Simulation of Bicycle Infrastructure Along Padre Faura Street in Manila Using Simulation of Urban Mobility (SUMO)

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***Abstract*: Manila has seen a surge in cycling since COVID-19 caused a great deal around the world. City dwellers resort to different means of transportation to minimize their contact with other commuters. Due to this factor, it aimed to simulate a bicycle infrastructure along Padre Faura Street in Manila to determine its effect on traffic speed and traffic congestion. This study used Simulation of Urban Mobility (SUMO) to simulate the intersections of Taft Avenue, Mabini Street, and del Pilar Street. Twelve models were developed consisting of the current traffic situation and simulation with bicycle lanes both in morning and evening peak hours. They were validated using Geoffrey E. Havers (GEH) Values. Vehicle count, speed, and other parameters were collected manually using a video camera, and the area of study was selected using the OSM Web Wizard Application. The results indicated that the demand for cyclists during evening peak hours (4:00-7:00 PM) was much higher, especially on Sunday, Monday, and Tuesday. The calculated level of service ranges from B-C, showing a free-flowing to the moderate traffic situation, which would make implementing bicycle infrastructure possible. Although the traffic density may affect the vehicular speed, the results may vary depending on other factors that may be considered. Results presented that all three intersections showed an improvement in average vehicular speed during morning peak hours and only in the intersections of Taft Avenue and Mabini Street during evening peak hours.**

***Keywords:* Bicycle Infrastructure, Simulation of Urban Mobility (SUMO), Level of Service, Geoffrey E. Havers (GEH)**

I. INTRODUCTION

City dwellers around the world turned their means of transportation to bicycles because of the increasing number of Coronavirus Disease (COVID-19) cases. For the city of Manila, the Philippine capital, it meant keeping up with the notoriously bad traffic. The surge in cycling is not a wonder since the city has several cases of infection and is one of the countries with the worst urban congestion [1]. But cycling in one of the most congested urban places in the country is not as peaceful and comfortable as the public would like. Last February 2019, several cycling advocates called on the government to build exclusive bike lanes for up to 190 miles to protect aggressive riders and larger vehicles such as cars and trucks [2].

As most families find themselves in the comfort of their respective homes, this time also saw the boom for food-delivery apps such as Grab and Foodpanda. Along with this is the increase in delivery riders using bicycles as their means of transportation. As an initiative by the City of Manila, the Manila City mayor and Foodpanda PH director, on June 9, 2021, signed an agreement for a program called “pandaBIZikleta” to give bicycles and safety gears to the first 30 beneficiaries of the program as well as hire them as Foodpanda freelance riders [3].

According to the Metro Manila Accident Reporting and Analysis System (MMARAS) 2020 Annual Report, bike, e-bike, and pedicabs have a total of 3,026 cases involved in an accident, thirty-six of which were fatal. The report from 2019 with 1,759 cases states that side sweeps caused most bicycle-related road crashes. It shows that for the past years, with an increasing number of cyclists, road safety and the issue of bicycle infrastructures should be prioritized.

To establish the solution for the problems concerning the safety and orderliness of the pedestrians, cyclists, and motorists, the goal to model and simulate a bicycle infrastructure will be possible using a micro traffic simulator. Simulation of Urban Mobility (SUMO) helps investigate route choice, traffic light algorithm, and simulating communication of vehicles [4]. It is an open-access software that supports the traffic simulation community where its algorithms can be applied.

It was considered using Padre Faura Street as the road segment for the study because they passed along the road section when going to school and back home before the pandemic. After observing that many cyclists use the street to get to nearby establishments, particularly during rush hours, the entire section of Padre Faura Street was chosen to design a model of bicycle infrastructure. The said study area is about 1.2 kilometers long and 9 meters wide; that is a three-lane one-way west-bound street with its starting point from Paco Park in the district of Paco towards the intersection of Taft Avenue and exits through Roxas Boulevard in the district of

Ermita. This bicycle infrastructure will connect to other bicycle infrastructure on Taft Avenue and Roxas Boulevard, which are considered main roads in Manila.

The increased use of bicycles due to the rising number of COVID-19 cases and its contribution to traffic congestion and travel time delays without entire infrastructure allowed to come up with a solution. This study aimed to design a bicycle infrastructure along Padre Faura Street and to determine its potential effect on the traffic congestion in the area. The number of cyclists in the study area, the traffic situation, the speed and density of vehicles, and the impact of the exclusive bicycle lane were used to determine the overall potential effect of the exclusive bicycle lane.

The study is about developing a designed bicycle lane along Padre Faura Street, as well as simulating the traffic condition before and after. This intends to solve the need for bicycle facilities in the City of Manila and ease the traffic congestion affecting the area. Also, to determine whether there is a difference in traffic congestion with and without the presence of bicycle infrastructure. This study will be of utmost importance to the people, especially the planner or designers and cyclists, since it will bring them understanding and knowledge about the importance and relevance of bicycle infrastructure, especially in urban areas. This study will also benefit motorists, pedestrians, and future researchers.

