Proposing An Ideal Cycling Network Through Accessibility Analysis Using Isochrones: A Case Study of Two Adjacent Metro Manila Cities, Makati and Mandaluyong

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Abstract: The traffic congestion in Metro Manila has had various impacts on transportation. In response, the government has introduced cycling lanes as a possible solution to encourage a shift towards a sustainable transportation alternative. However, majority of these bike lanes are shared with vehicular traffic and unprotected; often overlooking vital user needs, such as distance directness, speed, incline, and safety. This study aims to assess demand-adjusted accessibility of bike lanes via isochrone mapping and propose a viable cycling network. This involves creating impedance functions based on slope and bike lane infrastructure type impedance factors. Additionally, transportation forecasting will uncover potential shifts in user demand within the study area. The results portray a scenario where network gaps are considerably reduced, with the increased volume allocation reflecting real user's choice. Notably, the demand projection model suggests a similar distribution on the suggested bike lane expansions, rendering it the most practical proposal. These findings underline the potential of augmenting cyclist accessibility to broaden route options.

Keywords: Bike Lanes, Isochrone Mapping, Impedance Function, Transportation Forecasting, Accessibility

1. INTRODUCTION

1.1 Background and Context

The Philippines has adopted a positive stance regarding the pursuit of transportation sustainability by actively promoting the use of alternative modes of transport to combat the ongoing traffic congestion. In Metro Manila, the Department of Public Works and Highways (DPWH) and the Department of Transportation have successfully constructed bike lanes that span over 278 km (Sicat, 2022) to accommodate cyclists. Alongside the promotion of cycling as a viable mode of transportation, the construction of efficient bike lanes also enhances public transportation by fostering inclusive mobility (National Economic and Development Authority, 2021).

This study focuses on the accessibility analysis of proposed cycling networks in the cities of Mandaluyong and Makati using isochrone maps, all while considering actual user demand and various impedance factors. The results of this study bear significant implications for transportation planners and policymakers, providing an innovative approach to assess and enhance the cycling network's accessibility and further promoting sustainable transportation. This paper basically attempts to identify priority areas for improvement and propose gradual changes on the cycling network through multiple scenarios in the two cities, ultimately selecting the most viable scenarios at present.

1.2 Objectives

The main objective of the study is to propose an ideal cycling network in Makati and Mandaluyong that caters to the actual user demand and provides better accessibility. Moreover, the proposed cycling network would take into consideration the various inefficiencies caused by the factors affecting cycling networks. The specific objectives of the study are as follows:

- To define the present level of accessibility within the cycling networks of Mandaluyong and Makati by generating isochrones.
- To identify road segments with the potential for accommodating bicycle lanes.
- To determine changes in the volume of bike users in the proposed scenarios using the demand forecasting model.
- To determine priority areas by forecasting user volume and employing it to calibrate the network's accessibility scale.

1.3 Scope and Limitations

The study focuses only the volume of bike users on the current and proposed bike lanes in Makati and Mandaluyong. The volume of other transport modes is not assessed. Additionally, the impedance factors are limited to slope, road/bike lane classifications, and turns. Another limitation pertains to the multiple external constraints, such as space, that influence the positioning of transportation-related infrastructure like bike lanes. These constraints were not considered in the study. Lastly, the investigated area was limited within the boundaries of Mandaluyong and Makati cities.

2. RELATED LITERATURE

2.1 Isochrones in Transportation-related Studies

The use of isochrones in transportation-related studies has been occurring for more than a century as a means of investigating the relationship between time and space in various contexts (Dovey *et al.*, 2017). In recent years, studies have gravitated towards using isochrones for accessibility analysis (O' Sullivan, 2000; Pfertner *et al.*, 2023; Dovey *et al.*, 2017; Sleszynski *et al.*, 2021). Accessibility analysis using isochrones is based on a function that sums up locations reachable from a given starting point within a specified time (O' Sullivan, 2000).

While previous studies have efficiently demonstrated the use of isochrones in accessibility analysis across various modes, a gap in knowledge exists regarding the level of accessibility scaled by the existing demand. It is more practical to initially address areas that are more severely affected by the issue, such as inaccessibility in this case. By scaling accessibility or inaccessibility with demand, a metric is developed that defines which areas need to be prioritized based on a higher number of users and greater inaccessibility.

Another instance highlighting the absence of existing studies is the integration of impedance factors in the creation of isochrones. Although previous studies have extensively investigated the effects of impedance factors (Zhang, 2020; Li and Lai, 2019; Nassir *et al.*, 2016; Ewedairo *et al.*, 2018), none have attempted to integrate these factors in an accessibility analysis using isochrones. Notably, even studies employing similar methodology acknowledged the significance of impedance factors in accessibility analysis (O' Sullivan, 2000; Pfertner *et al.*, 2023; Dovey *et al.*, 2017; Sleszynski *et al.*, 2021). Bridging these gaps in knowledge is crucial in defining accessibility more accurately by producing a more realistic isochrone, thus potentially providing transport planners with enhanced tools for decision-making.

2.2 Impedance Function for Cyclists

The impedance function, within the context of transportation, accounts for a range of variables or factors, such as distance, elevation change, traffic congestion, and road conditions (Gomari, 2016). Concerning cycling, the impedance function represents the level of difficulty or resistance experienced by a cyclist due to elevation changes (slopes) and when traveling along different routes or types of cycleways. In a study conducted by Dill and McNeil (2016), an assumption was made that network impedance, or the difficulty of traversing the network, can be classified into four types based on cyclists' preferences and their willingness to utilize the infrastructure. In this study, only the weighting of the bike lane infrastructure types is considered as an impedance factor.

Furthermore, slope represents another impedance factor that significantly impacts cyclists' performance, as considered in this research. In accordance with the study conducted by Castro *et al.* (2022), the road or bike lane gradient has a notable effect on cyclists' speed and acceleration. During an uphill section, cyclists exert more effort and employ various riding tactics, resulting in a proportional reduction in speed compared to a flat section. If the slope is excessively steep, cyclists tend to dismount and push their bicycles uphill. Conversely, while traveling downhill, cyclists experience increased speed and reduced effort. However, they must simultaneously exercise caution, adhering to traffic regulations and remaining vigilant about potential hazards.

Regarding turns, intersections have been established for interconnected bike lanes, mostly featuring traffic control devices like traffic lights and signs. In general, these traffic signals can have an adverse impact on cyclists' intersection experience, particularly during heavy traffic conditions. Conversely, cyclists find more convenience at unsignalized intersections (Dill *et al.*, 2012). In this study, turn functions and their corresponding turn-penalty function (*tpf*) values are integrated into the model, employing the values displayed in Table 6. These values are applied at signalized and crucial unsignalized intersections with road blockades. Cyclists are assumed to adhere to the traffic signals. The traffic flow for 'left' turns is given the highest priority, while the 'through' traffic flow receives the least. These turn function values align with the standard values implemented for other modes of transportation.

