A Microsimulation Model of An Exclusive Bus Lane: The Case of EDSA Busway

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Abstract: With its full operation starting on July 1, 2020, the EDSA Busway features a dedicated median lane for buses running from Monumento Station to the Paranaque Integrated Terminal Exchange (PITX). However, establishing an exclusive bus lane has posed challenges, as the infrastructure initially served as an ad-hoc augmentation to the EDSA-MRT3 services. Transit stops are not properly designed to handle long queues of commuters, exacerbated by extended bus dwell times and irregular schedules. The overarching goal of this study is to evaluate the network performance of the EDSA Busway across various transport and traffic measures. The proficient use of the mobile crowdsourcing application SafeTravelPH is demonstrated for effectively gathering and analyzing data on bus operational parameters. Additionally, this study adeptly showcases the traffic simulation tool AIMSUN to simulate actual bus conditions and conduct scenario analyses aimed at enhancing the EDSA Busway's network performance.

The results indicate that implementing an optimal dwell time significantly improves total travel time during peak hours, with notable changes in fuel efficiency and pollutant emissions. Moreover, incorporating the headway strategy further enhances travel time efficiency and reduces pollutant emissions. The addition of overtaking lanes also demonstrates a significant impact on improving the EDSA Busway's network performance. Furthermore, the study emphasizes the importance of evidence-based policies to enhance EDSA Busway transport operations.

Keywords: EDSA Busway, Bus Operations, Mobile Crowdsourcing, Microsimulation

1. INTRODUCTION

1.1 Background of the Study

Epifanio de los Santos Avenue, commonly referred to as EDSA, spans a distance of 24 kilometers. Serving as the primary thoroughfare of Circumferential Road 4 (C-4), it traverses the Metro Manila, connecting the cities of Caloocan, Quezon City, San Juan, Mandaluyong, Makati, and Pasay from north to south. Addressing issues involving buses along EDSA have been studied through the years. In 2012, the EDSA Bus Segregation Scheme was enforced with the aim of minimizing traffic congestion along the thoroughfare, particularly at loading and unloading areas. Under the said scheme, buses that ply EDSA have been tagged as Bus A, B, or C. Bus type C is allowed to load and unload passengers in the 15 bus stops along EDSA while bus types A and B are only allowed to load and unload passengers in bus stops exclusively assigned to them (MMDA, 2012). In 2016, the government made efforts to address the congestion caused by the bus terminals along EDSA by issuing a regulation prohibiting the construction of new terminals alongside the Nose In, Nose Out policy (MMDA, 2016). This policy mandates provincial buses to enter and exit their designated terminals using the front-end first, instead of the rear-end first, which often causes bottlenecks along EDSA. Meanwhile, in 2019, all the business permits for public utility bus terminals and operators along EDSA were revoked (MMDA, 2019). Additionally, interim terminals were designated to other areas as their respective terminals along EDSA greatly contribute to the traffic congestion.

1.2 EDSA Busway

The concept of a dedicated bus lane on EDSA dates back to a 2006 EDSA Bus Route Revalidation Survey funded by the Japan International Cooperation Agency (JICA). This study highlighted the potential benefits of a BRT system to alleviate the chronic congestion on EDSA. In 2016, the Asian Development Bank (ADB) funded a study on the BRT system, laying the groundwork for what would become the EDSA Busway. However, the EDSA Busway faced significant delays due to a decade of intense debate during the planning process. Implementation finally began in 2020 when the opportunity arose to introduce reforms in the bus system.

The creation of the EDSA Busway was part of the nation's proposal to the modernization of the existing transportation system and to combat the spread of the increasing cases of Covid-19 infections after the Inter-Agency Task Force on Emerging Infectious Disease (IATF) imposed a community lockdown which ceased all private and public transportation operations traversing EDSA with limited services to healthcare workers. In order to minimize commuters' exposure, a Light-Quick-Cheap transport solution had to be made available within 6 weeks (Martinez, 2021).

Through Memorandum Circular 2020-019 of the Land Transportation Franchising and Regulatory Board (LTFRB), 31 rationalized bus routes in Metro Manila have been implemented. Included in these 31 routes was the EDSA Busway. With its full operation on July 1, 2020, the EDSA Busway features a dedicated median lane for buses that run from Monumento Station up to Paranaque Integrated Terminal Exchange (PITX) as shown in Figure 1. Buses continuously traverse along a loop known as the EDSA Carousel. Bus stations were located mostly under MRT and LRT structures (see Figure 2). These at-grade stops are accessible through MRT entrances and existing footbridges, suggesting that passengers must ascend stairs to reach the bus concourse.

Currently, 565 authorized bus units from two consortiums—Mega Manila Consortium Corporation and ES Transport & Partners Consortium—have been implemented to service the EDSA Busway. Each bus boasts a capacity ranging from 45 to 60 passengers, contributing to an average daily ridership of 129,000 individuals (DOTr, 2022). The other features of the EDSA Busway are depicted in Table 1.

Figure 1. EDSA Busway Route Map

Figure 2. EDSA Busway Monumento Station

Table 1. EDSA Busway Features

Component	EDSA Busway
Franchise	Operators consolidated into two consortium (Mega Manila Consortium Corporation & ES Transport and Partners Consortium)
Lane Utilization	Dedicated median lane with some portions operating in mixed traffic (from MOA to PITX and from PITX to Roxas Blvd)
Authorized bus units	565 authorized bus units as of September 2023
Running Speed	13 kph on the average as of September 2023
Stations/stops	19 stations northbound (26.79 km) and 21 stations southbound (27.37 km) as of March 2024

1.3 Issues and Challenges

The initiative of putting an exclusive bus lane on EDSA has been met with several challenges. A study conducted by Tiglao et. al. (2021) outlined the following issues and challenges. First, the infrastructure was mainly an ad hoc augmentation to the EDSA-MRT3 services on which bus stops are not properly designed to service the long queues of commuters. Second, the current travel demand far exceeds the EDSA Busway capacity. The basis of travel demand was based on the Metro Manila Urban Transportation Integration Study (MMUTIS) Update and Capacity Enhancement Project (MUCEP) conducted way back in 2015. This travel demand does not capture the current travel demand patterns of commuters in Metro Manila. Also, compounding to the problem is the infrequent arrival and inadequate supply of buses. Currently, only an average of 322 bus units operates daily out of the total 565 authorized bus units. There are also certain portions of the EDSA Busway where it operates with mixed traffic which causes delay among buses. It is also clear that bunching of buses has not been resolved. Most of the time, their designated dispatch schedule is not being followed. Many buses operating on the EDSA Busway still has right-facing doors that do not align with the designated bus stops. This system slows down the boarding and alighting. Passengers may need to wait longer for others to safely enter or exit the bus, leading to delays in departure times. The lack of real-time transit information leads to longer waiting times and overcrowding inside the buses. Lastly, the lack of monitoring and feedback systems restricts the government's capacity to guarantee the compliance of operations with safety protocols among operators and bus drivers.

Commuters have to endure long queues at EDSA Busway stations due to inefficient transport operations. This indicates that the busway is operating beyond its service capacity. This study enters this discourse as a guiding framework to evaluate and maximize the transport performance of the EDSA Busway. Through this pursuit, the study positions itself as a contributor to transport planners and policymakers, aiming to devise effective policies for enhancing EDSA Busway transport operations.

1.4 Research Objectives

The main objective of this study is to evaluate the operational performance of the EDSA Busway under different transport and traffic measures. It aims to achieve the following specific objectives:

- To develop the microsimulation model of the EDSA Busway using AIMSUN and evaluate its operational performance by determining reductions in travel time, delay, dwell time, pollutant emissions, and fuel consumption under different scenarios.
- To assess the potential implications for planning and public policy in improving EDSA Busway transport operations.

2. LITERATURE REVIEW

2.1 Effectiveness of Bus Rapid Transit (BRT) systems

A BRT is a high-quality bus system for faster travel. It has a dedicated bus-only lane that ensures buses are never delayed. BRT systems generally outperformed conventional bus systems in various service attributes such as travel time and reliability (Hidalgo and Gutierrez, 2013). Moreover, it combines advantages such as flexibility of conventional buses and rail transit operational efficiency (H.S. Levinson et al, 2011; L. Schramm et al, 2010). A study conducted by Filipe and Macario in 2013 suggested that effective BRT do not need to strictly follow the standard concept of BRT. The main implication is that there is flexibility in how BRT systems can be designed and operated. They don't necessarily have to follow every aspect of the standard model to be efficient. And as of now, dedicated bus lanes have been done on EDSA.

Evidence from studies have shown the effectiveness of BRT systems and how it can possibly reduce the private vehicle dependency as well as GHG emissions. Travel time efficiency significantly affects the mode shift to public transportation. This follows the study conducted by Nurdden, Abdullah et al. (2007) who examined the policies encouraging public transport use in Malaysia and found that reduction of travel time and distance from home to public transport stations as well as subsidized fare are the most important aspects that affects the traveler's transport mode choice. Furthermore, McDonnell and Zellner (2011) evaluated the effectiveness of BRT under various scenarios in Dublin, Ireland. They found out that the dedicated bus lane improves travel efficiency among commuters. Meanwhile, Nguyen Hoang-Tung et al. (2021) studied the impacts of the BRT introduction in Hanoi, Vietnam. The report revealed that the introduction of the exclusive bus lanes has improved the travel time efficiency of the commuters. A 20% travel time reduction has been observed due to the prioritization of bus lanes and signal priority. Travel time savings were also testified in the TransMilenio BRT system in Bogota, Colombia (Hidalgo et al. 2013).

Modal shifts towards BRT services were testified in Thailand (Satiennam et al., 2016). Based on the Stated Preference (SP) survey, modal split models were developed to predict the choices of motorcycle and car users. It was reported that the proportion of mode shift from motorcycle users to BRT was much larger than the private car users. Ernst, J. (2005) studied the performance of BRT system in Jakarta Indonesia during the first month of operation. It has been revealed that 14% of its new passengers previously used private cars for the same trips and 6% from motorcycle users. Meanwhile, Currie, G. and Delbosc, A. (2010) reviewed the BRT impacts on travel behavior from 2001 to 2010 in Brisbane, Australia. Steady growth of ridership has been found and outperformed the rail transit in attracting new passengers.

Wright and Fulton (2005) examined the role of BRT in mitigating emissions from transport in conjunction with improved fuel technology in Bogota, Colombia by conducting an ex-ante analysis. Results showed that land use changes, the use of walking and cycling, as well as mode shares were the main drivers to achieve a 25% reduction on GHG emissions. A study on Bogota's TransMilenio showed that 8% of the total benefits from health-cost savings and reduced emissions are mainly attributed to air pollution and traffic accident savings (Hidalgo et al., 2013). Meanwhile, Vincent et al. (2012) showed that the BRT system in Bogota achieved reductions in CO_2 emissions of 1.7% of the city-wide transport emissions.

2.2 Microsimulation Applications

Several studies have also examined the different simulation approaches in improving the BRT transport operations. Liao et al. (2007) simulated eastern and western BRT lines using the microsimulation tool "Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks" (AIMSUN). This study compares BRT with and without the presence of transit signals priority. In achieving travel time reductions, providing signal priority for buses is necessary. Travel time, delay and speed were measured to evaluate the impact of the transit priority strategy. Simulation results showed a 12% to 15% reduction in bus travel at morning peak and 4% to 11% reduction at afternoon peak. Meanwhile, the average bus delay time was reduced from 16% to 20% and 5% to 14% during am and pm peak hours.

Ilahi and Irawan (2013) develop a microsimulation traffic condition of the BRT line in Yogyakarta, Indonesia. AIMSUN microsimulation software and car following model are used. Four (4) scenarios were considered in the study namely – first scenario is to simulate existing condition, second scenario is simulating transjoga that operates with a special priority lane, third condition is when signalized intersection is prioritized and Transjoga will operate with the mixed traffic, and lastly, combination of special bus lanes and area traffic control systems.

Simulation results showed that the scenario in which buses were prioritized at traffic control signals reduced commute times by 41% and 57% reduction in delays.

Abbasi et al. (2020) investigates Tehran's first line of BRT by employing the AIMSUN software to simulate exclusive bus lanes, decreasing bus headways, implementing actuated traffic signals and revising the bus stations under different scenarios. Non-linear regression models were also used to predict reductions in travel time, fuel consumption and pollutant emissions. Results showed that by converting shared lines to exclusive lines, travel times could reduce by 2.95%, fuel consumption by 5.3% per kilometer and 9% reduction in CO emissions, PM emissions by 1.13%, and NO_x emissions by 3.45%.

2.3 Gaps in Literature

Current research exemplified by Liao et al. (2007), Ilahi and Irawan (2013), and Abbasi et al. (2020), focuses primarily on scenarios involving exclusive bus lanes or integrated traffic control measures. However, there is a notable absence of studies that directly compare the operational impacts of exclusive and non-exclusive bus lanes on the reduction of travel time, dwell time, delay time, fuel consumption, and pollutant emissions within a single microsimulation framework.

