cost to increase the train speed, such as increasing maintenance and repairs, this might still be worth exploring as it might not cost as much as procuring new trains; making this action point more feasible in terms of improving the MRT-3 operations.

Future researchers may improve upon this study by conducting separate data collection step to further increase the accuracy of the model representation, especially with regards to (1) the passenger arrival per Northbound and Southbound side of a station, and (2) the number of passengers alighting per station, as this study based some of these figures on assumptions due to time constraints and data availability. Researchers may also test the effects of applying the different factors simultaneously, or adding more complex methods in deciding how the factors are applied (e.g., adding specific conditions) to see if there are optimal conditions that can be applied to maximize the waiting time reduction while minimizing the possible cost needed to implement to the MRT-3 line.

References

[1] *2.1 Defining Rapid Transit Modes*. (n.d.). The Institute for Transportation and Development Policy. https://brtguide.itdp.org/branch/master/guide/why-brt/defining-rapid-transit-modes

[2] Department of Transportation. (n.d.). *Department of Transportation*. https://dotr.gov.ph/9-dotc.html#mrt3-ridership

[3] Phillip Rice, A Queueing Theory Approach to Railway Capacity in Urban Commuter Railways, IFAC Proceedings Volumes, Volume 9, Issue 4, 1976, Pages 267-276, ISSN 1474-6670, https://doi.org/10.1016/S1474-6670(17)67303-8. (https://www.sciencedirect.com/science/article/pii/S1474667017673038)

[4] D'Acierno, L.; Botte, M. Railway System Design by Adopting the Merry-Go-Round (MGR) Paradigm. *Sustainability* 2021, *13*, 2033. https://doi.org/10.3390/su13042033

[5] Fergyanto E. GUNAWAN, Design and Implementation of Discrete-event Simulation Framework for Modeling Bus Rapid Transit System, Journal of Transportation Systems Engineering and Information Technology, Volume 14, Issue 4, 2014, Pages 37-45, ISSN 1570-6672, https://doi.org/10.1016/S1570-6672(13)60139-7.

[6] R. Dantas, J. Dantas, C. Melo, D. Oliveira and P. Maciel, "Sensitivity Analysis in a BRT System," *2019 IEEE International Systems Conference (SysCon)*, Orlando, FL, USA, 2019, pp. 1-8, doi: 10.1109/SYSCON.2019.8836823.

[7] S. S. Chua, "Feasibility improvement of transportation for light rail train system," *2018 5th International Conference on Business and Industrial Research (ICBIR)*, Bangkok, Thailand, 2018, pp. 221-225, doi: 10.1109/ICBIR.2018.8391196.

[8] S. Poomrittigul, A. Koomsubsiri, P. Sasithong, D. Deenuch and L. Wuttisittikulkij, "The Simulation of Queuing Model for Bangkok Rapid Transit Train Ticket System Using Python," *2019 34th International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC)*, JeJu, Korea (South), 2019, pp. 1-4, doi: 10.1109/ITC-CSCC.2019.8793309.

[9] BusinessWorld. (2020, January 24). *BusinessWorld*. Https://Www.Bworldonline.Com/Mrt-3-Ticket-Sales-Rider-Count-Further-Fall-as-Repairs-Continue/. https://www.bworldonline.com/mrt-3-ticket-sales-rider-count-further-fall-as-repairs-continue/

[10] A. L. Balinbin, "MRT-3 ridership rises on increase in permitted capacity," *BusinessWorld*, 04-Nov-2020. [Online]. Available: https://www.bworldonline.com/mrt-3-ridership-rises-on-increase-in-permitted-capacity/. [Accessed: 05-Apr-2021].