2.3 Transport Forecasting Model

As previously discussed, one of the objectives of this study is to introduce a metric that establishes a relationship between accessibility and demand, enabling the identification of prioritized areas for the proposed improvements. Aside from utilizing the projected demand to create the proposed metric for the study, there are several other purposes that necessitate the process of transport forecasting. For instance, an increase in the number of bike users, as indicated by an accurate transport forecasting model, signifies a shift toward active modes of transport like cycling. According to Moriarty and Honnery (2004), there are multiple reasons why predicting long-term future transport technology and travel is essential. One of these reasons is that transport forecasting allows for the determination of the cost-revenue of a transport infrastructure. Another reason pertains to the use of transport forecasting for traditional modes of transport, such as motorized vehicles. Through transport forecasting or prediction, energy consumption of motorized vehicles is estimated, which also provides environmental related information. Most importantly, transport forecasting provides crucial information with regards to a transport network's demand and capacity, which are necessary parameters when it comes to transport planning.

In this study, a transport forecasting model for the selected study areas was generated using the EMME software. Apart from the baseline scenario, the subsequent two scenarios were developed as the most feasible proposed improvements for the cycling network. These improvements involve connecting the two cities and addressing the identified gaps in bike lanes along road segments. This contrasts with the proposed incremental enhancements in the QGIS scenarios, which considered major roads and narrow streets.

Furthermore, the model was calibrated using the collected field bike counts to ensure accuracy. Various other mobility traffic parameters, such as turns, delays, attraction zones, and other relevant factors, were taken into consideration during the creation of the transport forecasting model. Specifically, the model was employed to generate demand forecasts for each proposed scenario in both software tools, QGIS and EMME.

3. METHODOLOGY

3.1 Study Flowchart

The methodology employed in this study follows the flowchart presented in Figure 1. In order to generate the isochrones, data on the network's topology was acquired from OpenStreetMap. This data was subsequently processed and validated through cross-referencing with images from Google Maps' Street View feature. Once the network's accessibility was defined using the generated isochrone, it was then adjusted according to the demand obtained from the EMME forecasting model. This scaled adjustment allowed for the identification of the areas that needed prioritization in terms of improvement. Specifically, priority areas are those with significantly high demand and inaccessibility.

To calibrate the model, data on cycling counts within the study area was manually collected. The data for bike volume in both directions at control and coverage locations are presented in Table 1. Then, the gathered data underwent validation through AI-based analysis provided by MobilityVision+. Impedance caused by slope, types of road/bike lane classifications, and turns were all considered during the development of both the isochrones and forecasting model. This iterative process was replicated across multiple scenarios to examine various proposed networks and determine the most ideal and viable based on resulting accessibility, as defined by the isochrone. Additionally, separate scenarios were investigated within the forecasting model to gauge changes in volume upon implementation of its own viable proposed networks.

Table 1. Data of control and coverage volume counts

Type of Volume Count	Location	Date	Time	Total Bike Count
Control	High Pointe Medical Hub, Shaw Blvd., Mandaluyong,	February 23, 2023	8:00 AM to 5:00 PM	913
	Barangka, Boni Avenue, Mandaluyong	March 1, 2023	8:00 AM to 5:00 PM	658
	746 Dr Jose P. Rizal Ave, Makati	March 15, 2023	8:00 AM to 5:00 PM	1382
	NEX Tower, 6786 Ayala Ave, Legazpi Village, Makati	March 29, 2023	8:00 AM to 5:00 PM	1157
Coverage	515 Shaw Blvd, Pleasant Hills, Mandaluyong	March 17, 2023	9:00 AM to 10:00 AM	92
	Corner, Boni Avenue, 1550 Rt. Rev. G. Aglipay, Mandaluyong	March 17, 2023	12:00 PM to 1:00 PM	82
	F. Martinez Ave, Mandaluyong	March 17, 2023	2:00 PM to 3:00 PM	64
	325, 1200 Sen. Gil J. Puyat Ave, Makati	March 17, 2023	4:00 PM to 5:00 PM	35

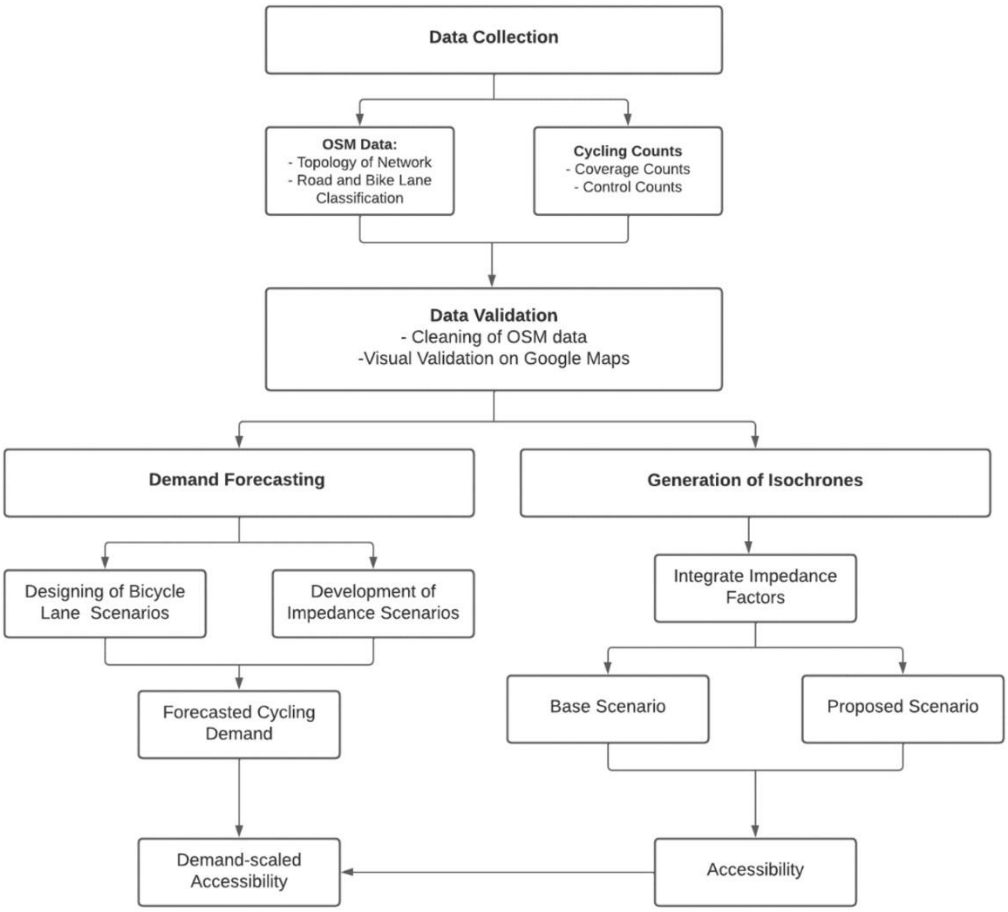


Figure 1. Methodology Flowchart

3.2 Experimental Design

To demonstrate a step-wise approach to achieve an ideal cycling network, gradual improvements are introduced into the network with the last scenario as the most ideal one where the cyclists are affected only by the slope impedance, as shown in Table 2. These improvements are simulated by modifying the assigned weight/factor of the bike lane classification on the selected road segments into the that of the proposed ones. These assigned weights, which serve as impedance factors based on various road and bike lane classifications, are detailed in subsequent Table 5.