Additionally, there is a lack of research specifically tailored to the unique operational challenges of the EDSA Busway, which serves as a critical augmentation to existing LRT and MRT routes. This study aims to address these gaps, particularly in contexts where busways serve as vital complements to rail-based transit systems.

3. METHODOLOGY

3.1 Study Area

The EDSA Busway was designed as a 28-kilometer route that runs within a dedicated lane on EDSA. There are two station maps for the EDSA Busway—one for the Northbound direction, covering the route from PITX to Monumento, with 19 stops and another for the Southbound direction which runs from Monumento to PITX with 21 total stops as illustrated in Figure 3. The discrepancy in the number of stations between northbound and southbound is due to a combination of spatial constraints, existing infrastructure limitations, and traffic management considerations.

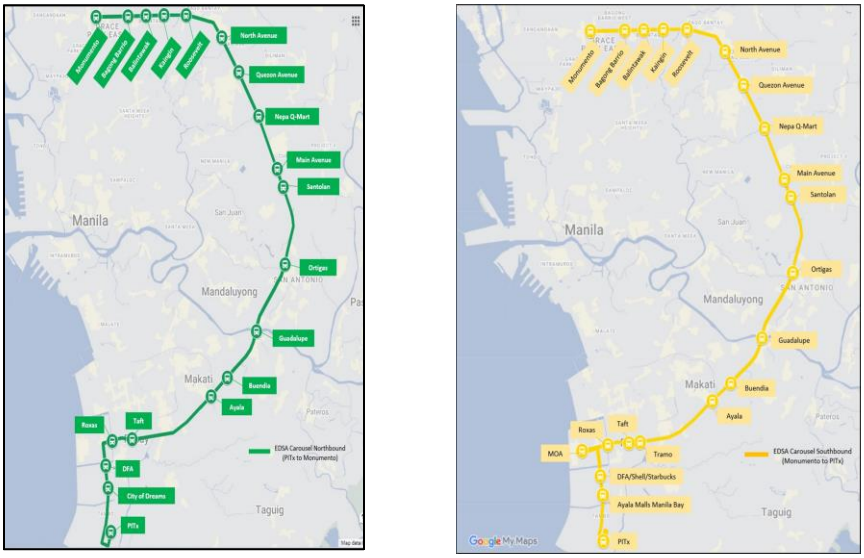

Figure 3. Northbound and Southbound Map

3.2 Research Framework

Figure 4 presents the conceptual framework used in this study. The transportation activity, expressed in vehicle-kilometers traveled (VKT), was obtained from the bus flow, travel time, dwell time, headway, and bus driver behavior. The dwell time encompasses bus and passenger-related activities, such as passenger queues, boarding time, and alighting time. Bus driver behavior, including idling, accelerating, and decelerating, affects bus speed and the efficiency of the bus network. Idling occurs when the bus is stationary or at a transit stop with the engine running, while accelerating and decelerating describe increases and decreases in bus speed. Fuel consumption is calculated by multiplying the VKT by the fuel economy factor. Meanwhile, pollutant emissions are estimated using VKT and speed, along with the adopted local emission factors. The interaction of these variables culminates in the overall network performance of the EDSA Busway.

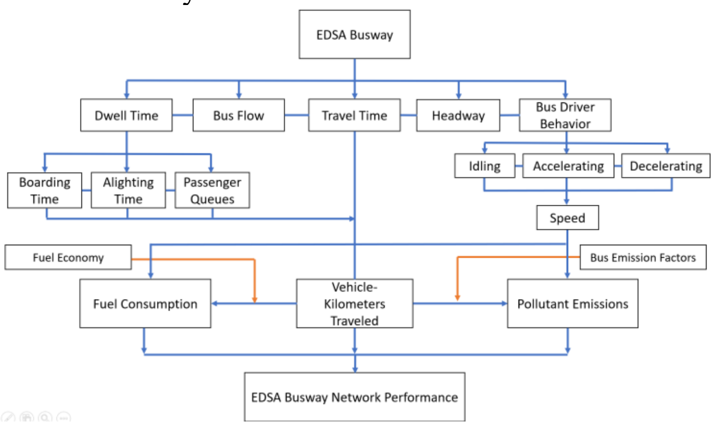

Figure 4. Conceptual Framework

Figure 5 presents the methodological framework utilized in this study. Boarding and alighting survey was conducted using the *SafeTravelPH* app to gather data on vehicle flow, bus operating speed, bus headway, total travel time, as well as dwell time. In order to create the modeled network in AIMSUN, data on the road network was acquired from OpenStreetMap, and the exact locations of transit stops were determined using the captured GIS during the survey. Initial input parameters were set in the traffic simulation software. The modeled data was then assessed using the calibration criteria, 'GEH Statistics' outlined in the AIMSUN manual. Demand and capacity calibration is thus achieved by making adjustments to running speed and total bus input flow in an iterative process. Lastly, a series of transport and traffic measures were developed for the scenario analysis to improve the performance of the EDSA Busway transport operation. These measures aimed to reduce travel time, delay, dwell time, fuel consumption, and emissions.

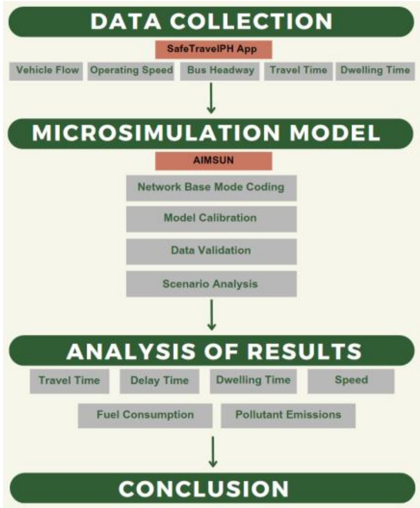

Figure 5. Methodological Framework

3.3 SafeTravelPH App

During the peak of the COVID-19 pandemic, the public transport crowdsourcing app *SafeTravelPH* was developed to address the lack of real-time transit information and proper management of route-based fleets. This information exchange platform highlights the significance of collaborative design and crowdsourcing, achieved through robust partnerships among system developers, government and private institutions. These collaborations are pivotal in crafting systems, data gathering, and shaping policy development (Tiglao, et. al., 2021).

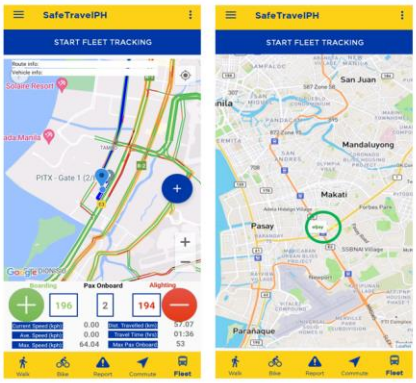

Figure 6. Fleet Tracking Feature

This study utilized the crowdsourcing mobile application *SafeTravelPH*, which gathers and analyzes real-time data on bus arrival at transit stops, boarding and alighting data, and public transport operational parameters. Figure 6 demonstrates the Fleet tracking feature of the *SafeTravelPH* app. Passenger occupancy data is generated through the activation of boarding and alighting buttons in the app. Furthermore, it provides information on vehicle speed, distance covered, and travel duration.

3.4 Transportation Survey

The boarding and alighting survey was conducted over a span of 8 days, focusing on 29 buses. Throughout this period, a total of 105 roundtrips were observed and analyzed.

Table 2. Coverage of the Boarding and Alighting Survey

Operator	Date of Survey	Number of Buses Deployed	Total Roundtrips
RRCG	July 11, 2023	5	20
RRCG	July 12, 2023	5	18
RRCG	July 13, 2023	5	16
RRCG	July 17, 2023	2	8
RRCG	July 18, 2023	2	8
Vil 5000	July 19, 2023	3	7
Pascual Liner	July 19, 2023	3	12
Pascual Liner	July 21, 2023	3	12
Pascual Liner	July 28, 2023	1	4
	Total	**29**	**105**

One (1) roundtrip of the EDSA Carousel consists of the route from PITX to Monumento and from Monumento going back to PITX. Each surveyor completed 2 roundtrips for the AM shift and another 2 roundtrips for the PM shift. The surveyor goes onboard the bus and strategically occupies the middle seat of the bus to gather data, having a clear view of both the front and middle doors. The surveyor utilized the fleet tracking feature of the *SafeTravelPH* app to record the loading/unloading of passengers at each station. This process continues until they return to the terminal where they started. Similarly, the surveyors of the PM shift follow the same buses used during the AM Shift.

Multiple factors contribute to the quality of the collected data. The precise locations of the buses (coordinates) rely on the mobile GPS, mobile data connection, and various types of coverage such as expressways, buildings, bridges and trees. This issue is addressed by adjusting the output of the app to record bus locations at every second when cellular signal is strongest Any missed coordinates are considered negligible as data is available for every second of the bus journey along the designated route. Path location can be easily traced and continued through GIS mapping. Also, the accuracy of surveyors in recording boarding and alighting passengers was ensured through a one-day face-to-face demonstration and training session. Furthermore, during the conduct of the survey, surveyors are required to report any inaccuracies or issues encountered after each roundtrip at the same location where the supervisor is stationed. Relievers or vacant surveyors were assigned to fill these gaps in order to meet the daily quota. Additionally, the exact location of the surveyor was also monitored throughout the day using the tracking feature of the app to ensure the accuracy of the data being gathered.

4. MICROSIMULATION MODELLING

The Advance Interactive Microscopic Simulator for Urban and Non-Urban Networks or AIMSUN, developed by Transportation Simulation Systems (TSS) in Barcelona Spain, is a widely used commercial transport modeling software (AIMSUN, 2010). It is a microsimulation tool that delivers strategic transportation planning and real-time mobility management by simulating future traffic flows. AIMSUN Microsimulation model follows a microscopic simulation approach in which the behavior of each vehicle in the road network is continuously modeled throughout the simulation time period (AIMSUN user's manual, 2010).

4.1 Network Model

The base map of the baseline model is imported from OpenStreetMap (OSM) files to create the roadway features as shown in Figure 7. The exact location of the EDSA Carousel stops was plotted by using captured GPS data during the conduct of the survey.

Figure 7. AIMSUN Network Model

4.2 Vehicle Properties

Transit vehicles are modeled in AIMSUN by incorporating vehicles in the simulation that adhere to fixed routes and operate according to a defined timetable. According to transport experts, type of vehicles plays a pivotal role in shaping both user and non-user perceptions of BRT. An RRCG Bus, measuring 15 meters in length, characterized as a low-entry bus with front and middle doors, and boasting a maximum seating capacity of 43, was employed in the study. The maximum acceleration and deceleration are 1.00 m/s² and 5.00 m/s², respectively, with a maximum yield time of 35 seconds.

4.3 Traffic Supply Data

Bus transport supply data in AIMSUN is represented through input link flows from end-to-end stations. Input link flows were assigned for each time interval.
Table **3** shows the number of buses from Monumento to PITX station and vice versa for each hourly time splice.

Table 3. Number of Buses from End-to-End Station

Time	Monumento - PITX	PITX - Monumento
5:00 am - 6:00 am	79	53
6:00 am - 7:00 am	69	73
7:00 am - 8:00 am	73	82
4:00 pm - 5:00 pm	59	73
5:00 pm - 6:00 pm	69	63
6:00 pm - 7:00 pm	73	41

4.4 Public Transport Plan

To define the traffic route for buses, a reserved lane is defined for public transit. This lane would only be available for buses. Exclusive bus lanes from Monumento up to PITX and vice versa were modeled in AIMSUN. Moreover, the type of transit stop affects both the efficiency of transit operations and the behavior of passengers boarding and alighting at designated stops. Hence, various transit stops are defined within AIMSUN as depicted in Figure 8.

Normal bus stop is the type of transit stop that is located along the roadside. A normal bus stop is situated alongside the roadside of the EDSA Busway, such as those at Tramo and MOA. At these specific stops, transit vehicles halt in the designated lane, thereby blocking traffic in that lane. The most common transit stop along EDSA Busway is the Bus Bay stop. Bus Bay type features a dedicated short lane at the roadside for the bus to move out of the traffic stream. This may briefly block traffic in that lane, but only during the lane-changing maneuver. However, even with this type, buses still find it difficult to overtake other buses. Terminal stops, on the other hand, are used to model transit stations for a limited number of buses. PITX and One Ayala are the two bus terminals on the EDSA Busway. Lastly, informal bus stops refer to transit stops where buses regularly pick-up and drop-off passengers with no formal infrastructures typically found at designated bus stops or terminals, such as those at Ayala (Northbound), City of Dreams (Northbound), DFA (Northbound), Ayala Malls/Aseana (Southbound), and DFA/Shell/Starbucks (Southbound).