This study focused on simulating an appropriate bike lane along Padre Faura Street with a length of approximately 1.2 km and a width of 9 meters. The portion of the street considered in collecting data such as vehicle count, vehicle speed, and other parameters is limited to its intersection in Taft Avenue, A. Mabini Street, and M. H. del Pilar Street.

Collecting data was done on-site by counting the number of vehicles traveling along the street. The Manual Classified Traffic Count of DPWH - National Road Traffic Survey Program Manual Version 2002-A was used. Identification of traffic conditions and the number of cyclists in the study area was limited to a 7-day (Saturday to Friday) survey during the morning peak hours, 7:00-10:00 AM, and evening peak hours, 4:00-7:00 PM.

Other factors affecting traffic conditions such as the psychological behavior of drivers and cyclists, road conditions, ongoing maintenance or construction, and the volume of pedestrians seen within the study area were not included because it is beyond the resources and capabilities. Due to some irregularities and health protocols given by the Philippine government because of the Covid-19 pandemic, there was limited access to data such as vehicle count.

From the Department Order No. 88 Series of 2020, the type of bicycle infrastructure designed is Class II, the Separated Bike Lane using Pavement Markings or Physical Separation. Class III, the Shared Roadway, was not considered in the study. Application and determination of the effects of the bike infrastructure were made through simulation of the traffic flow without and after the insertion of the bicycle infrastructure using the software Simulation of Urban Mobility (SUMO) version 1.12.0 licensed under Eclipse Public License version 2.0 (EPLv2). OpenStreetMap was used for importing the traffic network of and surrounding Padre Faura Street to SUMO. Python programming version 3.10.0 was used to assist the process of simulation. The infrastructure design was based on the Guidelines on the Design of Bicycle Facilities Along National Roads of the Department of Public Works and Highways (DPWH). The simulation of bicycle infrastructure was designed on the right side of the road since the SUMO is limited to only one side of a road.

II. METHODOLOGY

To provide a more specified framework that is inclined in the study, specifically the development of bicycle infrastructure, a framework was developed, as shown in Figure 1.1. Through a series of collection of necessary data for simulation, an effect of an exclusive bicycle lane on the traffic congestion along Padre Faura Street can be determined. Data collection was done to determine the traffic situation in the study area and to be able to ensure the feasibility of such a project. The bicycle infrastructure design was based on the guidelines provided by a different government agency, so this study could become their basis for establishing and maintaining a bicycle infrastructure. The Geoffrey E. Havers Statistics was used to determine the accuracy of the simulation to the data collected from the present condition, thus validating the fitness of values. By using SUMO, an open-source software helpful in simulating different traffic networks. Simulation of bicycle infrastructure with and without bicycle infrastructure was done to determine the potential effect it has on the average speed, flow, density, and traffic congestion in the selected road section. It also determines whether a bicycle lane will be helpful to commuters, private vehicle drivers, pedestrians, and cyclists.

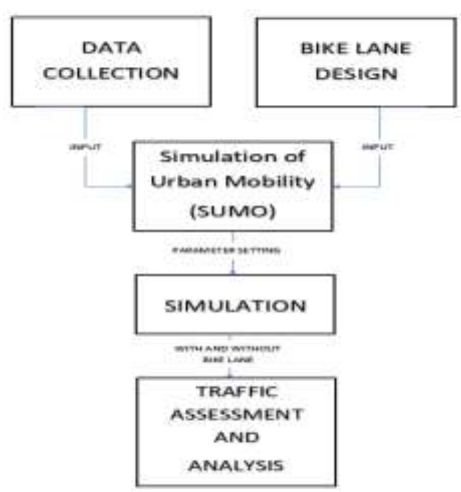

Figure 1.1 Bicycle Infrastructure Design Impact on Traffic Congestion

The demand on the cyclists proved the need to establish an exclusive lane for them. To do these, different factors must be considered to determine their effect on them, and all the motorists and pedestrians were crossing and traveling along the study area. Numerous studies evaluated the interactions between bicycles and vehicles, especially at intersections.

To develop a methodology that allows interdisciplinary research problems like the impact of a vehicular system on traffic flow or the traffic scenarios that a newly designed vehicular system must deal with to be investigated, the ideal and typical workflow developed was adopted, shown in Figure 1.2 [5]. The development of bicycle infrastructures through microscopic simulation allows determining its impact on traffic congestion until it resolves the research problem arising in the study.