To determine the effectiveness of a proposed scenario, the gap between the areas covered by 20-minute isochrones of the proposed and ideal scenario is computed. In essence, the objective of the experimental design is to lower or minimize this computed gap area as much as possible. This gap is computed using equations 1 and 2.

As this study does not include a feasibility analysis regarding the applicability of the proposed scenario, an alternative approach is to propose the study's experimental design as a long-term project. This approach involves the gradual implementation of each scenario over several years until the ideal scenario is attained.

3.3 Development of Isochrones

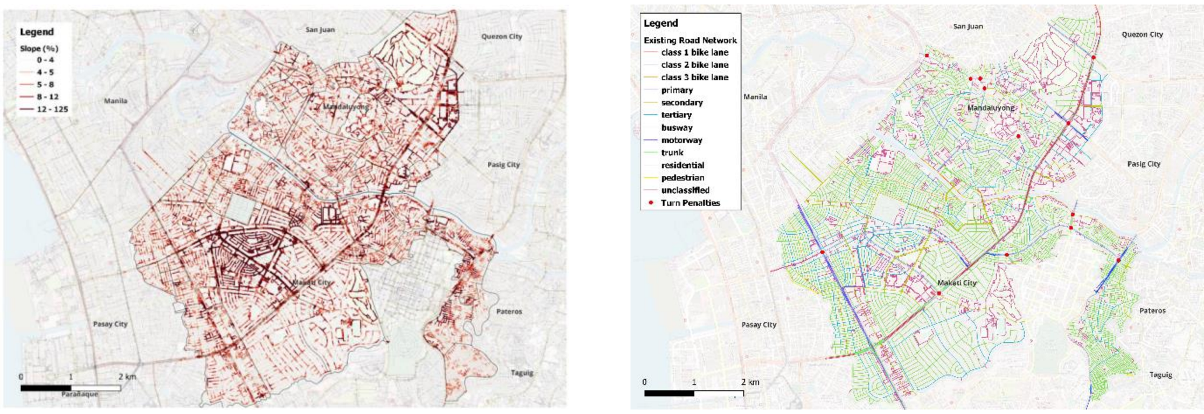
Across all scenarios, the starting points of the isochrones were strategically chosen to allow the determined optimal 20 to 25-minute travels throughout the entire city network for cyclists travelling at a cruising speed of 15 kph, which aligns with the mean speed of a typical bicycle (Schleinitz *et al.*, 2017). A 20-minute trip for a cyclist travelling at 15 kph is equivalent to a 5 km trip, representing the typical average trip distance for cyclists. Additionally, the Institute of Labor Studies (Tacadao and Villena, 2021) conducted a nationwide cycling-related survey, revealing those travel distances of 5 km or less account for the highest percentage at 37%. Using the QGIS plugin, *QNEAT3*, the size of the isochrones was set at 2700 seconds or 45 minutes, with contour intervals at every 300 seconds or 5 minutes. (The use of the *QNEAT3* plugin will be further discussed in the following section.) Impedances were considered by changing the speed values along different parts of the network based on their slope and road classification. Figure 2 shows the map of the considered impedance factors along the entire network. The spatial resolution of the utilized DEM has a grid size of 12.5 meters. Based on the map, areas significantly affected by impedance caused by slope, as defined in equation 3, can be readily identified.

$$\%covered = \frac{Isochrone_{scenario}}{Isochrone_{ideal}} \times 100 \tag{1}$$

$$gap = 100 - \%covered \tag{2}$$

where,

$\%covered$: area covered by 20 min. isochrone of the proposed scenario with respect to that of the ideal scenario
gap : percent difference of 20 min. isochrone area between proposed and ideal scenario
$Isochrone_{scenario}$: proposed scenario 20 min. isochrone area (km^2)
$Isochrone_{ideal}$: ideal 20 min. isochrone area (km^2)
Scenario : proposed scenario based on factors considered as shown in Table 2



(a) (b)

Figure 2. Network map of (a) slope percentage, (b) existing road classifications and turn penalties

Table 2. Experimental Design of Isochrones QGIS Scenarios

QGIS Scenario	Baseline	1	2	3	4	5	6	7	8	9	10	11	12
Road/Bike Lane Classification	**Assigned Weight/Factor**												
Primary	f	f	f	f	f	e	e	e	d	d	c	b	a
Secondary	f	f	f	f	e	e	e	e	d	d	c	b	a
Tertiary	g	g	d	d	d	d	d	d	d	d	c	b	a
Busway	f	f	f	f	f	e	e	e	d	d	c	b	a
Motorway	f	f	f	f	f	e	e	e	d	d	c	b	a
Trunk	f	f	f	f	f	e	e	e	d	d	c	b	a
Residential	c	b	b	b	b	b	a	a	a	a	a	a	a
Pedestrian	c	b	b	b	b	b	a	a	a	a	a	a	a
Class I Bike Lane	c	b	b	b	b	b	a	a	a	a	a	a	a
Class II Bike Lane	d	d	c	b	b	b	b	a	a	a	a	a	a
Class III Bike Lane	e	e	c	b	b	b	b	a	a	a	a	a	a
Intercity Bridges	f	f	f	f	e	e	e	e	d	c	c	b	a
Others	g	g	g	g	g	g	g	g	g	g	g	g	a

a – Path/Trail (1.0)
b – Bike Boulevard (0.939)
c – Quiet Residential (0.895)
d – Protected Bike Lane (0.701)
e – Painted Bike Lanes (0.409)
f – Major Street, no bike lane (0.261)
g – Avg. (0.555)
Source: Table 5 (Dill and McNeil, 2016)

Note that the impedance functions, i.e., slope percentages and turns, and starting points for bike travel employed in these QGIS scenarios are all identical to accurately depict the gradual changes in bike lane classification.

3.4 Isochrone mapping using QNEAT3

The QGIS software provides several graphical user interface tools, the majority of which are integrated into the software as plugins for diverse types of analysis. In this study, the plugin *QNEAT3* will be utilized to generate the isochrones of all the scenarios. *QNEAT3* offers users advanced network analysis algorithms, coded in Python, enabling the executing of complex tasks, such as the creation of isochrone areas (Raffler, 2018).

With regards to isochrone mapping, *QNEAT3* offers several algorithms, each with its own specifications to cater to the needs of the user. The iso-area interpolation algorithm outputs produce an interpolated distance raster starting from a point specified by the user and applies a TIN-interpolation method which is one of the primary features of *QNEAT3* (Raffler, 2018). The resulting distance raster layer is significantly useful in multi-criteria site analysis. Table 3 shows the parameters necessary for running the algorithm and its optimization criterion. To create isochrones, the 'fastest' option must be selected during analysis. With regards to the entry cost calculation method, *QNEAT3* uses a planar algorithm that takes into account distance measures and speed. However, it is possible to incorporate other factors such as impedance by changing the speed values of the network layer.