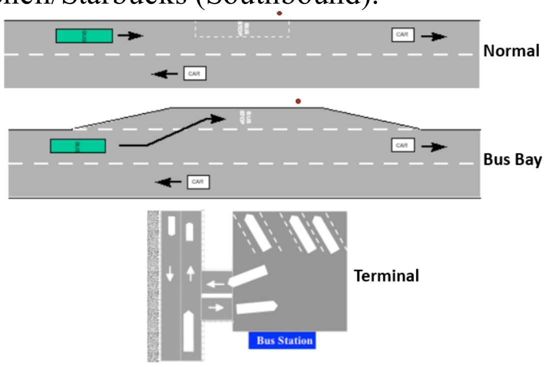

Figure 8. AIMSUN Representation of Different Types of Transit Stops

All other sections of the EDSA busway are operating in mixed traffic, such as those from One Ayala to Tramo Station (southbound), Roxas Boulevard to MOA (southbound), MOA to PITX (southbound), PITX to Roxas Boulevard (northbound), and Taft to Ayala Station (northbound).

A timetable consists of a set of time slices, each describing the transit vehicle's departure schedule and dwell at each transit stop allocated to the line. The amount of time spent at the designated stop is defined as the dwell time parameter. Mean dwell times were derived from the survey data and integrated into the model for each hourly time segment. The average dwell time for each station is shown in Table 4.

Table 4. Dwell Time Input Parameter

Dwell Time (in seconds)			Dwell Time (in seconds)		
Northbound	**AM Peak**	**PM Peak**	**Southbound**	**AM Peak**	**PM Peak**
PITx	107	78	Monumento	138	71
City of Dreams	17	22	Bagong Barrio	223	224
DFA	19	18	Balintawak	8	6
Roxas Boulevard	271	204	Kaingin	82	63

Taft Avenue	122	178
Ayala	114	103
Buendia	45	43
Guadalupe	35	55
Ortigas	96	286
Santolan	27	33
Main Avenue	102	120
Nepa Q. Mart	87	92
Quezon Avenue	101	202
North Avenue	267	285
Roosevelt	253	184
Kaingin	54	66
Balintawak	45	56
Bagong Barrio	68	87
Monumento	39	41

Roosevelt	135	103
North Avenue	110	136
Quezon Avenue	91	167
Nepa Q. Mart	122	143
Main Avenue	93	143
Santolan	42	51
Ortigas	105	200
Guadalupe	30	32
Buendia	39	27
Ayala	189	258
Tramo	25	38
Taft Avenue	140	106
Roxas Boulevard	84	67
MOA	87	214
DFA/Shell/Starbucks	12	8
Ayala Malls/Aseana	54	54
PITx	162	117

In the software, every bus schedule is equipped with an initial time and duration to specify the interval during which the bus will be generated according to that particular schedule as shown in Figure 9. Dispatch schedules such as the departure time of each bus at the end stations, PITX and Monumento station, were acquired from the Bus Management and Dispatch System (BMDS). The Department of Transportation (DOTr) and the Metropolitan Manila Development Authority (MMDA) implemented the BMDS to monitor bus units on the EDSA Busway. This system uses an automated process that enables contactless, comprehensive bus driver monitoring through QR code scanning of bus driver IDs.

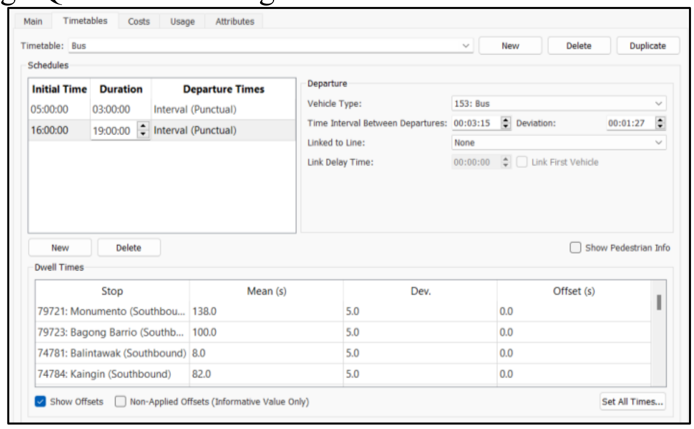

Figure 9. Bus Dispatch Schedule in AIMSUN

4.5 Model Calibration and Data Validation

A summary of GEH statistical values for the AM and PM peak models is shown in Table 5. Notice in the table that there are items that need further investigation. This is because in the AIMSUN Output, a bus is considered only when it completes the defined route. Consequently, during the simulation, buses that have not exited the network due to congestion or queuing at designated stations are not accounted for by the AIMSUN software.

Table 5. GEH Statistics

Southbound	Timetabled bus numbers (Actual)	Modeled bus numbers (AIMSUN)	Difference	GEH Stats	Remarks
5:00 am - 6:00 am	79	67	12	1.4	Good Fit
6:00 am - 7:00 am	69	54	15	1.91	Good Fit
7:00 am - 8:00 am	73	43	30	3.94	Good Fit
4:00 pm - 5:00 pm	59	44	15	2.09	Good Fit
5:00 pm - 6:00 pm	69	28	41	**5.89**	*Revisit*
6:00 pm - 7:00 pm	73	55	18	2.25	Good Fit
Northbound	**Timetabled bus numbers (Actual)**	**Modeled bus numbers (AIMSUN)**	**Difference**	**GEH Stats**	**Remarks**
5:00 am - 6:00 am	53	45	8	1.14	Good Fit
6:00 am - 7:00 am	73	65	8	0.96	Good Fit
7:00 am - 8:00 am	82	40	42	**5.38**	*Revisit*
4:00 pm - 5:00 pm	73	57	16	1.98	Good Fit
5:00 pm - 6:00 pm	63	28	35	**5.19**	*Revisit*
6:00 pm - 7:00 pm	41	33	8	1.32	Good Fit

Root Mean Square Error (RMSE) was also used to evaluate the accuracy of a simulation model by comparing the simulated bus speeds to the actual bus speeds. The fit measure used is defined as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(x_{obs}-x_{model})^2}{n}} \qquad (2)$$

where x_{obs} is the observation value and x_{model} is the modeled value

Calibration is performed to find the most optimal value for the set of parameters used in this model. Maximum desired speed and speed acceptance are the two parameters considered.

Table 6 presents the calibration parameters used for calibration. The maximum desired speed is divided into four experiments with varying maximum desired speeds. The observed speed range spans from a maximum of 17 kph to a minimum of 11 kph.

In AIMSUN, the speed acceptance is a parameter that influences how buses adhere to the speed limit or max desired speed set for the entire road network. It is a multiplier applied to the desired speed. Values of 0.8 and 0.9 indicate that buses will travel at 80% and 90% of the desired speed, respectively. A value of 1.0 means buses will travel at the exact desired speed. Conversely, values of 1.1 and 1.2 represent buses traveling at 110% and 120% of the desired speed, respectively, in order to stay on schedule.

Table 6. Calibration Parameters

Experiment	Bus Max Desired Speed (km/h)

1	11
2	13
3	15
4	17

The model underwent several iterations of adjustments. Each iteration includes adjusting the link parameters such as bus flow and speed and re-evaluating the RMSE until the values consistently fall within acceptable ranges, ensuring that the simulation closely matches the actual operating conditions of the EDSA Busway. From the obtained results shown in Table 7, Experiment 2 with speed acceptance value of 1.0 is the best possible result since it has the smallest RMSE value of 0.304. Figure 10 depicts the observed vs modeled maximum desired speed used in the model. By fine-tuning the speed acceptance values, the simulation can better replicate the actual conditions and behavior of buses on the EDSA Busway, leading to more accurate and reliable traffic models.

Table 7. RMSE Values

Speed Acceptance	Experiment 1	Experiment 2	Experiment 3	Experiment 4
0.8	1.976	1.538	1.19	1.828
0.9	2.354	2.294	1.94	5.83
1	0.656	0.304	1.397	1.093
1.1	7.859	3.065	1.966	3.76
1.2	4.925	3.993	5.135	13.115

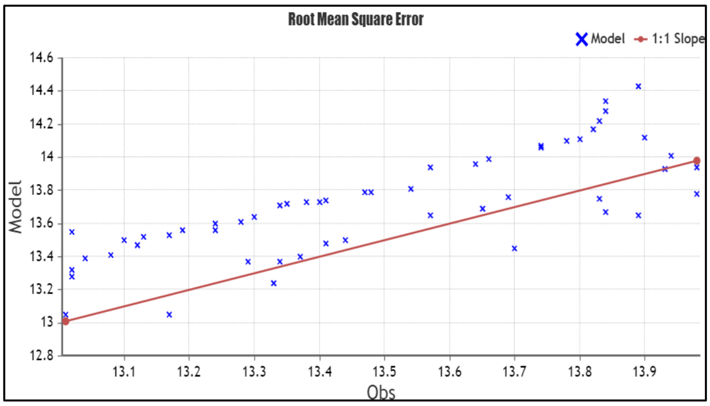

Figure 10. Observed vs Modeled Maximum Desired Speed

4.6 Challenges of Modeling an Exclusive Bus Lane using AIMSUN

Modeling an exclusive bus lane using AIMSUN presents challenges to both the modelers and the AIMSUN software platform due to the complexity of simulating real-world transportation systems. Some of these challenges are as follows:

- Three distinct buses from various operators – RRCG, Vil5000, and Pascual Liner Bus – were utilized during the survey. In the software, the public transport timetable restricts the generation of only one vehicle type throughout the time duration. This limitation makes it challenging to define various types of buses operating within a single time slot.

As a result, the RRCG Bus was selected as the modeled vehicle due to its predominant usage throughout the survey. However, this issue can be resolved through custom scripting or by integrating external data sources into AIMSUN. By using scripting, it is possible to simulate different bus types more accurately within the same time slot. Alternatively, other microsimulation software, such as VISSIM, can be considered. VISSIM offers similar functionalities to AIMSUN and has the capability to simulate multiple bus types simultaneously.

- Buses are generated based on the designated frequency for each hourly time interval until the software progresses to the subsequent scheduled time interval. The program continues to generate buses during a time interval without a specified frequency, maintaining the same frequency as the preceding time interval. The issue was addressed by incorporating a fixed timetable for every hourly time interval with suitable departure times.
- The software does not generate public transport operational performance results for each scheduled bus stop. Instead, it provides end-to-end results, from PITX station to Monumento station and vice versa. The software does not produce average travel times for each station along the EDSA Busway individually; it calculates them from the starting position to the end station. However, this comprehensive simulation output from AIMSUN offers a holistic perspective of the operational performance of the EDSA Busway. It enables the evaluation of the overall system efficiency, allowing transport planners and policymakers to understand how the system functions as a whole, from one station to its terminal.

The issues encountered have been reported to the software developer, Transport Simulation Systems (TSS), and certain solutions are currently being integrated into the most recent version of the software.

5. RESULTS AND DISCUSSION

5.1 Bus Headways

The headway between buses for each day of the week at Monumento Station and PITX station is demonstrated in Figure 11. The shortest headway occurs on Monday for the PITX station and Tuesday for the Monumento station. In contrast, the longest average headway is experienced on Sunday with buses arriving approximately 82 seconds apart at PITX Station and 76 seconds apart at Monumento Station, attributed to reduced passenger demand. Consequently, passengers faced longer waiting times.

Meanwhile, the average bus headway during a typical day trip is shown in Figure 12. At Monumento station, the highest headways occur in the afternoon, specifically between 4-5 pm, with 78 seconds. This trend continues into the evening, with headways of 76 seconds observed from 8 to 9 pm. Similar pattern was observed at PITX Station where the highest headways were observed during the mid-day period, particularly at 2-3 pm with 97 seconds and from 8 to 9 pm with 99 seconds, respectively.

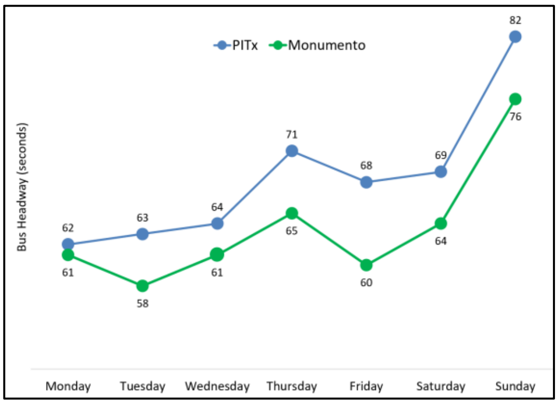

Figure 11. Average Bus Headway at End Stations (Day of Week)

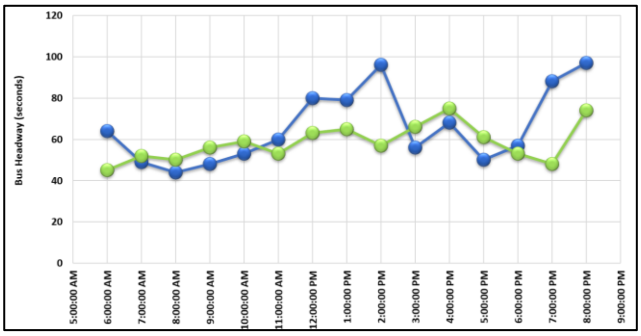

Figure 12. Average Bus Headway at End Stations (Hour of Day)

5.2 Travel Time

Figure 13 illustrates the average end-to-end travel time of buses by different periods of the day on July 11, 2023. The data is analyzed into segments corresponding to each 3-hour time interval for the 2 directions accordingly. Commuters during peak hours, from 5 am to 8 am and from 4 pm to 7 pm, experience shortest travel times, whereas those traveling during off-peak hours, endure comparatively longer durations. The recorded average travel time between end-to-end stations ranges from 1 hour and 35 minutes to 2 hours and 43 minutes. This stands in stark contrast to the 45-minute to 1-hour travel time as claimed by transport officials. In reality, buses tend to stay longer at bus stops to accommodate more passengers, as the EDSA Carousel now operates on a profit-driven scheme. This further increases the waiting times and travel times among commuters.