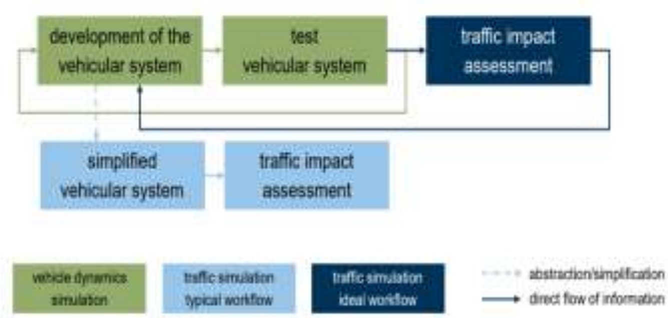

Figure 1.2 Vehicular systems' impact on traffic flow

Source: Adopted from Kaths and Krause (2016)

Equations

a. Traffic Flow

Based on the fundamental traffic flow theory, the relationship between flow, speed, and density is:

$$q = k \times v \qquad \text{Equation (1.1)}$$

Where q = traffic flow

k = vehicle density

v = vehicle speed

b. Passenger Car Unit

The formula for PCU allows to determine the given passenger car equivalent factor [6].

$$PCU = volume \times PCEF \qquad \text{Equation (1.2)}$$

Where volume = number of vehicles per time

PCEF = passenger car equivalent factor

c. Volume Capacity Ratio

Volume capacity measures the congestion level on a roadway by diving the volume traffic to the roadway capacity. VCR is used to determine the level of service of the road [7].

$$VCR = volume/capacity \qquad \text{Equation (1.3)}$$

d. Geoffrey E. Havers Statistics

The traffic volumes or speed may be compared to determine the precision of the observed and simulated data called GEH or Geoffrey E. Havers Statistics.

$$GEH = \sqrt{\frac{2(M-C)^2}{(M+C)}} \qquad \text{Equation (1.4)}$$

Where, M = Simulated Traffic Volume

C = Observed Traffic Volume

e. Linear Regression Analysis

Linear Regression determines the relationship of one dependent and independent variables and has the form of equation into

$$y = a + bx \qquad \text{Equation (1.5)}$$

$$b = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{n\Sigma x^2 - (\Sigma x)^2} \qquad \text{Equation (1.6)}$$

$$a = \frac{\Sigma y - b(\Sigma x)}{n} \qquad \text{Equation (1.7)}$$

Where, y = dependent variable

a = y-intercept

b = slope of the line

x = independent variable

f. Percent Difference

Percent difference is used to determine the numerical comparison between two values to each other. It can be calculated into the equations below [8].

$$\%\, difference = \frac{a-b}{a} * 100 \qquad \text{Equation (1.8)}$$

$$\%\, difference = \frac{a-b}{b} * 100 \qquad \text{Equation (1.9)}$$

$$\%\, difference = \frac{a-b}{\frac{a+b}{2}} * 100 \qquad \text{Equation (1.10)}$$

Research Design

The study used an observational research design where data for the traffic situation within the study area was gathered by manual observation. According to Methods & Applications of Observational Research, observational research is a method in which the subject is being observed and analyzed in their real-world setting. Observational research is used whenever data collection procedures are not effective and adequate. It is also used when the purpose of the study is to evaluate the ongoing behavior process, situation, or event. This study aimed to assess the traffic situation of the study area if an exclusive bicycle lane is implemented compared to its current situation.

Research Locale

The busy street of Padre Faura, a one-way directional three-lane road section with a total length of about 1.2 kilometers and a width of 9 meters, was considered. The portion of the street, such as intersections in Taft Avenue, A. Mabini Street, and M. H. del Pilar Street, was considered in collecting data for the vehicle count, classification, speed, and other parameters.

Figure 1.3 Padre Faura Street

Data Collection

From a steady point of location using a video camera at the intersection of Padre Faura with Taft Avenue, A. Mabini Street, and M. H. del Pilar Street, manual traffic survey data were collected at 10-minute intervals for seven days (Saturday-Friday) to determine peak hour traffic flow from 7:00-10:00 AM and 4:00-7:00 PM. Vehicle count, classification, speed, and detailed network geometry will be acquired. The data to be collected will be inputted in the table adopted from National Road Traffic Survey Program Manual Version 2002-A. Using the data and the values provided in Department Order No. 22, the Level of Service in the study area was determined. These were used to determine and define the current traffic situation on Padre Faura Street.

Using Trap Length Method, the time was counted as the vehicles approached the beginning of the 50 m distance that was considered, then stopped counting on the stopwatch when they exited the finishing points of the marked test section. The average vehicle speed was calculated by dividing the 50 m distance by the time it travels along the area. From the Technology News, spot speed studies prefer a sample size minimum of 50 up to 100 vehicles to be obtained [9].

SUMO Calibration

Using the OSM Web Wizard Application, the study area was selected to be converted into a .xml format. The geometry and street topology of the area was acquired, and the set values will then be processed to build a configuration in SUMO. After importing the map, crosschecking of data acquired and the actual traffic condition could be done, such as the direction and number of vehicles for each lane.