Table 3. Mandatory parameters for *QNEAT3* Iso-Area algorithm

Parameter	Type	Information
Network Layer	Vector Layer	Geometry type must be Line String
Start Point (x,y)	Coordinate pair	Obtain by clicking on map canvas
Size of Iso-Area	User input	Depends on strategy: max. distance/max. time
Optimization Criterion	Shortest/Fastest	-
Interpolation Layer	Output Raster Layer	-

3.5 Development of Parameters

The integration of bicycle parameters into EMME software plays a crucial role in analyzing travel matrices and incorporating bicycle travel demand into the transportation model. By inputting estimated bicycle trips into the matrix calculator, employing data sourced from Historical Interview Surveys (HIS), the interactions between bicycle travel and other transportation modes can be simulated. This simulation not only pinpoints potential infrastructure gaps or deficiencies but also evaluates the influence of cycling on the transportation network.

Table 4. Estimation of bicycle trips percentage

Others-private mode	#Trips	%
Bicycle	6,386	80.7
Pick-up / Delivery Van	590	7.5%
Others	937	11.8%

Source: HIS data (Fillone *et al.*, 2015)

According to the latest available data, the JICA study on modal share indicated that 2.3% of the total 35,503 trips are classified as "others: private mode." According to the analysis presented in Table 4, 80.7% of the trips are categorized as bicycle trips (Gaspay, 2021). Using this percentage, the estimated total number of bicycle trips is 667. Consequently, the percentage of bicycles in relation to the overall modal trips is calculated to be 1.88%. This value was input into the software to derive the cycling matrix based on the full matrix.

One of the impedance factors considered in this study is the weighting of the bike infrastructure types or their classifications. The weights for these classifications are presented in the table from Dill and McNeil (2016), and they vary based on the type and location of the bike lane. Since the two cities in question have only implemented the minimal requirements for each bike lane class, the most appropriate or nearest values for the impedance factor of each bike lane class are as follows: Shared Lane Alley as Class I, Protected Bike Lane as Class II, and Shared Roadway Bike Lane as Class III in accordance with the DPWH Bike Facilities Classification (2022). For sections of the network lacking an existing bike lane, assumptions were formulated based on the factors applied, as observed in Table 5.

Table 5. Weighting of Infrastructure Types

Road Classification	Bike Facility	Initial Weight	Final Weight (Initial/0.734)
Path or Trail	Path/Trail	0.734	1.000
Bike boulevard	Greenways	0.690	0.939
Quiet residential street	Shared Lane Alley	0.657	0.895
Major street protected bike lane	Protected Bike Lane	0.515	0.701
average	Buffered bike lane	0.408	0.555
Major street striped bike lane	Bike Lane	0.301	0.409
Major street, no bike lane	Secondary Road Primary Road/ Ramp City Street	0.192	0.261

Source: Dill and McNeil (2016)

The slope gradient of the road network varies depending on the direction of travel. Slope percentage values were determined by analyzing the digital elevation model (DEM) of the study area using QGIS terrain profile plugin. The speed as a function of slope is based on the study of Gölz (2007), in which he developed an equation, as seen in equation 3, after establishing the relationship between these two variables.

$$v(kph) = f(s) = \begin{cases} 20 & s < -5 \\ 15 - s & -5 \leq s \leq 10 \\ 5 & s > 10 \end{cases} \tag{3}$$

where,

v : speed as a function of slope (kph)

s : slope (%)

Turn functions and their corresponding *tpf* values are integrated into the model using the following values shown in table 6. They are placed on signalized and crucial unsignalized intersections. The 'left' turns are the most prioritized traffic flow while the 'through' traffic flow are the least prioritized.

Table 6. Turn components of traffic flow.

Traffic flow	Turn function	tpf value
Through	fp1 = 0.5	1
Left turn	fp2 = 1.0	2
Right turn	fp3 = 0.75	3

If no penalty	-1
If not allowed	0

The final impedance function applied in this study is:

$$T = \frac{length}{c_c \times v(s)} \times 60 \tag{4}$$

where,

T : Overall travel time (mins)
$length$: Bike lane length component of the function (km)
c_c : Weight coefficient of the bike lane classification
$v(s)$: Cycling speed as a function of slope
60 : Conversion of hours to minutes

3.6 Demand Forecasting Model Development

The primary purpose of the demand forecasting model in this study is to determine the cyclists' volume on the bike lanes based on the actual count data. It aims to create a simple prioritization model, aiding in the infrastructure development prioritization process and to generate basic scenarios that address the major gaps in the existing cycling network. However, this model is not the core of this study and is not intended to be comprehensive.

3.6.1 Cycling Network

The software tools utilized in producing the initial digital road networks of the cities of Mandaluyong and Makati were acquired from OSM, imported and cleaned in EMME. The cycleway generated from the QuickOSM plugin in QGIS was validated through visual observation using Google Maps Street View. The validated data was then classified based on the DPWH DO No. 263 (2022) as presented in Table 7.

Table 7. Type attribute of bike lanes

Type	Class	Description
1	I	Shared Use Path or Bike Path
2	II	Separated Bike Lane (using Physical Separator or Pavement Markings)
3	III	Shared Roadway

Source: Bike Lane Classification of DPWH DO No. 263 (2022)

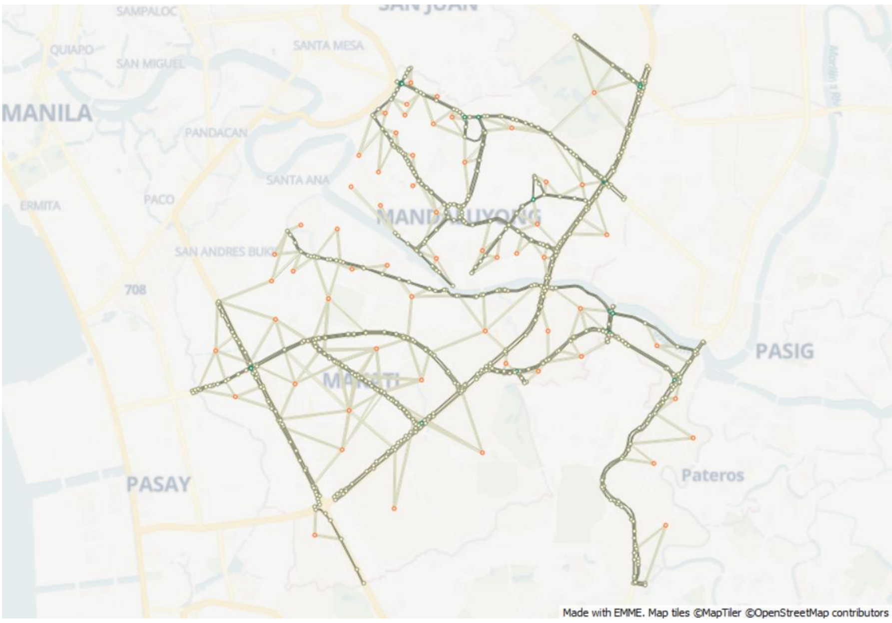


Figure 3. Cycling network of the cities of Mandaluyong and Makati

3.6.2 Assumptions

The demand forecasting model was developed through establishing a few assumptions, driven by the lack of data and time constraints. As previously mentioned, this forecasting model was not intended to be comprehensive and served to supplement the generation of isochrones.

