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School of Transportation Sciences

Master of Transportation Sciences

Master's thesis

Estimation of Various Scenarios of the Proposed Bus Rerouting Scheme along EDSA, Metro Manila, Philippines

Lovely Marie Calibo

Thesis presented in fulfillment of the requirements for the degree of Master of Transportation Sciences, specialization Traffic Safety

SUPERVISOR :
dr. Muhammad ADNAN

MENTOR :
De heer Shiraz AHMED

2018
2019

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PREFACE

The basis of this study is my pursuit of becoming a full pledged transportation engineer. Having worked in Metro Manila, I have realized that in order to solve the ever-worsening traffic conditions, there is a need to conduct quality research studies not only in terms of assessing improvements in traffic condition but also in improving the quality of life. I consider this study as only the beginning of my long career in the field of transportation engineering.

I could not have achieved my current level of accomplishment without a strong support group. First, to my family who have supported me with unconditional love and understanding. Secondly, my supervisors and mentor, each of whom has provided patient advice and guidance throughout the research process. To the Citilabs Support Team, who have offered their time in answering technical questions during the most critical part of my simulation. Lastly, to the VLIR-OUS for giving me this wonderful opportunity to pursue this degree. Thank you all for your unwavering support.

SUMMARY

Congestion issues arise due to increase in car ownership in densely populated areas such that road infrastructure cannot keep up with the increase in travel demand. In the case of Metro Manila, traffic congestion is worsening with traffic demand at 12.8 million trips. To address these congestion issues, government agencies have been focusing on policies that aim in increasing operational efficiency of urban streets.

For example, a truck restriction was introduced in 1978 to reduce competition for road space among cars and buses, followed by a number coding scheme preventing cars in using major streets depending on the license plate numbers. Although good in paper, the effectiveness of these policies in reducing congestion were never assessed and was just assumed. Recently, the Metro Manila Development Authority (MMDA) proposed a scheme preventing city buses in using EDSA, a major corridor in the metro.

Several studies have already identified the deterioration of air quality from traffic sources. The estimation and modelling of emissions can be a powerful tool for air quality managers and environmentalists in examining the impact of different transport plans. Specifically, traffic estimates have been utilized in allowing decision-makers to effectively manage local air quality. As governments continue to introduce new policies when it comes to alleviating traffic congestion, there is a need to consider its effects on the environment.

This study can aid traffic managers and local policy makers in understanding the effects of policies not only in the traffic perspective. With the introduction of the bus rerouting scheme, it is hypothesized that there would be an improvement in traffic condition along EDSA but there is an effect on the vehicle emissions. Hence, this study attempted to answer the question: Is there a significant improvement in terms of traffic and vehicle emissions with the proposed rerouting of public buses along EDSA?

Specifically, this paper also attempted to answer the following questions: What are the kilometers covered, average speed, and estimated vehicle emissions for the existing condition and alternative scenarios? Is there an improvement in terms of traffic conditions and vehicle emissions between the existing and alternative scenarios? Is there an improvement in terms of traffic and environmental impacts for selected road segments with the introduction of the bus policy?

To achieve these objectives, a traffic simulation was conducted using the Cube software. Input for the simulation such as road network and O-D matrices was collected from latest traffic studies in Metro Manila. The emission factors developed by UP-NCTS was utilized together with the fuel-types database from the Land Transportation Office and the Philippine Statistics Authority.

For this study, five major road segments were considered: North Luzon Expressway (NLEX), Paso de Blas, Epifanio de los Santos Avenue (EDSA), South Luzon Expressway (SLEX), and San Pedro National Highway. Traffic analysis were conducted in both total and segment-segment specific analysis. Considering the

total network, the introduction of the bus policy did not improve the traffic conditions. Specifically, the reduction of buses along the major thoroughfares only provided additional space for car users. In an environmental perspective, the emissions vary depending on the pollutant being considered. CO2, PM, and SOx emissions increased with the policy, but the NOx, CO, and HC reduced.

Looking into the segment-specific analysis, traffic conditions also varied depending on the segment considered. Specifically, NLEX, EDSA, and San Pedro National Highway had worse traffic conditions with the introduction of the policy. Whereas, Paso de Blas and SLEX had improved traffic conditions.

For the environmental emissions, results varied depending on the pollutant considered. Specifically, the introduction of the bus policy improved environmental conditions along EDSA with only CO and HC increasing and the rest reduced, and along Paso de Blas with only NOx emissions increasing. Whereas, San Pedro had the worse effect with all the emissions increasing.

Overall, the introduction of the bus policy did not improve traffic conditions along EDSA assumed by authorities. However, it did improve environmental conditions by reducing all emissions. In parallel, the implementation of the policy affected road segments connecting to EDSA with the NLEX, SLEX and San Pedro Highway worsening.