Figure 1.4 Area selection in OSM Web Wizard

Analysis

A comprehensive comparison of graphs of speed versus density was compared between simulations with and without the presence of an exclusive bicycle lane. A SUMO .xml output for every simulation contains data about vehicle time, position, and velocity at every time step. Velocity at every step will be obtained, then the average of all vehicles in the simulation will be determined. An analysis of these will yield a speed versus density graph, which could be used to determine how velocity depends on density.

Using the Geoffrey E. Havers Statistic,

$$GEH = \sqrt{\frac{2(M-C)^2}{(M+C)}}$$

the simulations in the intersection were compared to the actual traffic flow. The data collected were tabulated below.

Table 1.1 GEH values at different intersections

Intersection	Actual veh/hr(M)	Simulated veh/hr(C)	Difference veh/hr (M-C)	% Difference	GEH
Taft Avenue	1125	1120	5	0.44	0.1493
	1165	1160	5	0.43	0.1466
A. Mabini Street	713	706	7	0.98	0.2628
	739	736	3	0.41	0.1105
M. H. del Pilar Street.	563	558	5	0.89	0.2112
	601	599	2	0.33	0.0816

Model Validation: <5 Good Fit; 5-10 Requires Further Investigation; >10 Poor Fit

All the values from the three intersections, both in morning and evening peak hours, have the GEH values ranging from 0.0816 to 0.2628 that are less than five, which indicates that the simulation is a good fit and has been well validated to be almost the same as the observed field condition.

Speed comparison in the three intersections was also done to determine the accuracy of the simulated traffic from the observed data and was tabulated in the following tables.

Table 1.2 Comparison of observed and simulated speed on Taft-P. Faura intersection

Vehicle type	**Actual (km/hr)**	**Simulated (km/hr) w/o Bicycle Lane**	**% Difference w/o Bicycle Lane**
Bicycle	17	10.36	39.06
	19	8.40	55.79
Motorcycle	25	21.82	12.72
	27	21.06	22
Passenger Car	22	23.51	-6.86
	27	22.23	17.67
Passenger Utility	20	20.13	-0.65
	25	18.85	24.6
Goods Utility	20	25.35	-26.75
	23	25.02	-8.78

Table 1.3 Comparison of observed and simulated speed on Mabini-P. Faura intersection

Vehicle type	**Actual (km/hr)**	**Simulated (km/hr) w/o Bicycle Lane**	**% Difference w/o Bicycle Lane**
Bicycle	18	15.55	13.61
	20	16.59	17.05
Motorcycle	26	31.50	-21.15
	30	30.52	-1.73
Passenger Car	24	34.07	-41.96
	27	30.87	-14.33
Passenger Utility	23	29.49	-28.22
	26	27.38	-5.31
Goods Utility	24	34.01	-41.71
	27	27.99	-3.67

Table 1.4 Comparison of observed and simulated speed on del Pilar-P. Faura intersection

Vehicle type	Actual (km/hr)	Simulated (km/hr) w/o Bicycle Lane	% Difference w/o Bicycle Lane
Bicycle	18	17.45	3.10
	20	17.49	13.39
Motorcycle	28	28.18	-0.64
	32	29.45	8.30
Passenger Car	27	33.43	-21.28
	30	36.01	-18.21
Passenger Utility	26	25.39	2.37
	30	24.28	21.08
Goods Utility	26	28.9	-10.56
	30	25.72	15.36

III. RESULTS AND DISCUSSION

a. Number of Cyclists

The distribution of the number of cyclists throughout seven days was shown in Figure 1.5 for the intersection of Taft Avenue and Padre Faura Street. It was observed that the average number of cyclists during the peak hours of 7:00-10:00 AM is around 67 cyclists per hour, while there are an average of 68 cyclists per hour during the peak hours of 4:00-7:00 PM. There is a noticeable peak in the number of cyclists on Sunday and the lowest number on Wednesday.

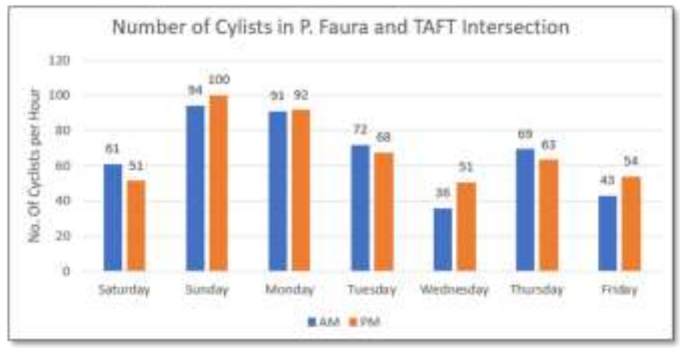

Figure 1.5 Number of Cyclists passing through the intersection of Taft Avenue and P. Faura Street

Figure 1.6 shows an average of 50 cyclists per hour that passes through the intersection of Mabini and Padre Faura Street during the peak hours of 7:00 AM – 10:00 AM, while the average for the afternoon peak hours is 58 cyclists per hour. It also showed that the highest number of cyclists during the morning peak hours is on Saturday with 61 cyclists per hour, and the lowest is on Thursday with 39 cyclists per hour. The afternoon peak hours' highest tally is on Tuesday with 65 cyclists per hour, and the lowest is on Saturday with 46 cyclists per hour.