The following assumptions were made for the model development of the cycling network:

- In the EMME Baseline Scenario, cyclists exclusively make use of the designated bike lanes and refrain from using any roads lacking such lanes. No volume of other transport modes was considered.
- The placement of the centroids is based on the geometric center of the barangay or the density of inhabitants in accordance with the buildings and land use observed in the layout and Google Maps Street View.
- The centroids' connectors are attached to the possible access points of the barangay's inhabitants to the nearby bike lanes. Most of these access points are road or street intersections.
- Amenities included within the administrative borders of both cities include general facilities such as offices, hospitals, schools, etc. Cycling transport facilities were also added as they are points of interest for accessibility. Furthermore, the matrix destination is produced from the respective population of each barangay and the number of amenity points and density.

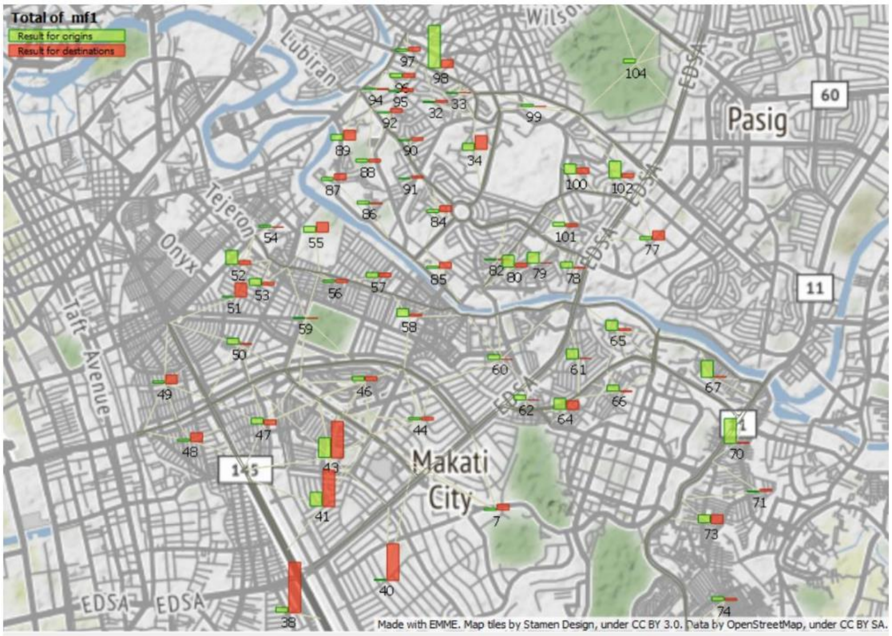


Figure 4. Origin-destination trips generated in the study areas' full matrix

4. RESULTS AND DISCUSSION

4.1 Resulting Isochrones

As previously discussed in the experimental design section, improvements are introduced in each proposed scenario by changing the assigned impedance factor weights of the current bike lane/road type classification. For instance, in QGIS Scenario 1, a weight value of 0.939 corresponding to a *Bike Boulevard,* was applied to various road segments of the network, specifically those classified as *Residential, Pedestrian,* and *Class I Bike Lane.* These road segments were originally assigned with a weight value of 0.895 corresponding to a *Quiet Residential Street* in the existing or baseline scenario. Changing the assigned factor to the selected segments from 0.895 to 0.939 is equivalent to changing the environment from a *Quiet Residential Street* to a *Bike Boulevard*. In doing so, the perceived impedance on cyclists along these selected road segments is lowered, thus improving the network. This process is repeated in the other scenarios by selecting more road segments or changing the assigned factors to other bike lane classifications with higher values. The visualization of how the changes is implemented in scenario 1 is presented in Figure 6.

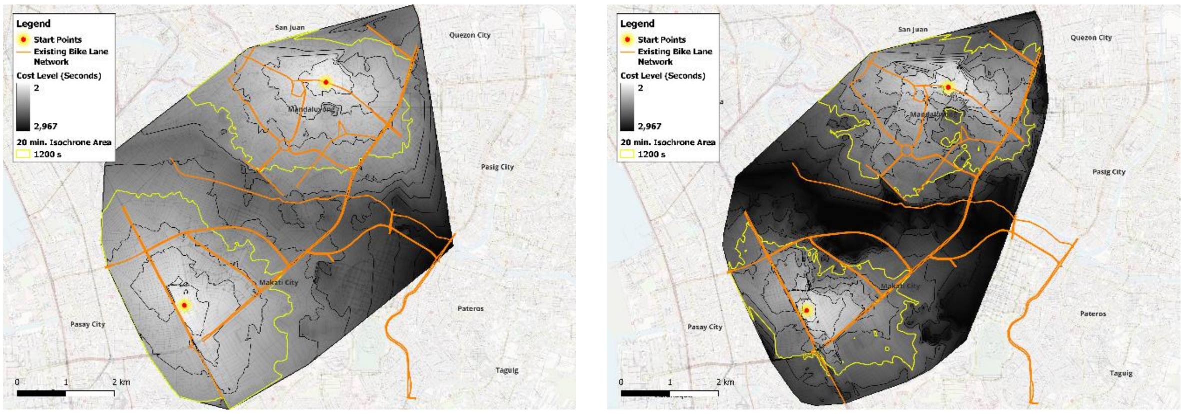
Figure 5(a) illustrates the isochrone for the ideal scenario, where the 20-minute isochrone area covers 28.25 sq. km, encompassing nearly the entire network of each city where the starting point is located. In the QGIS Baseline Scenario, which already incorporates impedance caused by various road or bike lane classifications, the area covered by the 20-minute isochrone is noticeably smaller, approximately 10.77 sq. km. This is equivalent to a 61.87% gap compared to the ideal scenario. Additionally, the area encompassed by the entire isochrone, maxed out at 45 minutes, is also smaller compared to the ideal scenario. No improvements or changes were proposed in the QGIS Baseline Scenario, providing insights into the current state of the network for cyclists.

Table 8 summarizes the computed gaps in each proposed scenario. Succeeding scenarios demonstrate a progressive reduction in the gap, culminating in a computed gap of 0% in QGIS Scenario 12. As depicted in Figure 5(c), this scenario proposes bike paths/trails, the most optimal infrastructure with an assigned weight of 1.0, throughout the entire network including all road classifications.