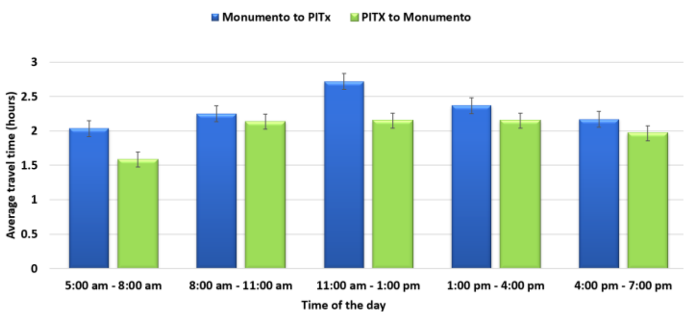

Figure 13. Average End-to-End Travel Time

5.3 Bus Running Speed

Prior to the implementation of EDSA Busway, the average speed of vehicles traversing EDSA averaged at 19 kph. Based on the survey conducted, results revealed that the average speed of all the buses that have completely traversed the entire loop of EDSA Busway is 13 kph. The range of speeds observed spans from a fastest recorded speed of 17 kph to a lowest recorded speed of 10 kph. This suggests that buses within the EDSA Busway are operating at a significantly slower pace compared to pre-implementation conditions.

5.4 Bus Dwell Time

Bus dwell time refers to the time the bus spends at a station of the EDSA Busway while passengers board and alight. Bus timers have been implemented on the EDSA Busway, establishing a 30-second limit for buses for boarding and alighting of passengers. However, this limit is often not adhered to, with some buses exceeding the 30-second duration and stay at stations for too long.

For the northbound direction, Roxas Boulevard, Quezon Avenue, and North Avenue stations have notably high dwell times during the AM Peak, indicating that these are major stops with significant passenger activity. Ortigas station shows an exceptionally high dwell time during the PM peak, reaching 286 seconds or 4 minutes and 46 seconds. This station is known for a substantial number of passengers heading northbound during the PM peak hour. On the other hand, stations like City of Dreams, DFA, and Santolan station exhibit low dwell times for both AM and PM Peak. This is because City of Dreams and DFA are stops lacking the infrastructure found at median stations on EDSA. Additionally, these stops have fewer passengers, which speeds up the boarding and alighting process.

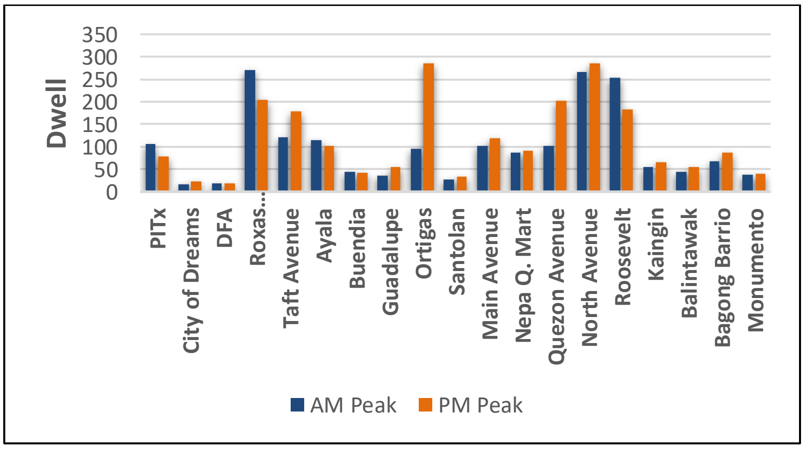

Figure 14. Bus Dwell Time (Northbound Direction)

Meanwhile, on the southbound route depicted in Figure 15. Bagong Barrio, Ayala Station, and PITX station record the highest dwell times during the AM Peak. During the PM Peak, Ayala station stands out with the longest bus dwell time, totaling 258 seconds or 4 minutes and 18 seconds. One Ayala station is known to be a prominent transport hub with increased passenger volume. Conversely, Balintawak, DFA/Shell/Starbucks, and Buendia station exhibits the lowest bus dwell times due to low passenger volume.

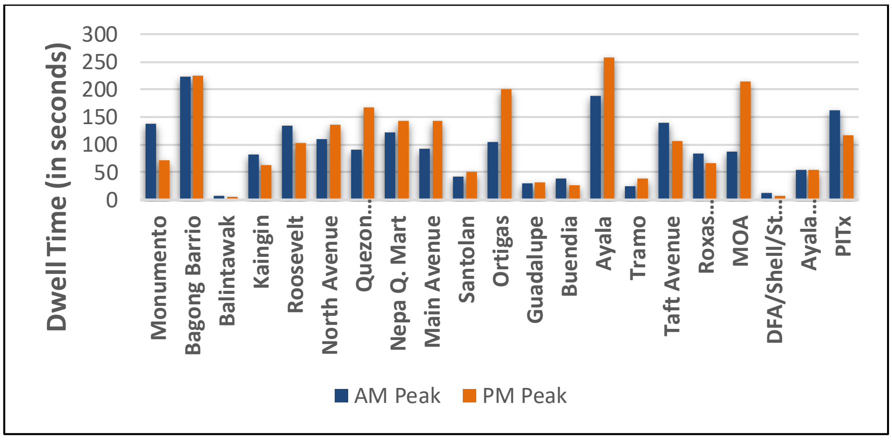

Figure 15. Bus Dwell Time (Southbound Direction)

5.5 Bus Occupancy

During peak hours, particularly in the morning (AM Peak) and afternoon (PM Peak), the influx of passengers can vary significantly along the northbound route. In the AM Peak, several stations experience high passenger loads. Notable among these are Main Avenue, Santolan Station, and Ortigas Station. Main Avenue had an occupancy of 50 passengers followed by Santolan Station with a similar count. Ortigas Station, while slightly lower at 44 passengers, still contributes significantly to the overall passenger load during this peak period.

Conversely, during the PM Peak, the highest passenger counts are recorded at Roosevelt and North Avenue Station, with an occupancy of 84 onboard passengers. Following closely behind is Quezon Avenue Station with 74 onboard passengers during this time. All of which exceeded the maximum seating capacity of an RRCG bus, which is 43 passengers, or the standing configuration, which allows for a maximum of 60 passengers.

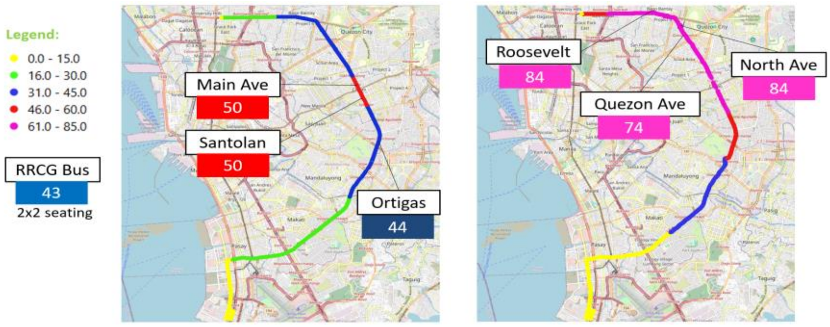

Figure 16. Northbound Average Occupancy (AM and PM Peak)

For Southbound direction, Roosevelt station had an average occupancy of 60 passengers during the AM Peak. Following closely behind, Main Avenue recorded 55 passengers and Nepa Q. Mart at 54 onboard passengers.

Transitioning to the PM Peak of Southbound direction, Main Avenue emerges as the station with the highest onboard passenger count with 73 commuters. Nepa Q Mart Station with 72 onboard passengers while Roosevelt station continues to experience substantial demand, recording 70 passengers. All of which exceeded the maximum seating capacity of an RRCG bus, which is 43 passengers, or the standing configuration, which allows for a maximum of 60 passengers.

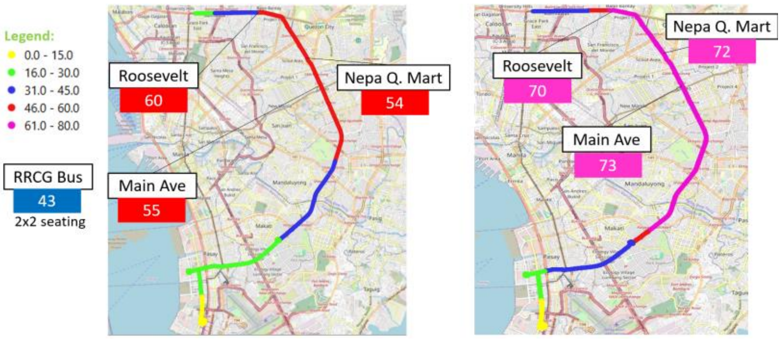

Figure 17. Southbound Average Occupancy (AM and PM Peak)

Overcrowding within EDSA buses leads to cramped conditions, causing discomfort for passengers during their commute. This discomfort can result in dissatisfaction and discourage commuters from opting for public transportation. Additionally, positioning the doors on the wrong side of the bus presents challenges for commuters. The exit and entrance doors of the buses do not align with the transit stop platforms. Passengers must walk in front of the bus and wait for others to alight before they can board, rather than seamlessly boarding and alighting with left-facing door buses. This also poses challenges for passengers with disabilities, hindering the boarding process for those using mobility aids like wheelchairs or strollers. Furthermore, the overcrowding and right-side facing doors of buses prolong the time required for boarding and alighting passengers at each station, contributing to delays and extending travel times.

5.6 Scenario Analysis

A series of transport and traffic measures were proposed to explore ways to improve the EDSA Busway operational performance. The proposed scenarios include adjustments to bus dwell time, headway, and traffic management strategies in the form of addition of overtaking lanes. The various strategies are detailed in the succeeding sections:

5.6.1 Base case scenario

The first scenario modeled in AIMSUN is the current situation of the traffic network along EDSA Busway. Private vehicles travel in general lanes while buses utilize exclusive bus lanes. Government emergency vehicles, patrol units, and ambulances are also allowed in EDSA Busway. There are also certain portions of the EDSA Busway wherein buses operate with the mixed traffic. This scenario serves as the base case and is used to analyze the impacts of the succeeding transport and traffic measures.

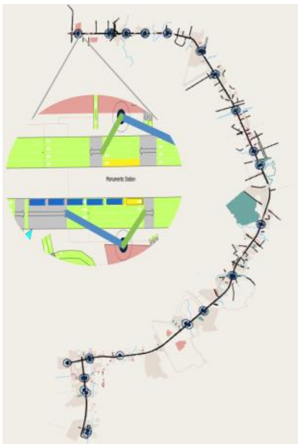

Figure 18. EDSA Busway Network Modeled in AIMSUN (Base Case)

5.6.2 Scenario 1 – Bus dwell time regulation (30 seconds)

The bus dwell time refers to the total amount of time a bus spends at a particular stop or station. Bus dwell time is one of the most important factors that could influence the bus transit system's level of service (Khoo, H.L., 2013).

The process of bus queueing can be modeled as a FIFO (First-In, First Out) queue. Every bus exhibits the same behavior as follows:

(a) Queueing to enter the bus bay
(b) Boarding and alighting of passengers
(c) Closing the bus door and departing from the bus bay

Bus timers have been set at EDSA Busway stations. These timers serve to regulate the amount of time a bus can spend at each station. Specifically, a 30-second maximum duration limit has been implemented to pick-up and drop-off passengers for each bus unit. Once a bus departs, the timer resets automatically for the next bus in line. But despite the implementation of the bus timer system, it has been observed that the duration limit is not consistently being followed. Hence, this Scenario 1 involves the strict implementation of the bus dwell time regulation to ensure buses adhere to the designated time limit. The purpose of this time limit is to minimize dwell time or the time spent stationary at a specific station which can contribute to delays and congestion. A maximum dwell time of 30 seconds is set in AIMSUN for each of the stations.

5.6.3 Scenario 2 – Bus dwell time regulation (Optimal Dwell Time - 60 seconds)

To determine the optimal dwell time, we analyzed 461 data points from the boarding and alighting data, plotting them to identify the best-fit line.