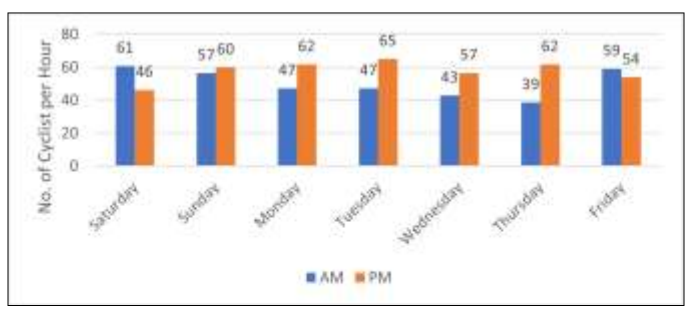

Figure 1.6 Number of Cyclists passing through the intersection of Mabini Street and P. Faura Street

During the morning peak hours, it was shown that the average number of cyclists passing through the intersection of Padre Faura Street and del Pilar Street are 50 cyclists per hour. From Figure 1.7, the volume was higher on Saturday, which is 66 cyclists per hour compared to the 33 cyclists per hour on Wednesday. On the other hand, the average number of cyclists from evening peak hours is 57 cyclists per hour. It can also be seen in the figure that there are more cyclists on Monday, which is 72 cyclists per hour, while there are only 36 cyclists per hour on Thursday.

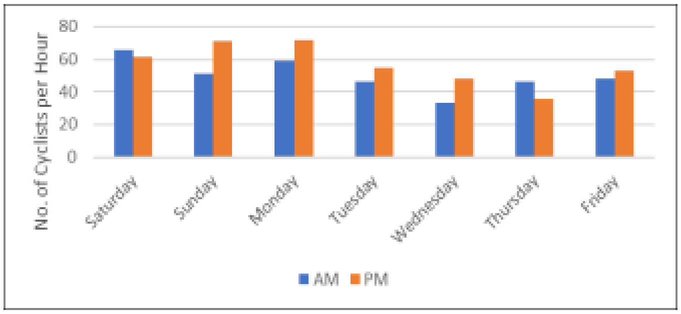

Figure 1.7 Number of Cyclists passing through the intersection of del Pilar Street and P. Faura Street

A street without a cycling facility records only 5.4 bicycles per hour [10]. The data gathered from the three intersections showed that the study area has a much higher demand for cyclists than the average.

This study reveals that establishing a bicycle infrastructure will be more convenient for them and allows the improvement of their time travel and speed. This study can be utilized by encouraging them to use the specified right of way that is or will be exclusively designed for them. Having a separate bike lane will allow them to not worry about involving and interfering with the other motorists.

b. Traffic Situation

In recent years, road capacity in Metro Manila has not improved much, leaving it unable to keep up with the tremendous increase in traffic volume [11]. But because of, the pandemic has caused significant changes in every aspect, one of which is in the transportation sector. Passenger Car Unit (PCU) and Volume-Capacity Ratio were calculated, and Table 1.5 determined the corresponding Level of Service (LOS) at the three intersections.

Table 1.5 Taft Avenue and P. Faura Street Intersection Level of Service

DAY	AM (7:00-10:10)			PM (4:00-7:10)		
	PCU	**VCR**	**LOS**	**PCU**	**VCR**	**LOS**
SATURDAY	1738.71	0.506	**B**	1989	0.58	**C**
SUNDAY	1269.86	0.37	**B**	1419	0.413	**B**
MONDAY	2775.43	0.808	**D**	2285	0.665	**C**
TUESDAY	2054.71	0.598	**C**	2132	0.621	**C**
WEDNESDAY	1845	0.537	**C**	1808	0.527	**C**
THURSDAY	1863.43	0.543	**C**	1864	0.543	**C**
FRIDAY	1504.29	0.438	**B**	1905	0.555	**C**

Table 1.5 shows the level of service at the intersection along Taft Avenue and Padre Faura Street. Notice that the highest level of service observed is on Monday, with a volume-capacity ratio of 0.808 in the morning and 0.665 in the evening. Most levels of service for the observed peak hours are levels B and C, which indicates free-flowing traffic to moderate traffic, with Sunday showing the minor volume-capacity ratio and PCU value.