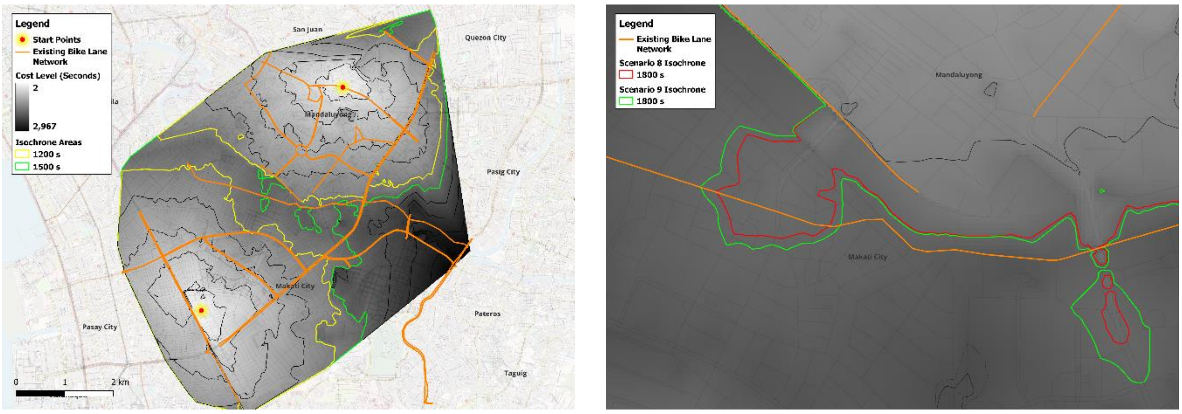
In QGIS Scenario 9, a shared bike lane was proposed for the intercity bridges, namely the Makati-Mandaluyong and Estrella Pantaleon, connecting the two cities. However, both QGIS Scenarios 8 and 9 resulted in 20-minute isochrones covering the same amount of area. This suggests that intercity bridges have a minimal impact on network accessibility. The actual reason for this, however, is the considerable distance between these bridges and the two designated starting points. Regardless of the consideration of the impedance factors, the distance between the bridges and the starting points cannot be traversed within 20 minutes at a speed of 15 kph. Looking at the areas covered by the 30 minute or 1800 seconds isochrones as seen in Figure 5(d), a slight improvement occurs in QGIS Scenario 9 wherein a shared bike lane impedance factor was applied at the intercity bridges as compared to QGIS Scenario 8.

Table 8. Summary of computed gaps per each QGIS scenario

QGIS Scenario	20 min. isochrone area (km^2)	% Covered	% Gap
Baseline	10.77	38.13	61.87
Scenario 1	14.62	51.74	48.26
Scenario 2	17.10	60.55	39.45
Scenario 3	18.39	65.11	34.89
Scenario 4	19.68	69.66	30.34
Scenario 5	20.18	71.42	28.58
Scenario 6	20.84	73.79	26.21
Scenario 7	21.11	74.77	25.23
Scenario 8	23.77	84.14	15.86
Scenario 9	23.77	84.14	15.86
Scenario 10	25.33	89.69	10.31
Scenario 11	26.77	94.76	5.24
Scenario 12	28.25	100.00	0.00



(a) (b)



(c) (d)

Figure 5. Isochrones for (a) 15 kph free-flow speed with slope impedance, (b) QGIS Baseline Scenario, (c) QGIS Scenario 12, (d) QGIS Scenarios 8 and 9

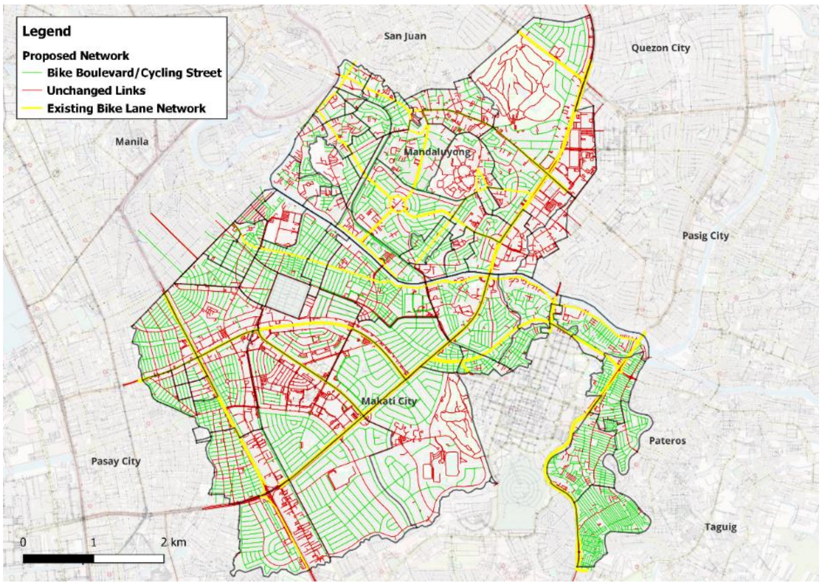


Figure 6. Proposed QGIS Scenario 1 map

4.2 Demand Forecasting Results

Three scenarios were modeled in EMME. The EMME Baseline Scenario is based on the existing cycling network of both cities with no actual counts included. On the other hand, the EMME Adjusted Baseline Scenario utilizes the collected nine-hour count data to adjust the traffic demand, reflecting the real-time volume of cyclists. As for the EMME Scenario 2, bike lane links were added on Mandaluyong-Makati and Estrella-Pantaleon Bridges, Nueve de Febrero Road, 2248 Chino Roces Road, and 2310 Chino Roces and 313 AH26 Roads. Meanwhile, EMME Scenario 3 is derived from EMME Scenario 2, incorporating modifications to Class I on the bike lane classification along Ayala Avenue and a short bike lane segment on JP Rizal Avenue.

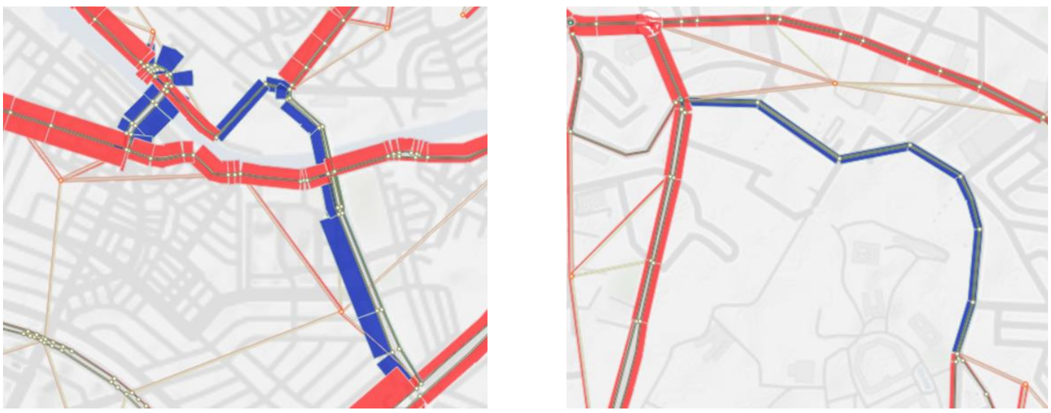
Table 9. Modelling results from the EMME scenarios