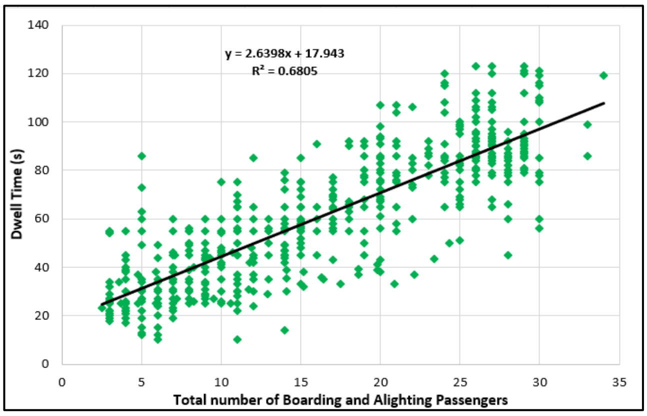

Figure 19. Linear Trend Line of Total Number of Boarding and Alighting Passengers vs. Dwell Time

Numerous outliers are present, attributed to factors such as buses waiting for passengers and late runners, and also the inefficient implementation of bus timer system by I-ACT and MMDA personnels. Figure 19 illustrates the linear regression between the total number of boarding and alighting passengers and the bus dwell time, demonstrating a strong fit. These results show that using the average of the linear regression could be a good way of scheduling bus dwell times. The average dwell time of the linear regression is found to be 60 seconds. Therefore, in Scenario 2, a maximum dwell time of 60 seconds is set in AIMSUN for each of the stations.

The bus is unable to depart from the designated station until the pre-defined bus dwell time has elapsed.

5.6.4 Scenario 3 – 60-second Headway Strategy at End Stations during Peak Hours and 30-Second Dwell Time

Bus arrivals and headways during the survey period were highly unpredictable. Buses were not scheduled or managed properly, resulting in an uncoordinated bus dispatch system and irregular bus headways. The average bus headway was 65 seconds for the northbound direction and 62 seconds for the southbound direction. However, the interval between buses can extend up to 17 minutes to 26 minutes. This resulted in extended passenger waiting times and long queues of commuters. Moreover, the inconsistency led to periods where no buses arrived for a long time, followed by times when multiple buses arrived at once. Therefore, Scenario 3 involves introducing a centralized dispatch system at the end stations, Monumento and PITX station. This system aims to ensure buses arrive every minute to serve commuters during peak hours. Moreover, it will incorporate the 30-second dwell time from Scenario 1, along with the new headway strategy.

5.6.5 Scenario 4 – 60-second Headway Strategy at End Stations during Peak Hours and 60-Second Dwell Time

Scenario 4 incorporates the headway strategy outlined in Scenario 3, but with a modification to the bus dwell time at stations along the EDSA Busway. Instead of the 30-second dwell time, a 60-second optimal dwell time will be implemented. This adjustment aims to assess the impact of optimizing operational performance.

5.6.6 Scenario 5 – Providing Passing Lanes for Buses, 60-Second Headway Strategy and 30-Second Dwell Time

Buses in exclusive bus lanes avoid the delays caused by mixed traffic. However, congestion may occur when buses maneuvering in and out of the station platform disrupt the flow of other buses (Widanapathiranage et. al., 2015). Congestion also happens when a queue of buses forms upstream of the station, thereby blocking incoming traffic. Scenario 5 includes the provision of passing lane for buses as shown in the sample station below. The ability to overtake enables more buses to operate on the same route simultaneously without causing congestion, minimizing delays, and increasing the service frequency. Along with the overtaking lanes, Scenario 5 will also incorporate a 60-second headway strategy and a 30-second bus dwell time.

Figure 20. Passing Lane for Buses

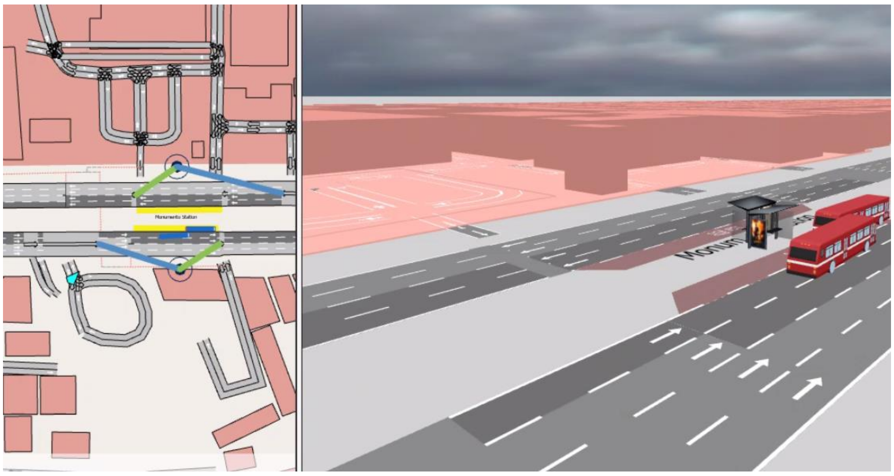

Figure 21. Passing Lane for Buses at Monumento Station (AIMSUN Model)

5.6.7 Scenario 6 – Providing Passing Lanes for Buses, 60-Second Headway Strategy and 60-Second Dwell Time

In Scenario 6, the provision of overtaking lanes allows buses to pass each other at stations, preventing congestion and ensuring a smooth flow of traffic. Buses arrive at 60-second intervals (headway) at the end stations, PITX and Monumento Stations, respectively. Scenario 6 features a 60-second bus dwell time, double the dwell time of Scenario 5.

5.7 Comparison of the Network Performance of the Different Scenarios

The succeeding figures provide a comparison of total travel times across different scenarios, which include running time, dwell times, and delay times. Running time refers to the duration taken for a bus to complete a round trip from PITX to Monumento and vice versa, excluding dwell and delay times. Dwell time indicates the period during which a bus remains stationary at a specific transit stop for passengers to board and alight. Delay time encompasses various factors, such as time spent at dispatching areas like Monumento and PITX, buses navigating through traffic (especially in segments lacking dedicated bus lanes), negotiating areas with conflicting U-turn slots, interactions between buses, and delays caused by government emergency vehicles utilizing dedicated lanes for buses. Each scenario shows a percentage decrease in both AM and PM peak periods, highlighting how certain interventions (represented by the scenarios) can significantly improve travel time, dwell times, and delay times during peak times.

Figure 22 and Figure 23 illustrate the total travel time comparison using the dwell time modification in the northbound direction, while Figure 24 and Figure 25 illustrate the comparison for the southbound direction. Implementing a 30-second dwell time (Scenario 1) significantly improves transit performance. Northbound routes had dwell time reductions of 71% (AM peak) and 75% (PM peak), with delay reductions of 6% and 9%, respectively. Southbound routes had dwell time reductions of 70% (AM peak) and 73% (PM peak), with delay reductions of 22% and 15%, respectively. In contrast, a 60-second dwell time (Scenario 2) results in smaller improvements. Northbound routes achieved dwell time reductions of 42% (AM peak) and 50% (PM peak), with delay reductions of 2% and 4%. Southbound routes experienced dwell time reductions of 39% (AM peak) and 46% (PM peak), with delay reductions of 10% and 11%.

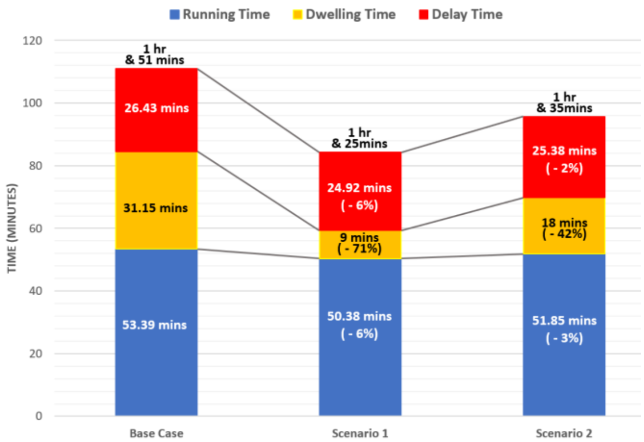

Figure 22. Comparison of Total Travel Time under Dwell Time Strategy (Northbound - AM Peak)

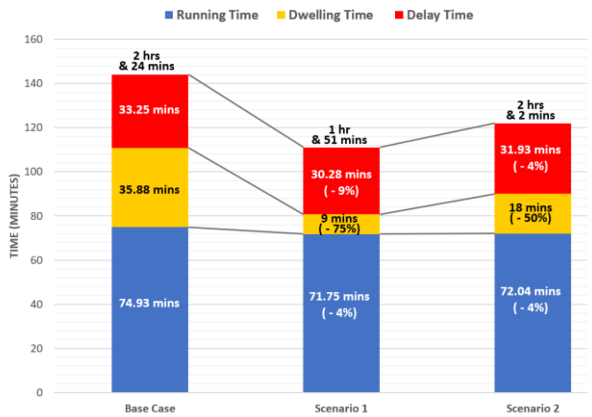

Figure 23. Comparison of Total Travel Time under Dwell Time Strategy (Northbound - PM Peak)

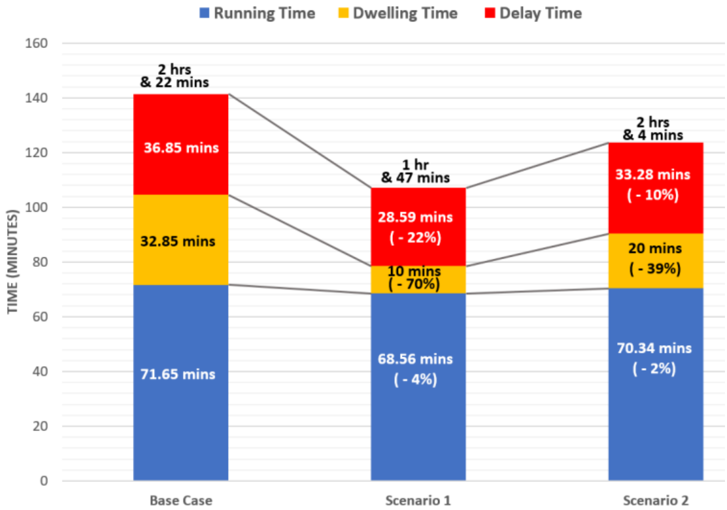

Figure 24. Comparison of Total Travel Time under Dwell Time Strategy (Southbound - AM Peak)

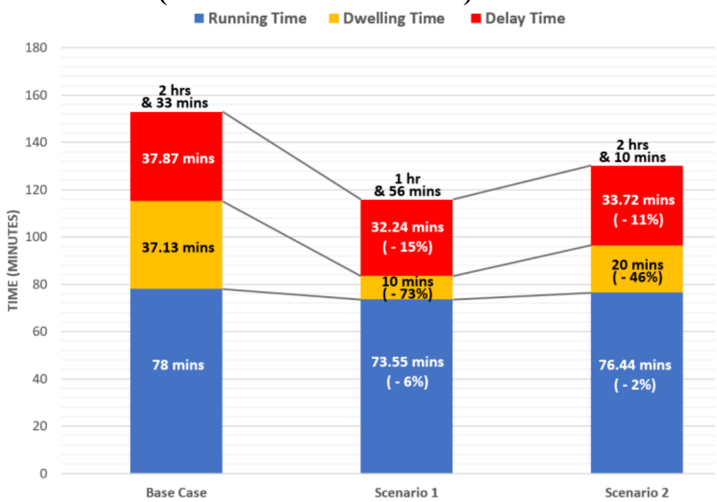

Figure 25. Comparison of Total Travel Time under Dwell Time Strategy (Southbound - PM Peak)

Figure 26 and Figure 27 show the total travel time comparison under the headway and dwell time strategy in the northbound direction, while Figure 28 and Figure 29 present the comparison for the southbound direction. Incorporating a 60-second headway at end stations alongside a 30-second dwell time (Scenario 3) yields significant reductions in dwell and delay times. For the northbound route, dwell time is reduced by 71% and 75% during the AM and PM peaks, respectively, with delay times reduced by 10% and 14%. Similarly, the southbound route showed reductions of 70% and 73% in dwell time during the AM and PM peaks, accompanied by reductions in delay times of 28% and 21%.

Meanwhile, a 60-second headway and a 60-second dwell time (Scenario 4) achieved smaller reductions. For the northbound route, dwell time is reduced by 42% and 50% during the AM and PM peaks, respectively, with delay times reduced by 9% and 13%. Similarly, the southbound route showed reductions of 39% and 46% in dwell time during the AM and PM peaks, accompanied by reductions in delay times of 23% and 17%.