Table 1.6 Mabini Street and P. Faura Street Intersection Level of Service

DAY	**AM (7:00-10:10)**			**PM (4:00-7:10)**		
	PCU	**VCR**	**LOS**	**PCU**	**VCR**	**LOS**
SATURDAY	778.29	0.227	**B**	904	0.263	**B**
SUNDAY	605.14	0.176	**A**	806	0.235	**B**
MONDAY	1346.14	0.392	**B**	1372	0.400	**B**
TUESDAY	1328.14	0.387	**B**	1305	0.380	**B**
WEDNESDAY	1274.57	0.371	**B**	1275	0.371	**B**
THURSDAY	1320	0.385	**B**	1320	0.385	**B**
FRIDAY	1336	0.389	**B**	1336	0.389	**B**

It can be seen in Table 1.6 that the level of service along the intersection of Mabini and Padre Faura Street is mostly level B which is relatively free-flowing traffic. The only time that the level of service is at level A is on Sunday during the morning peak hours, with a low volume-capacity ratio of 0.176. The highest PCU tallied is during Monday morning and afternoon, with a PCU value of 1346.14 and 1372, respectively. All level of service is at level B since the range of the V/C is from 0.227 to 0.44 aside from the one mentioned above.

Table 1.7 del Pilar Street and P. Faura Street Intersection Level of Service

DAY	**AM (7:00-10:10)**			**PM (4:00-7:10)**		
	PCU	**VCR**	**LOS**	**PCU**	**VCR**	**LOS**
SATURDAY	750.86	0.219	**B**	792.43	0.231	**B**
SUNDAY	471.83	0.137	**A**	643.29	0.187	**A**
MONDAY	1035.43	0.302	**B**	1195.71	0.348	**B**
TUESDAY	1018.29	0.297	**B**	956.14	0.278	**B**
WEDNESDAY	1014.43	0.295	**B**	976.71	0.284	**B**
THURSDAY	860.14	0.251	**B**	923.57	0.269	**B**
FRIDAY	930	0.271	**B**	1033.29	0.301	**B**

As presented in Table 1.7, the level of service is much higher on Monday morning and evening peak hours which is B with a volume-capacity ratio of 0.302 and 0.348, respectively. However, the level of service during Sunday, both in morning and evening peak hours, is A with a volume-capacity ratio of 0.137 and 0.187, respectively, indicating the free flow of traffic in the intersection. In comparison, the rest of the days have LOS of B, which have relatively free-flowing traffic with V/C ranging from 0.219-0.297 for morning peak hours and 0.231-0.301 for evening peak hours.

The data showed that Metro Manila's congestion level dropped to 53% in 2020 from 71% in 2019. The current pandemic significantly affects road capacity, especially in the country's capital. It supports the data on how the level of service in the study area, which is in Manila, only ranges from A-C and one D. One of the factors that also affect the current traffic situation in the area is that it is only a street where most that were passing through were small vehicles and only a few buses and trucks [12].

c. Simulation

Table 1.8 Comparison of average speed of all vehicles between simulations with and without bicycle lane (AM)

Intersection	Observed (km/hr)	Simulated (km/hr) (Without Bicycle Lane)	Simulated (km/hr) (With Bicycle Lane)	% Difference (Without Bicycle Lane)	% Difference (With Bicycle Lane)	Impact
Taft Avenue	21	20.236	21.985	3.64	-4.69	Improved
A. Mabini Street	27	28.93	29.12	-7.15	-7.85	Improved
M. H. del Pilar Street	30	26.67	26.78	14.286	6.897	Improved

Table 1.9 Comparison of average speed of all vehicles between simulations with and without bicycle lane (PM)

Intersection	Observed (km/hr)	Simulated (km/hr) (Without Bicycle Lane)	Simulated (km/hr) (With Bicycle Lane)	% Difference (Without Bicycle Lane)	% Difference (With Bicycle Lane)	Impact
Taft Avenue	24	19.11	21.494	20.38	10.44	Improved
A. Mabini Street	26	26.67	29.75	-2.58	-14.42	Improved
M. H. del Pilar Street	29	26.59	26.18	8.67	10.22	Reduced

As seen in Table 1.8, the traffic situation along the intersection of Taft Avenue and Padre Faura Street has improved in terms of average vehicle speed. The simulation shows an increase in average vehicle speed from the initial simulation without a bike lane and with a bike lane; the same result is shown in Table 1.9 for the said intersection. It suggests that the presence of a bike lane positively impacts the speed of vehicles traversing the intersection. The traffic situation at the intersection of del Pilar and P. Faura Streets showed an improvement in the average speed from 26.67 kph to 26.78 kph. It is considered that bike lanes help improve traffic flow and safety on city roadways. They also added that when the traffic flow of bicycles is large, some bicycles may run close to the vehicles or even run outside of the lane because it may not be able to accommodate the demand [13]. In this case, it may also affect the vehicular operation, and an increase in traffic delay may occur.