Parameters	EMME Baseline	EMME Adjusted Baseline	EMME Scenario 2	EMME Scenario 3
Total Length, km	96.29	96.29	110.84	110.84
Average travel speed, kph	9.69	9.69	9.63	9.90
Average total volume	372	331	402	403
VDT (veh-km)	35320.82	30658.74	39216.64	39267.99
VHT (veh-hr)	3593.08	3211.83	4419.14	4322.67

The analysis of the scenarios yields significant findings regarding the overall impact of the proposed bike lanes on the road networks of Makati and Mandaluyong. As observed in Table 9, the adjustment of the baseline results in a notable reduction of the average total volume by 41, accounting for the current demand of bicycles in the assigned control areas. This subsequently reduced the values of vehicle distance travelled (VDT) and vehicle hours travelled (VHT). It is worth noting that the average travel speed remained constant since the utilized cycling network, along with the applied impedance functions and corresponding time values, remained consistent throughout the analysis.

In EMME Scenario 2, the addition of bike lanes on various road networks and on the proximity bridges, Estrella-Pantaleon Bridge and Makati-Mandaluyong Bridge, has significantly influenced the network by alleviating the volume from the conventional bike lanes to these new ones. The VDT has risen to 39216.64 from the VDT of 30658.74 in the EMME Adjusted Baseline Scenario, indicating an increase in the distance to be covered. Also, the average total volume of links increased to 402 while a negligible decrease of 0.06 can be observed on the average total speed. These additional bike lanes enable cyclists to travel through both cities in both directions without resorting to non-bicycle lane roads, thereby easing the accessibility of the interconnected cycling network. Despite the slope and infrastructure impedance factors on the bridge, cyclists can efficiently utilize the dedicated bike lanes, demonstrating effectiveness in facilitating travel. However, as for the added bike lanes on 2310 Chino Roces and 313 AH26 Roads, no presence of any volume can be discerned.

EMME Scenario 3 maintains an approximately equal VDT to EMME Scenario 2 but exhibits lower VHT at 4322.67. These results also indicate that the implementation of the proposed bike lanes has increased the confidence of bicycle users to travel at higher speeds, thereby reducing travel times.



(a) (b)

(c) (d)

Figure 7. Volume for the added links (specified in blue) on (a) Mandaluyong-Makati & Estrella-Pantaleon Bridges, (b) Nueve de Febrero Road, (c) 2248 Chino Roces Road, and volume of bike lanes changed to Class I in Scenario 3 (d) Ayala Avenue and JP Rizal Road segment.

Furthermore, in Figure 7, a high volume of traffic was observed on the links in Shaw Boulevard. However, the addition of bike lanes on Nueve de Febrero Street in EMME Scenario 2 has produced an extensive effect on the demand of the cycling network. Accessibility on the bike lanes has increased for the two bordering barangays, where it resulted in a shift in volume on other road segments.

The noteworthy results arise from the comparisons between the following EMME scenarios: the Adjusted Baseline Scenario and Scenario 2, and Scenario 2 and Scenario 3. In Figure 8, the redistributing of demand from the existing bike lanes of adjusted baseline to the proposed new ones highlights its positive impact in alleviating volume and improving traffic flow. On the other hand, the comparison between Scenario 2 and 3 highlights the impact of improving bike lane classification on specific bike lane segments. The diversion of traffic flow from Sen. Gil J. Puyat Avenue and Buendia Avenue to the modified Class I bike lane on Ayala Avenue can be attributed to the enhanced conditions it now offers. However, the same cannot be said for the changes to Class I on the JP Rizal Avenue segment, as no reduction in volume is observed in its adjacent bike lanes. This may be due to the limited modification applied to only a short portion of the extensive bike lane. Thus, the changes only demonstrate marginal differences in relation to the EMME Scenario 2 across the five notable parameters.

Overall, the introduction of these bike lanes on potential road segments has enhanced the cycling network and improved the user experience. EMME Scenario 3 exhibits the do-all scenarios in the forecasting model which displays the positive impact of strategically placing bike lanes, modifying selected lane classifications, and considering impedance factors to optimize accessibility. However, given the raised costs involved in its execution as indicated by the DPWH (2022), it might not be the most feasible option at present. Instead, EMME Scenario 2 appears to be a more practical choice.

Figure 8. Volume at links and turns of the EMME scenarios for (a) Adjusted Baseline, (b) Scenario 2, (c) Scenario 3; and (d) traffic volume and times comparison of EMME Adjusted Baseline Scenario and Scenario 2.

4.3 Demand-scaled Accessibility

Using the forecasted demand from the model in EMME, a map that overlays the demand of the existing bike lanes on top of the computed accessibility in seconds, obtained from QGIS Scenario 12 (most ideal) isochrone, is created. As discussed earlier, this process produced a metric that relates accessibility with the current demand to determine priority areas.

Table 10. Demand-scaled accessibility proposed metric

$\boldsymbol{Volume \times minutes}$
$0 - 1290$
$1290 - 6200$
$6200 - 18548$
$18548 - 70155$

In Figure 9, the map presents the demand-scaled accessibility in the existing bike lanes across Makati and Mandaluyong. In terms of the proposed metric, the existing bike lanes along EDSA are considered priority areas, with values ranging from 18548-70155. This indicates that along these areas, accessibility is low relative to the amount of demand it caters. In other terms, bike lanes in these areas are within the coverage of the longer duration isochrones and have significantly high demand. Improving accessibility in these areas will produce the most significant results compared to the other existing bike lanes.