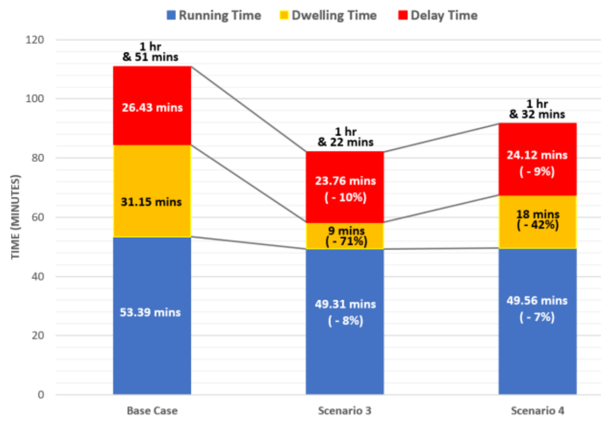

Figure 26. Comparison of Total Travel Time under Headway and Dwell Time Strategy (Northbound - AM Peak)

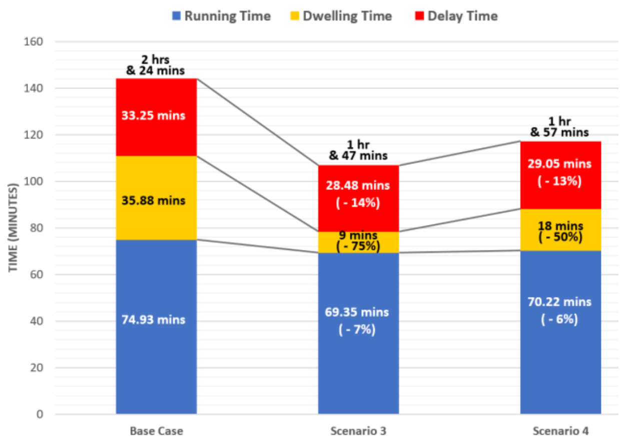

Figure 27. Comparison of Total Travel Time under Headway and Dwell Time Strategy (Northbound - PM Peak)

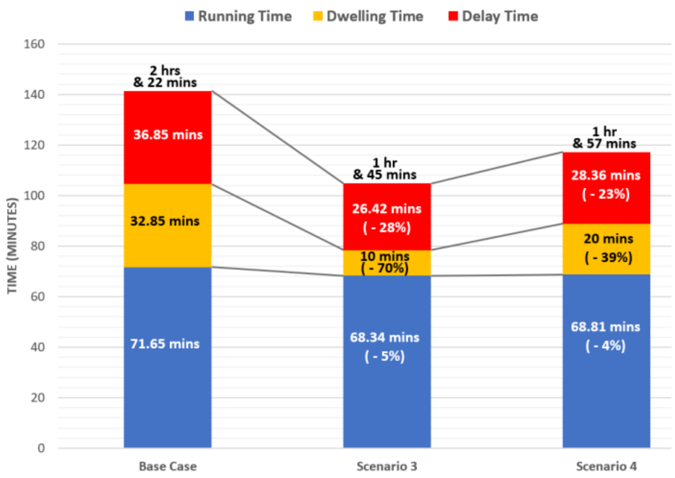

Figure 28. Comparison of Total Travel Time under Headway and Dwell Time Strategy (Southbound - AM Peak)

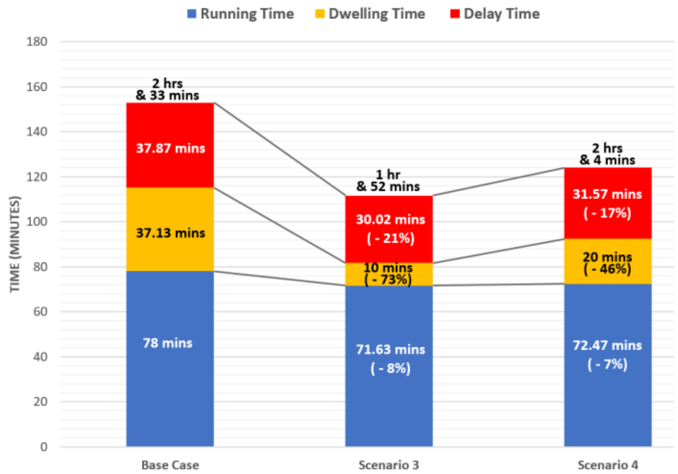

Figure 29. Comparison of Total Travel Time under Headway and Dwell Time Strategy (Southbound - PM Peak)

The introduction of passing lanes for buses yielded significant improvements. During the AM and PM peaks, the northbound route experiences reductions of 71% and 75% in dwell time, coupled with 20% and 28% reductions in delay time. Similarly, for the southbound route during these peak periods, dwell time decreases by 70% and 73%, accompanied by reductions in delay time of 39% and 28%.

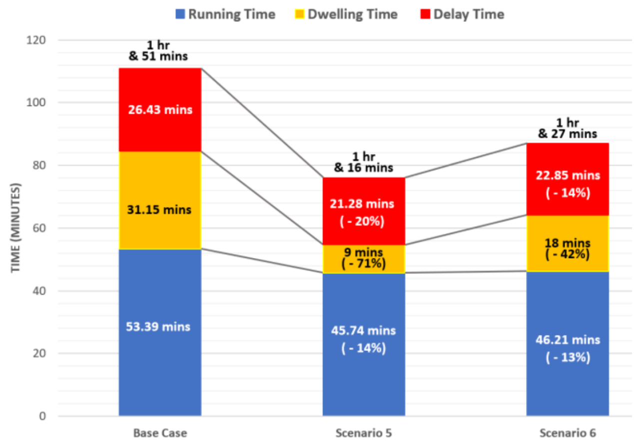

Figure 30. Comparison of Total Travel Time under the Provision of Passing Lanes, Headway and Dwell Time Strategy (Northbound - AM Peak)

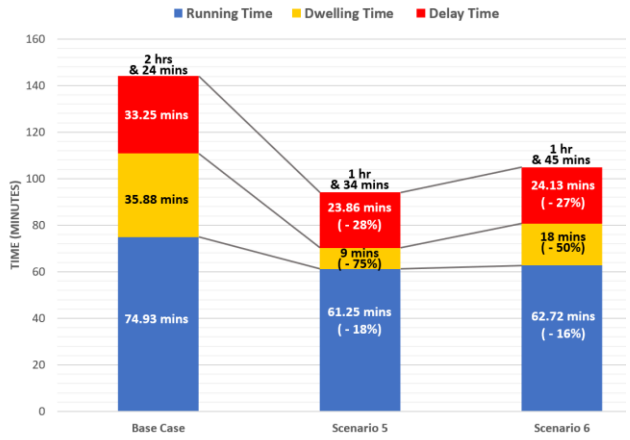

Figure 31. Comparison of Total Travel Time under the Provision of Passing Lanes, Headway and Dwell Time Strategy (Northbound - PM Peak)

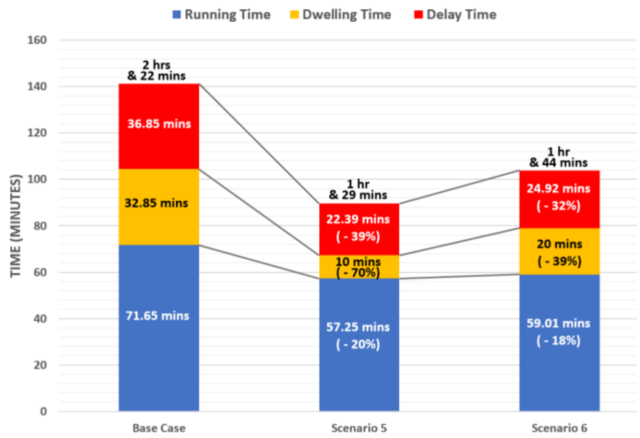

Figure 32. Comparison of Total Travel Time under the Provision of Passing Lanes, Headway and Dwell Time Strategy (Southbound - AM Peak)

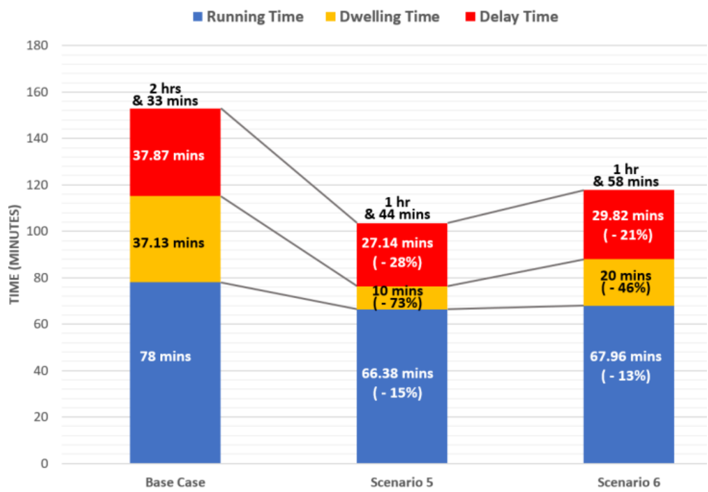

Figure 33. Comparison of Total Travel Time under the Provision of Passing Lanes, Headway and Dwell Time Strategy (Southbound - PM Peak)

In conclusion, the combination of optimized dwell times, strategic headway management, and dedicated infrastructure such as overtaking lanes proves effective in significantly reducing both dwell and delay times, thereby enhancing overall transit efficiency and service reliability.

Figure 34 and Figure 35 present a comparative analysis of bus speeds under various scenarios during the AM and PM peak periods on the EDSA Busway. During the AM and PM Peak, Scenario 5 demonstrates the highest improvement, more than doubling the speed of base case scenario, which implies effective interventions. Scenario 6 also shows significant improvement but slightly lower than Scenario 5. With overtaking lanes, slower buses or stopped buses can be bypassed by other buses, preventing bus bunching and maintaining a smoother flow of traffic, thereby reducing delays. It also allows faster buses to maintain their optimal speed rather than being forced to match the speed of slower buses.

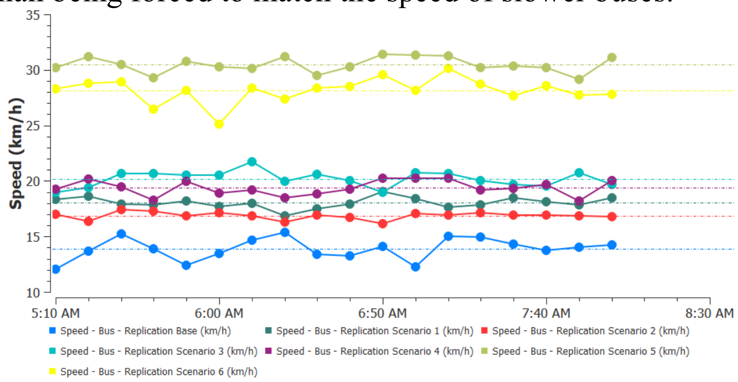

Figure 34. Comparison of Travel Speeds of Buses for the Different Scenarios (AM Peak)

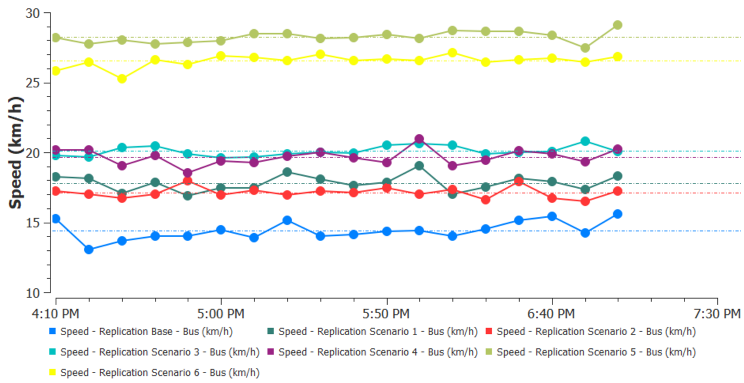

Figure 35. Comparison of Travel Speeds of Buses for the Different Scenarios (PM Peak)

The fuel economy used has a value of 3.6 km/L for a diesel bus, which was derived from a local study by Clean Air Asia (2012). The actual fuel efficiency is 4.38 km/L during the AM Peak and 3.85 km/L during the PM Peak, while the simulated base case fuel efficiencies are 4.77 km/L for the AM Peak and 4.12 km/L for the PM Peak. The percent differences between the actual and simulated fuel efficiencies are 8.90% and 7.01% for the AM and PM Peak periods, respectively.

Figure 36 illustrates the fuel efficiency for AM and PM peak periods using a dwell time strategy of 30 seconds (Scenario 1) and 60 seconds (Scenario 2). Scenario 1 shows a 3.56% increase in AM peak fuel efficiency and a 6.31% increase in PM peak fuel efficiency compared to the base case. Scenario 2 shows a 2.72% increase in AM peak fuel efficiency and a 7.28% increase in PM peak fuel efficiency compared to the base case. Overall, Scenario 1 shows a marginally better fuel efficiency in the AM peak, whereas Scenario 2 shows a slightly improved efficiency in the PM peak compared to Scenario 1.

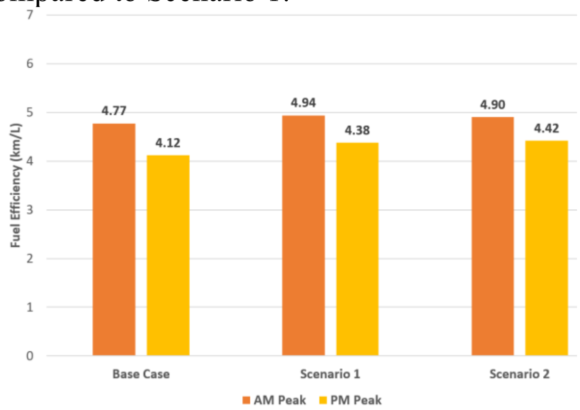

Figure 36. Comparison of Fuel Efficiency under Dwell Time Strategy

The fuel efficiency using headway and dwell time strategy is presented in Figure 37. Scenario 3, with a 30-second dwell time per bus station and a 60-second headway, shows an increase to 5.59 km/L in the AM peak (17.18% increase) and 4.20 km/L in the PM peak (1.94% increase). Scenario 4, with a 60-second dwell time per bus station and a 60-second headway, further improves fuel efficiency to 5.77 km/L in the AM peak (20.96% increase) and 4.28 km/L in the PM peak (3.88% increase). This comparison indicates that longer dwell times, coupled with a 60-second headway, result in higher fuel efficiency, particularly in the AM peak period.