Table 1.10 Comparison of average speed of vehicle classes between simulations with and without bicycle lane in del Pilar – P. Faura intersection (AM)

Intersection	Observed (km/hr)	Simulated (km/hr) (Without Bicycle Lane)	Simulated (km/hr) (With Bicycle Lane)	% Difference (Without Bicycle Lane)	% Difference (With Bicycle Lane)	Impact
Bicycle	17.93	17.45	17.92	2.69	0.03	Improved
Motorcycle	28.36	28.18	26.72	0.64	5.94	Reduced
Passenger Car	26.57	33.43	32.99	-22.85	-21.56	Reduced
Passenger Utility	26.21	25.39	25.38	3.21	3.21	Reduced
Goods Utility	26.36	28.90	30.87	-9.21	-15.76	Improved

Table 1.10 showed that the average bicycle speed increased by 0.47 kph and goods utility by 1.97 kph. However, the average speed of the motorcycle, passenger cars, and passenger utility was reduced to 1.45 kph, 0.44, and 0.01 kph, respectively. Despite the reduced speed on other vehicles, the overall speed for the simulation was increased, but the improvement was much lower than the other two intersections.

Table 1.11 Comparison of average speed of vehicle classes between simulations with and without bicycle lane in del Pilar – P. Faura intersection (PM)

Intersection	Observed (km/hr)	Simulated (km/hr) (Without Bicycle Lane)	Simulated (km/hr) (With Bicycle Lane)	% Difference (Without Bicycle Lane)	% Difference (With Bicycle Lane)	Impact
Bicycle	20.14	17.49	17.19	14.12	15.83	Reduced
Motorcycle	32	29.45	28.48	8.31	11.64	Reduced
Passenger Car	30.29	36.01	34.62	-17.28	-13.34	Reduced
Passenger Utility	29.71	24.28	24.28	20.13	20.12	Maintained
Goods Utility	30	25.72	26.35	15.37	12.95	Improved

As shown in Figures 1.8.1 to 1.8.6, the average simulation speed of bicycles, motorcycles, and passenger cars decreased by 0.30, 0.97, and 1.39 kph, respectively. In comparison, the passenger utilities maintained their average speed of 24.28 kph, and the goods utilities showed an improvement of 0.63 kph.

Contrary to the results, while the volume of the vehicles remains the same, travel time in different streets studied decreases. Even if narrowing the lane widths or decreasing the lane, the results could maintain or even improve the travel time rather than causing a delay [14].

The figures below show the simulation done on SUMO and the proposed bicycle infrastructure design in Padre Faura Steet in Manila.

Figure 1.8.1 Simulation along Padre Faura Street and Taft Avenue intersection without bicycle lane

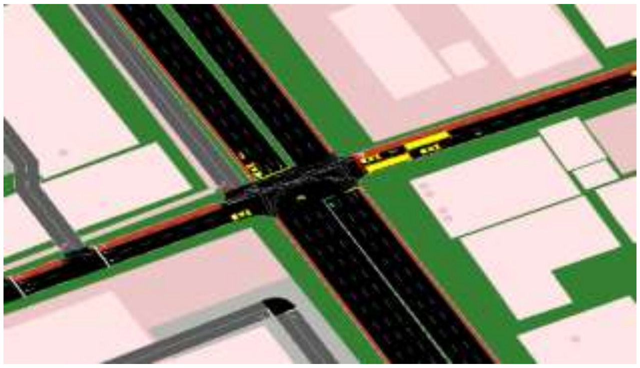

Figure 1.8.2 Simulation along Padre Faura Street and Taft Avenue intersection with bicycle lane

Figure 1.8.3 Simulation along Padre Faura Street and Mabini Street intersection without bicycle lane

Figure 1.8.4 Simulation along Padre Faura Street and Mabini Street intersection with bicycle lane

Figure 1.8.5 Simulation along Padre Faura Street and del Pilar Street intersection without bicycle lane

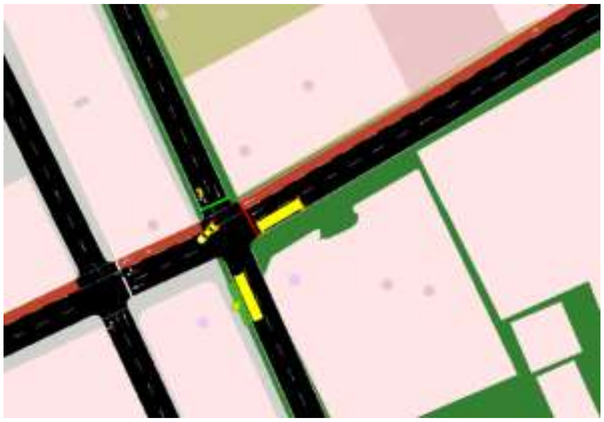

Figure 1.8.6 Simulation along Padre Faura Street and del Pilar Street intersection with bicycle lane

The speed performance index showed that low average speed determines a poor road traffic state, thus indicating a heavy congestion traffic state level [15]. The simulation determined the effect of bicycle infrastructure on the average speed of vehicles and the traffic congestion in the study area. The figures below illustrate the current situation and proposed bicycle infrastructure design in Padre Faura Street.