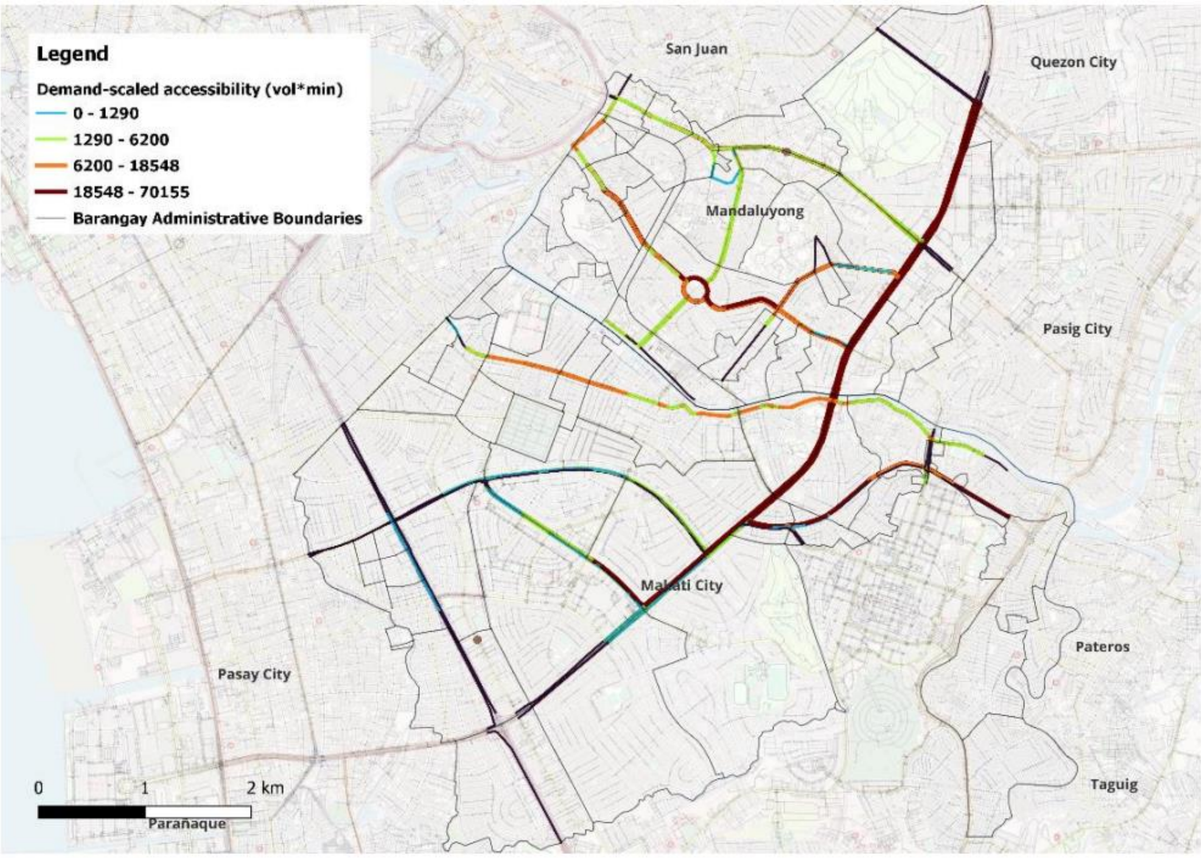


Figure 9. Demand-scaled accessibility along existing bike lanes

5. CONCLUSION

This study has demonstrated that achieving 20–25-minute accessibility through bicycle usage is possible by introducing bike lane infrastructure into the existing network and implementing appropriate modifications. Furthermore, the study proposes a demand-scaled accessibility metric designed to determine the priority areas for network improvements. This metric defines areas with low accessibility relative to the demand they cater. Areas characterized by high demand and low accessibility, as defined by long travel times from starting points, will be granted higher prioritization compared to other areas. A prime example for improvement in terms of bike lanes is the EDSA route, which currently serves as a major thoroughfare for a significant volume of buses and cars.

Regarding the impedance factors, the study's results have revealed how they affect the accessibility of a network specifically for cyclists through the visualization provided by the generated isochrones. The apparent lack of bicycle infrastructure in both Makati and Mandaluyong explains the lack of accessibility indicated by the isochrones of the QGIS Baseline Scenario. Specifically, the primary and secondary roads that lack bike lanes are one of the most significant factors as they diminish the speed of cyclists significantly.

With regards to dealing with accessibility through the proposed scenarios in QGIS, the results indicate that, among all the proposed scenarios, either QGIS Scenario 8 or 9 would be the most viable scenario to implement. With a 23.77 km^2 20-minute isochrone area, this corresponds to a 15.86% gap compared to the ideal scenario. These two scenarios offer the greatest improvement in terms of accessibility, all while taking into account major constraints associated with constructing such infrastructures. Specifically, it does not significantly compromise the level of service of the facilities for other modes.

Moreover, the most viable scenario proposed by the model results is EMME Scenario 2. This approach differs from the more extensive development proposed in QGIS Scenarios 8 and 9. EMME Scenario 2 represents a practical choice for immediate improvement on the cycling network as the additional bike lanes help better connect the two cities and address the major gaps. As discussed earlier, significant volume alleviation can be observed from the existing lanes to the new ones. Additionally, this scenario provides cyclists with more route options to reach their destinations. Although no volume differences can be detected on 2310 Chino Roces & 313 AH26 roads, they are still worth considering since they are well-connected to other bike lanes outside the study area.

Overall, the results of this study propose a solution for enhancing the cycling accessibility within the network of Mandaluyong and Makati cities. It also supports the promotion of active transportation modes as substitutes for conventional means of travel, aligning within the objective of achieving transport sustainability. Notably, most of the tools utilized in this study are open source, with the exception of the EMME software. Thus, this study can be easily replicated in other scenarios or study areas.

6. RECOMMENDATIONS

Future research could focus more on investigating the effects of changing impedance factors on the accessibility between intercity facilities, such as the bridges involved in this study. Another direction is to develop a more comprehensive forecasting model, encompassing additional factors in the impedance function to reflect the Philippine context. A feasibility study could assess the cost implications of scenario implementations to also help with the determination of the most viable proposed scenario. Additionally, a preference survey might help gauge the perspectives of current cyclists and potential users. Finally, expanding this study to cover other cities within Metro Manila would provide a broader perspective.

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APPENDIX

Table 11. Summary of the road attributes for the additional bike lane segments in the proposed ideal cycling network.

Proposed Bike Infrastructure	**Existing Road Attributes**			
	Classification	Road/ Street Name	No. of Lanes	Length (m)
Bike path/trail	Secondary	San Francisco Street	3	636.77
Bike path/trail	Secondary	Boni Ave.	2	3100
Bike path/trail	Secondary	Maysilo Circle	3	706.28
Bike path/trail	Secondary	F. Martinez Ave.	2	1130
Bike path/trail	Secondary	Barangka Drive	2	1170
Bike path/trail	Tertiary	Coronado	4	1080
Bike path/trail	Tertiary	E. Pantaleon	2	357
Bike path/trail	Secondary	E. Pantaleon Bridge	2	506.38
Bike path/trail	Secondary	Nueve de Febrero	2	1560
Bike path/trail	Secondary	Dr. Jose Fabella Road	2	355.86
Bike path/trail	Secondary	Calbayog Ext.	2	291.90
Bike path/trail	Secondary	Domingo M. Guevara	2	754.03
Bike path/trail	Primary	Shaw Blvd.	2	5270
Bike path/trail	Secondary	New Panaderos	4	790
Bike path/trail	Tertiary	Acacia Lane	2	130
Bike path/trail	Primary	Buendia Ave.	4	5400
Bike path/trail	Secondary	Ayala Ave.	4	2300
Bike path/trail	Secondary	Chino Roces Ave.	4	5800
Bike path/trail	Primary	Kalayaan Ave.	3	6300
Bike path/trail	Trunk	Carlos P. Garcia Ave.	3	
Bike path/trail	Secondary	Jose P. Rizal Ave.	2	8100