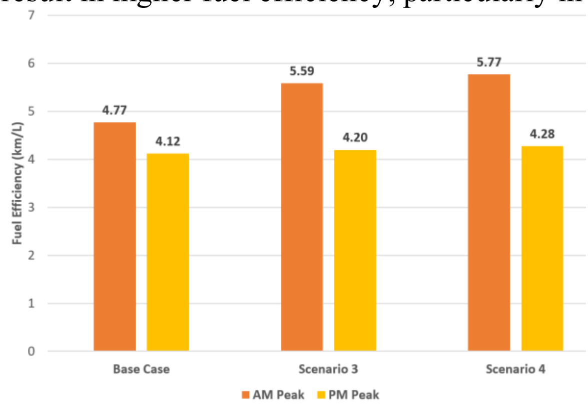

Figure 37. Comparison of Fuel Efficiency under Headway and Dwell Time Strategy

Figure 38 demonstrates the impact of passing lanes, headway, and varying dwell times on fuel efficiency. Scenario 5, which includes the provision of passing lanes, a 30-second dwell time per bus station, and a 60-second headway, fuel efficiency increases to 6.05 km/L in the AM peak (26.81% increase) and 5.07 km/L in the PM peak (23.05% increase). Scenario 6, with the provision of passing lanes, a 60-second dwell time per bus station, and a 60-second headway, results in fuel efficiency of 5.95 km/L in the AM peak (24.74% increase) and 4.73 km/L in the PM peak (14.81% increase).

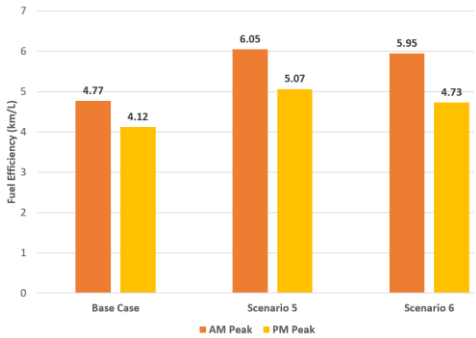

Figure 38. Comparison of Fuel Efficiency under the Provision of Passing Lanes, Headway and Dwell Time Strategy

AIMSUN can simulate pollutant emissions for buses within the model. Emissions are evaluated for each vehicle at each simulation time step based on the vehicle's state (idling, cruising, accelerating, or decelerating), speed, and distance traveled. The analysis considers up to four major pollutants: carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), and unburned hydrocarbons (HC), which are the most commonly produced pollutants. AIMSUN only considers the four major pollutants and does not model particulate matter (PM) and sulfur oxides (SO_x) due to their complexity in the context of traffic simulation, where real-time or near real-time data integration is crucial. Modeling PM and SO_x requires more detailed input on the vehicle's state (idling, cruising, accelerating, or decelerating) and sophisticated algorithms, which are not readily available in the software.

Table 8 and Table 9 enumerates the emission rates and local emission factors of buses used in the estimation of emissions.

Table 8. Emission Rates

Pollutant	**Idling Emission Rate**	**Acceleration Emission Rate**	**Deceleration Emission Rate**
	g/s		
HC	0.0383	0.02	0.0067
CO	0.05	0.377	0.072
NO_x	0.005	0.01	0.0005

Source: AIMSUN Manual, 2010

Table 9. Emission Factors

Speed	*g/veh-km*			*gCO_2e/km*
	Hydro-carbons (HC)	**Carbon Monoxide (CO)**	**Nitrogen Oxide (NO_x)**	**Carbon Dioxide (CO_2)**
10 - 20 kph	3.7	12.4	12.5	1097
greater than 20 kph	3.4	11.3	10.9	

Source: Emission Factors such as HC, CO, and NO_x were adapted from Vergel and Tiglao (2013) and CO_2 emission factors from Transport and Traffic Planners, Inc. and CPI Energy Phils. Inc. (2010)

Figure 39 illustrates the CO emissions of buses under the dwell time strategy. Scenario 1 shows a marginally better reduction in CO emission in the AM peak and PM peak, whereas Scenario 2 shows a slightly reduction in CO emission compared to Base Case. Figure 40 shows the CO emissions using the headway and dwell time strategy. In this scenario, Scenario 4 achieved a significant reduction in CO emissions while Scenario 3 achieved nearly a 50% reduction in CO emissions compared to the Base Case. Meanwhile, Figure 41 presents the CO emissions using the provision of passing lanes, headway and dwell time strategy. Both Scenario 5 and Scenario 6 significantly reduce CO emissions during both AM and PM peak periods compared to the Base Case. While both scenarios provide passing lanes and maintain a 60-second headway, the reduced dwell time in Scenario 5 allows buses to spend less time idling at stops, which contributes to lower CO emissions.

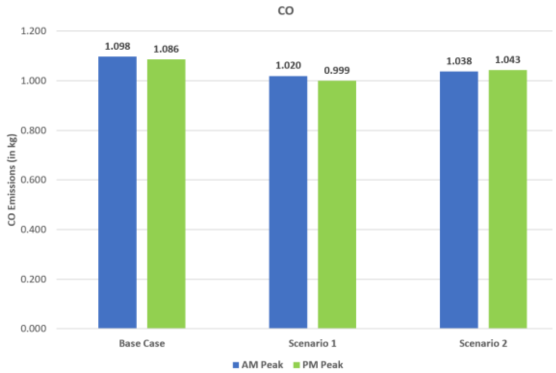

Figure 39. Comparison of CO Emissions under Dwell Time Strategy

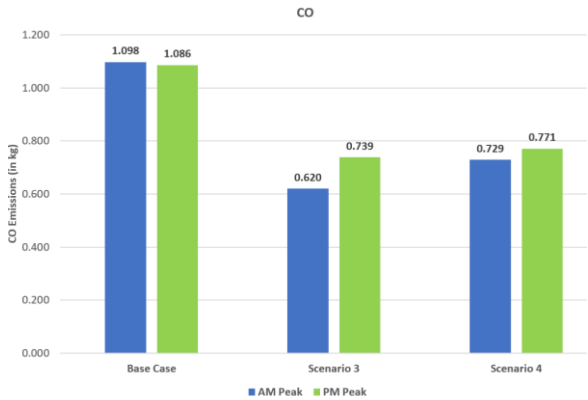

Figure 40. Comparison of CO Emissions under Headway and Dwell Time Strategy

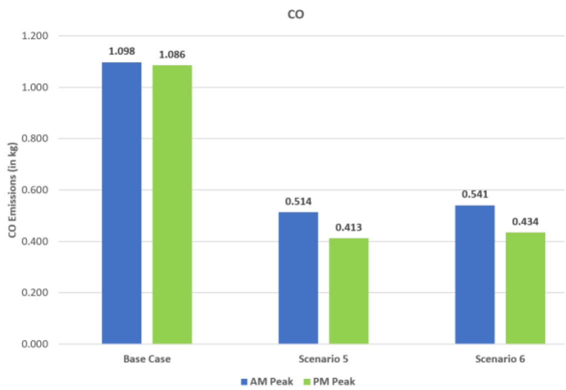

Figure 41. Comparison of CO Emissions under the Provision of Passing Lanes, Headway and Dwell Time Strategy

Figure 42 illustrates the NO_x emissions under the dwell time strategy. Both Scenario 1 and Scenario 2 exhibit slightly lower NO_x emissions compared to the base case. The PM Peak NO_x levels for Scenario 1 and Scenario 2 are the same. Implementing a 30-second and 60-second dwell times per station results in only a minor reduction in NO_x emissions. The comparison of NO_x emissions under the headway and dwell time strategy is presented in Figure 43. Scenario 3, with a shorter dwell time achieves lower NO_x emissions than Scenario 4 during both AM and PM peaks. Reduced dwell times translate to less idling at stops, thereby contributing to lower emissions. Figure 44 provides the comparison of NO_x emissions under the provision of passing lanes, headway, and dwell time strategy. Scenario 5 achieves the lowest emissions among the presented scenarios, indicating that the combination of passing lanes and a shorter dwell time can effectively minimize NO_x emissions.

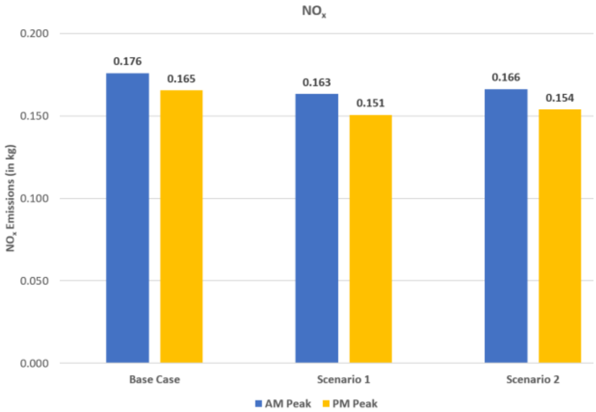

Figure 42. Comparison of NO_x Emissions under Dwell Time Strategy

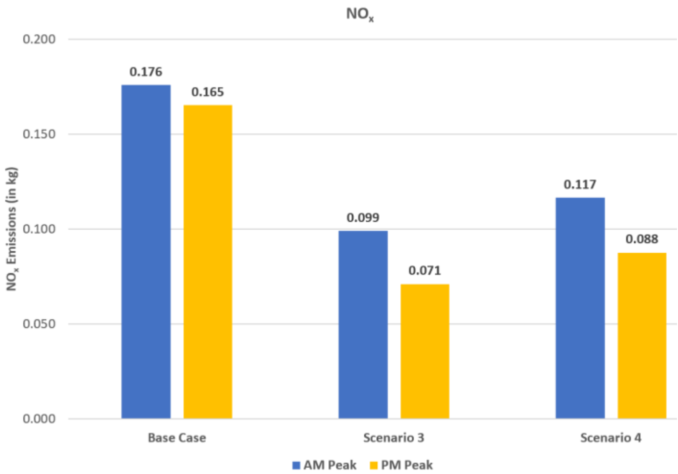

Figure 43. Comparison of NO_x Emissions under Headway and Dwell Time Strategy

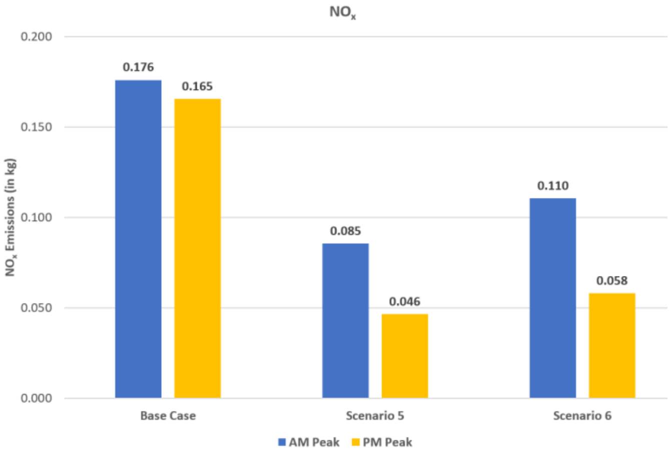

Figure 44. Comparison of NO_x Emissions under the Provision of Passing Lanes, Headway and Dwell Time Strategy

Figure 45 presents the HC emissions under the dwell time strategy. Both Scenario 1 and Scenario 2 demonstrate almost the same HC emissions. Implementing a 30-second and 60-second dwell times per station results in slight reduction in HC emissions. The comparison of HC emissions under the headway and dwell time strategy is presented in Figure 46. Scenario 3, with a shorter dwell time achieves lower HC emissions than Scenario 4 during both AM and PM peaks. Figure 47 presents the comparison of HC emissions under the provision of passing lanes, headway, and dwell time strategy. Scenario 5 achieves the lowest HC emissions among the presented scenarios, demonstrating that the combination of passing lanes and shorter dwell times can effectively minimize HC emissions.