The implementation of the policy can be a success or a failure depending on the priority of the government. In this case, the improvement of the traffic conditions did not necessarily guarantee an improvement with environmental conditions. Similarly, the results of the emissions varied with the pollutant being considered. Thus, there is a need for the government to identify its priority when it comes to selecting the deciding factors.

Other issues that arise from this study was the fact that at present, city buses are already at capacity even without the introduction of the bus rerouting scheme. The policy will further worsen the already problematic public transport system of Metro Manila. Hence, there is also a need for the government to address this issue prior to the implementation of the policy.

1. INTRODUCTION

1.1 Background of the Study

Globally, there are more people living in urban areas compared to rural areas, with 55% of the world's population residing in urban areas in 2018. It is estimated that by 2050 this number will increase to 68% of the world's population driven by both overall population increase and the shift in the percentage of people living in the urban areas. Urbanized regions include the Americas, the Caribbean, Europe, and Oceania. It is also projected that by 2030, there will be 43 megacities most from developing countries (United Nations, 2018).

Asia, despite being less urbanized compared to other regions has 54% of the world's population (United Nations, 2018). Specifically, the Philippines has a population of around 105 million people in 2017 (United Nations, 2017). Together with the increase of the national population, population within the National Capital Region (NCR) also increases as shown in Figure 1.

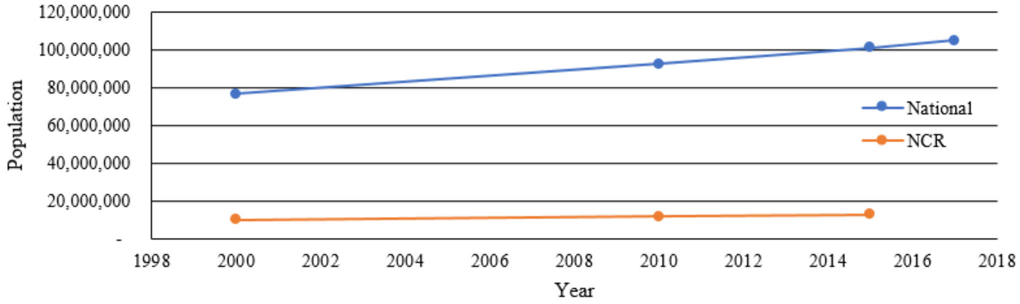

FIGURE 1 Philippines and NCR population (PSA, 2017 & United Nations, 2017).

Moreover, vehicle registrations in the country has been constantly increasing for the past few years as shown in Figure 2. This is due to continuous urbanization associated with economic growth that eventually leads to an increase in motorization. At present, the road network in Metro Manila consists of five (5) circumferential roads and ten (10) radial roads connected to the central business districts (CBD), commercial and residential areas. Three expressways connect Metro Manila to Regions III and IV-A, namely: the North Luzon Expressway (NLEX), South Luzon Expressway (SLEX), and Skyway. Within Metro Manila, the Epifanio De Los Santos Avenue (EDSA) is the city's busiest road section with two major economic centers: Ortigas CBD and Makati CBD. It also remains as the most heavily travelled road throughout the daytime (JICA, 2013).

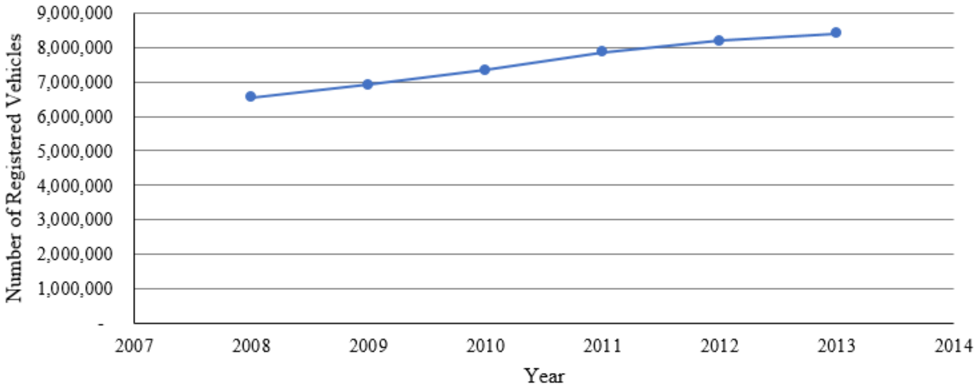

FIGURE 2 Registered vehicles in the Philippines (PSA, 2017).