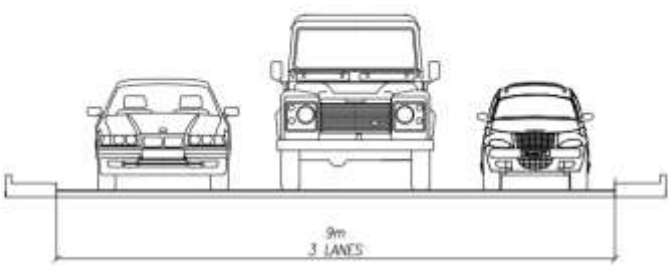

Figure 1.9. Present condition of Padre Faura Street

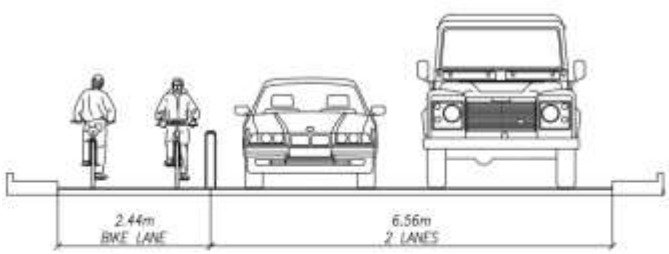

Figure 1.10. Proposed design of bicycle infrastructure along Padre Faura Street

IV. CONCLUSION

As one of the roads easily accessible to all and connected to various important establishments and government facilities, Padre Faura Street in Manila was selected as their area of study. With these, they determined the volume of vehicles traveling along, especially at the intersections of Taft Avenue, Mabini Street, and del Pilar Street. According to the data analysis and interpretation results, several conclusions can be drawn. Establishing an exclusive bicycle lane along Padre Faura Street in Manila is viable since the number of cyclists passing through is higher than the average demand. This bicycle infrastructure will accommodate the volume of bicycles ranging from 33 to 76 bicycles per hour, especially during the peak hours when there is much higher demand.

Despite this, it is important to know if the area can accommodate a bicycle lane. The traffic situation along the intersections of Padre Faura Street to Mabini Street and del Pilar was determined to have relatively free-flowing traffic. However, the traffic situation at the intersection in Taft Avenue was calculated to have moderate to heavy traffic. Since calculating the level of service only requires the volume and road capacity, it is safe to assume that it causes a moderate to heavy traffic demand since it is a major road. Many kinds of vehicles pass through Taft Avenue. As a result, creating bicycle infrastructure along the route will still be feasible due to the two intersections and the three lanes available on the road, which will readily handle such a construction.

The results obtained using linear regression analysis show no relationship between the vehicular speed and traffic density in the Taft Avenue and Mabini Street intersections. All the tests resulted in a negative coefficient and decreasing trend indicating that as the density increases, there is a minimal decrease in vehicular speed. However, it can be seen from the evening peak hours at the intersection of Taft Avenue, indicating a positive trend. This situation happened because, as a major road, the demand in the intersection is greater than the other two intersections, such that there is an increase in flow and speed. It was also shown that vehicles could decrease their speed even with lesser density, thus suggesting that the relationship between the variables may vary depending on the factors such as the traffic lights, emergency vehicles, pedestrians, and such.

The Simulation of Urban Mobility (SUMO) provides all the information needed and allows the configuration of the data inserted through its routing and trip generation. From the GEH values calculated, the simulation was fitted to give accurate results almost identical to the observed data. During the morning peak hours, all the three intersections considered showed an improvement in the average vehicular speed. This is also true for the evening hours but only at the intersections of Taft Avenue and Mabini Street. It was shown that there is a reduced average vehicular speed in the del Pilar - P. Faura Intersection during evening peak hours. Only the goods utility benefits from the improvement, but the other types of vehicles decreased by less than two kph of speed. The results imply that establishing a bicycle infrastructure in the stretch of Padre Faura Street in Manila will significantly improve vehicular speed. Since it was also stated that vehicular speed could determine traffic congestion, it may be effectively reduced, and the chances of cyclists having conflict with motorists and vice versa will be low.

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