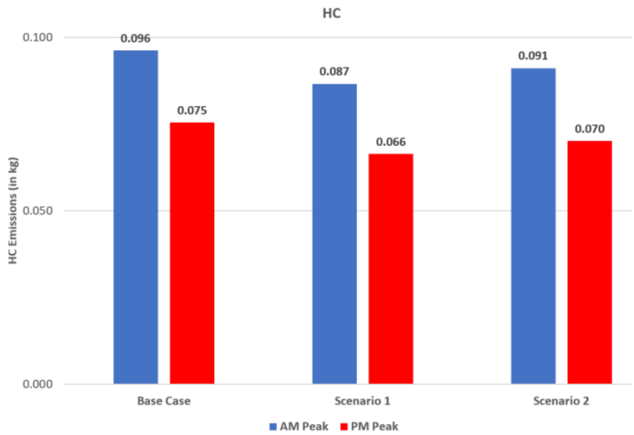

Figure 45. Comparison of HC Emissions under Dwell Time Strategy

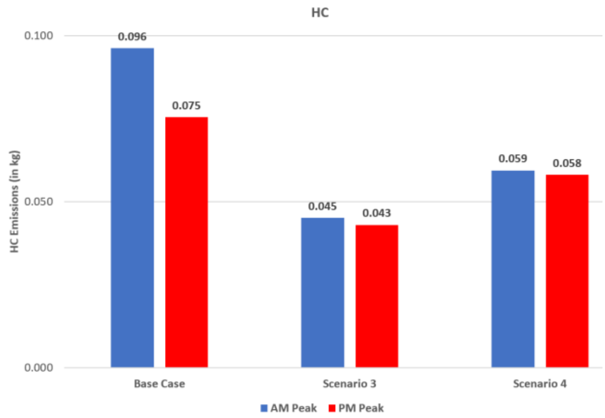

Figure 46. Comparison of HC Emissions under Headway and Dwell Time Strategy

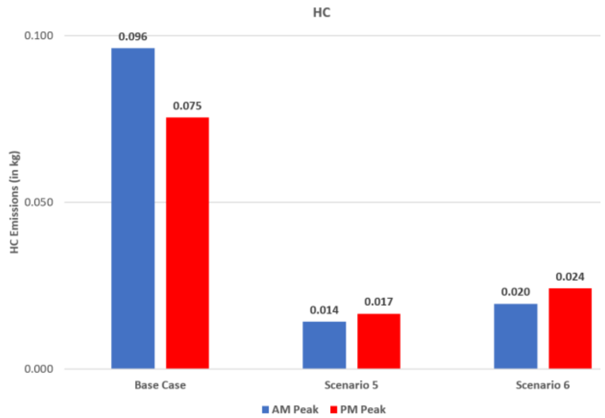

Figure 47. Comparison of HC Emissions under the Provision of Passing Lanes, Headway and Dwell Time Strategy

The summary of the percent reduction in pollutant emissions is presented in Table 10. Based on the results, Scenario 1 shows modest reductions (7% for CO and NOx, 10% for HC), while Scenario 2 shows slightly smaller reductions. Scenario 3 and Scenario 4 have more significant reductions, particularly in CO and NOx emissions. The highest reductions are seen in Scenarios 5 and 6, especially in HC emissions, which are reduced by up to 85% during AM Peak. For the PM peak, Scenario 1 shows moderate reductions across all three pollutants. Scenario 2 shows slightly smaller reductions. Scenario 3 achieves more significant reductions, indicating a substantial improvement in emission control. Scenario 4 also demonstrates notable reductions, though slightly less than Scenario 3. The most substantial reductions are seen in Scenarios 5 and 6, with Scenario 5 achieving the highest overall reductions, closely followed by Scenario 6.

Table 10. Change in Pollutant Emissions of Each Scenario Compared to Base Case

AM Peak	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
CO	-7%	-5%	-44%	-34%	-53%	-51%
NOx	-7%	-6%	-44%	-34%	-51%	-37%
HC	-10%	-5%	-53%	-38%	-85%	-80%
PM Peak	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
CO	-8%	-4%	-32%	-29%	-62%	-60%
NOx	-9%	-7%	-57%	-47%	-72%	-65%
HC	-12%	-7%	-43%	-23%	-78%	-68%

Figure 48 shows the CO_2 emissions during AM and PM peak under the dwell time strategy. Based on the results, Scenario 1 shows a significant reduction in CO_2 emissions compared to the base case, with PM peak emissions slightly higher than AM Peak. While, Scenario 2 demonstrates lower CO_2 emissions. This comparison suggests that increasing the dwell time per station from 30 to 60 seconds can significantly reduce CO_2 emissions during both peak hours.

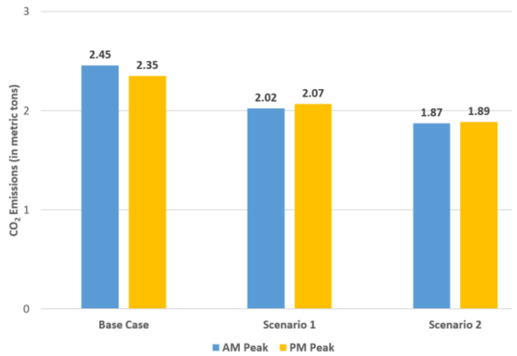

Figure 48. Comparison of CO_2 Emissions under Dwell Time Strategy

Figure 49 presents the CO_2 emissions during AM and PM peak under the headway and dwell time strategy. Both Scenario 3 and 4 significantly reduce CO_2 emissions compared to the Base Case. Scenario 4, which involves a 60-second dwell time and a 60-second headway, is the most effective in reducing emissions, achieving the lowest CO_2 emissions under the headway and dwell time strategy.

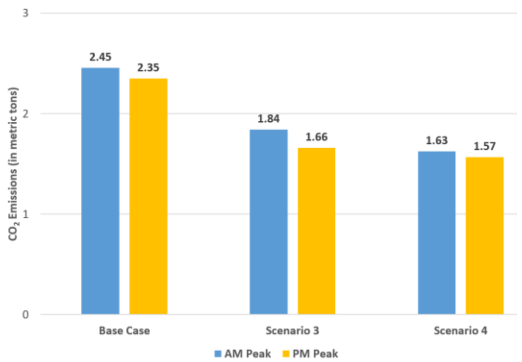

Figure 49. Comparison of CO_2 Emissions under Headway and Dwell Time Strategy

Figure 50 illustrates the CO_2 emissions during AM and PM peak under the provision of passing lanes, headway, and dwell time strategy. Scenario 5 demonstrates a significant reduction in CO_2 emissions as compared to the base case. Scenario 6 also provides substantial reductions in emissions but is less effective than Scenario 5. The provision of passing lanes combined with a shorter dwell time and headway (Scenario 5) yields the lowest in CO_2 emissions.

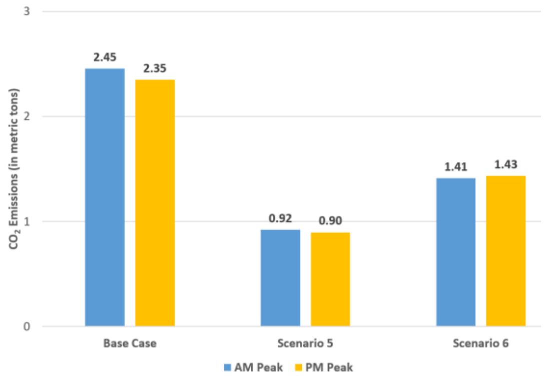

Figure 50. Comparison of CO_2 Emissions under the Provision of Passing Lanes, Headway and Dwell Time Strategy

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

This study demonstrated the effective utilization of the mobile crowdsourcing application, *SafeTravelPH*, for gathering and analyzing real-time data on bus arrival at transit stops, boarding and alighting patterns, and various public transport operational parameters. Moreover, this study showcased the use of traffic simulation tool, AIMSUN, in simulating actual bus conditions and conduct scenario analysis aimed at enhancing the EDSA Busway network performance.

Considering bus travel times, dwell times, and delay times, the implementation of a 30-second dwell time demonstrates substantial improvements in transit efficiency. Moreover, incorporating a 60-second headway strategy further enhances these benefits.

The inclusion of overtaking lanes within the exclusive bus lane facilitates faster buses to pass slower or stopped buses without interruptions, while also enabling smoother maneuvering for all buses. This smoother operation aids in maintaining optimal speeds more consistently, which, in turn, enhances fuel efficiency compared to the frequent, abrupt starts and stops common in bus queues. This not only reduces the dwell time and delay of buses but also decreases pollutant emissions.

6.2 Potential Implications for Transport Planning and Public Policy

The results of this study provide highlights on the effectiveness of targeted interventions such as dwell time optimization, headway strategy, and provision of overtaking lanes for buses in improving EDSA Busway network performance.

The inefficient implementation of the bus timers at EDSA stations exacerbates the issue by causing buses to stay for extended periods, resulting in longer passenger waiting times. Instead of streamlining the boarding and alighting process, these flawed timers inadvertently contribute to congestion and delays. This inefficiency not only frustrates commuters but also undermines the intended goal of the EDSA busway system. While the deployment of bus timers across multiple stations along the EDSA Busway aims to standardize passenger boarding and alighting procedures, it is imperative to recalibrate the 30-second duration limit according to the optimal bus dwell time. This should reduce the extended time of buses at certain stations to fill with passengers and also to minimize passenger waiting times. Additionally, monitoring mechanisms should be put in place to identify stations experiencing prolonged bus stays, allowing for timely interventions to minimize delay time.

Right-facing doors disrupt the efficient flow of passengers and slow down the boarding and alighting process. Boarding passengers must wait for all alighting passengers to safely exit the bus before entering, which prolongs dwell times at stations. Introducing left-facing doors would align the bus properly with the platform layout and provide separate entry and exit points, thereby improving passenger flow efficiency and reducing delays at stations. Additionally, station infrastructure should be redesigned to accommodate theses buses with clear signage and physical barriers to guide passenger movement. This could be complemented by policy measures such as mandating the use of left-facing doors on all new buses operating on the EDSA Busway and retrofitting existing buses to meet the new standard.

During the operation of the EDSA Busway in 2021, the LTFRB acquired the Central Public Utility Vehicle Monitoring System (CPUVMS). This system aims to standardize the daily monitoring of buses through GPS tracking. However, due to poor execution in enforcing the GPS installation policy, the LTFRB reverted back to manual monitoring of buses. As a policy recommendation, the use of the SafeTravel App for tracking buses is highly recommended. The app has features to monitor the exact location of buses and track the number of passengers boarding and alighting at each station. This system is crucial for determining bus demand and optimizing operations, addressing the lack of real-time transit information and improving the management of route-based fleets.

At end stations of the EDSA Busway, specifically PITX station, there is a problem with how buses are dispatched because two different consortiums are responsible. This leads to delays because both consortia take longer to dispatch buses, resulting in long queues of passengers. The confusion arises from passengers not knowing which consortium's bus to board at specific bays, and there's also uncertainty about how many passengers each bus should take. The competition between these consortia makes the situation worse by causing inconsistencies in the timing of buses. To address this, a centralized dispatch system is needed to streamline the process and ensure uniformity in dispatching procedures. This involves establishing standardized operating procedures for both consortiums to follow, including clear guidelines on bus dispatching intervals, passenger boarding processes, and bus loading capacities. Additionally, mechanisms should be established to monitor compliance with dispatching protocols and to enforce penalties or incentives based on performance metrics such as queue lengths, passenger waiting times, and adherence to dispatching schedules.

Institutionalizing data systems should also take precedence. This entails establishing mechanisms for monitoring both the demand and supply of EDSA bus services. By having reliable data systems in place, authorities can better understand the transportation needs of the commuting public and adjust their planning and management strategies accordingly.

These findings serve as a call to action for urban planners, transport authorities, and policymakers involved in the EDSA Busway transport operations to leverage data-driven decision-making and to align transport planning with operational needs.

6.3 Recommendations for Future Work

Continuing the research, it would be valuable to delve into the development of dwell time models specifically tailored for the EDSA Busway stations. This entails examining the intricate relationship between bus dwell time and pertinent factors, such as the volume of passengers boarding and alighting, door width configuration, the strategic placement of doors on the left side of buses to align with existing platform layouts. By comprehensively understanding these dynamics, researchers can devise more accurate and effective strategies to reduce dwell times.

Future research should also focus on the impact of a fully exclusive bus lane on EDSA compared to the current condition, wherein there are still portions operating in mixed traffic.

This research should encompass assessments of traffic flow, congestion, and analysis of environmental benefits.

Future research can focus on utilizing other traffic simulation tools that analyze public transport operational performance results for each transit stop along the EDSA Busway since this study only considers the end-to-end results. In this way, this would offer a more detailed understanding of service quality and potential areas of improvement.

The application of artificial intelligence will be a key area of focus for future research on bus transit priority strategies. Through AI, researchers can develop dwell time models that would analyze various factors such as passenger boarding and alighting times, and bus stop characteristics to accurately predict and minimize bus stop delays. Additionally, integrating AI with real-time data could enhance adaptive signal control systems, allowing for dynamic adjustments to traffic signals based on bus locations and predicted arrival times. This approach can reduce delays experienced by buses at segments with U-turn slots where mixed traffic affects the exclusive bus lane.

Another area with significant potential for future research includes incorporating metrics that focus on commuters' experiences. This involves passenger waiting times, crowding levels at station platforms, and accessibility. By integrating these user-centric metrics into the analysis, researchers can gain valuable insights from the perspective of the commuters. Additionally, understanding the accessibility of the EDSA Busway system for different demographics can aid in designing a more inclusive and equitable public transportation system. In essence, focusing on commuters' experiences in future research endeavors has the potential to enhance the operational performance of the EDSA Busway, aligning it more closely with the needs of commuters.

7. ACKNOWLEDGEMENTS

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