Metro Manila is a result of the integration of 17 previously municipalities surrounding the city of Manila when it became highly urbanized (Magno-Ballesteros, 2000). Based from a report by the Philippine Statistics Authority (PSA), Metro Manila was the most densely populated administrative region in the country with a population density of 20,785 persons/km^2 in 2015.

Specifically, the city of Manila was the most densely populated followed by Mandaluyong and Pasay. Five other highly urbanized cities (HUCs) within the region surpassed the regional population density: Caloocan, Navotas, Makati, Malabon and Marikina. The surrounding provinces of Rizal, Cavite, and Laguna from Region IV-A, and Pampanga and Bulacan from Region III were the most populated provinces for the same year (Philippine Statistics Authority, 2018).

In Metro Manila and its surrounding provinces: Bulacan, Rizal, Laguna, and Cavite (BRLC), car travel accounts for 30% of per-km, but comprises 72% of the road traffic in terms of PCU-km. Moreover, modal split shows that public transport is still the dominant mode of travel. Additionally, in the Metro Manila and BRLC road network, the V/C ratio operates at 0.80, with almost 50% running below 20 km/hr. This is only one evidence of Metro Manila's issue on traffic congestion with traffic demand at 12.8 million trips in Metro Manila and 6 million in the BRLC, most of which are public services with 69% of total trips while the rest is in private mode but with 78% of road space (Almec Corporation, 2014).

There is already traffic congestion during the day from 6am to 9pm which not only reduces traffic speed of the road users but also increase uncertainty to distinctions and punctuality in transport operation (Almec Corporation, 2014). This is important because public transport is central to reducing road congestion and its corresponding costs in cities (Division for Sustainable Development Goals, 2016).

Congestion issues arise due to increase in car ownership in densely populated areas such that road infrastructure cannot keep up with the increase in travel demand. The reduction in road capacity cannot accommodate all trips made especially during peak hour periods (Metz, 2018). Private vehicle ownership increases with the development of nations and cities, especially with cultural and cultural pressures equating car ownership with success (Division for Sustainable Development Goals, 2016).

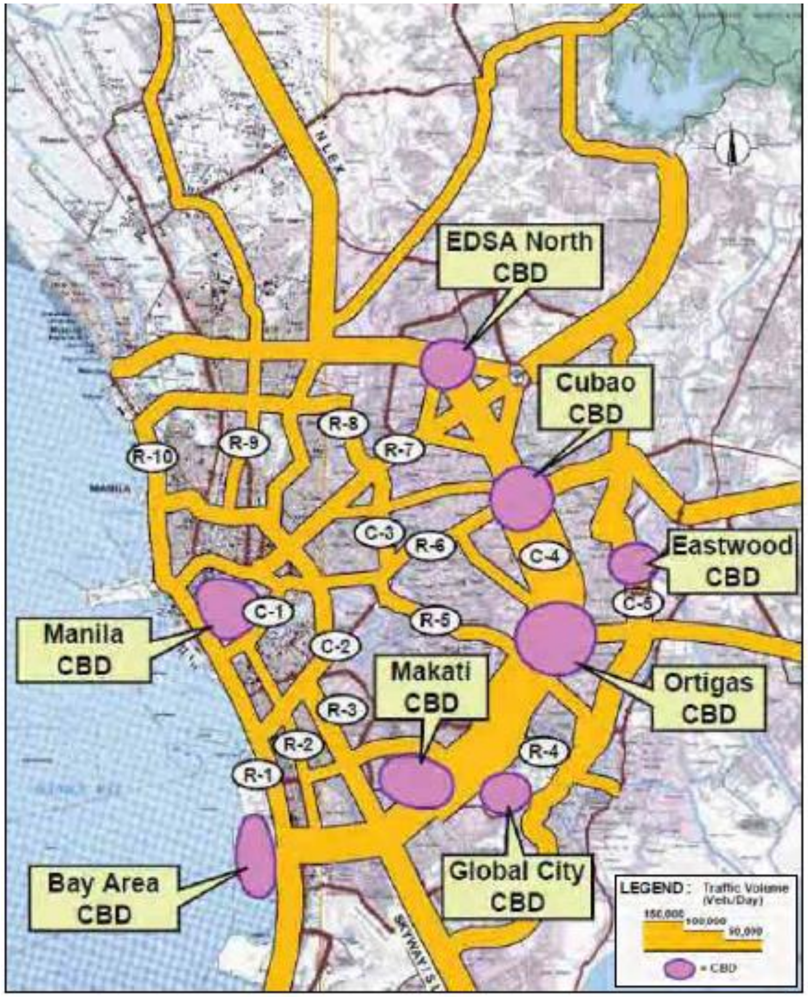

FIGURE 4 Major roads and CBD in Metro Manila (JICA, 2013).

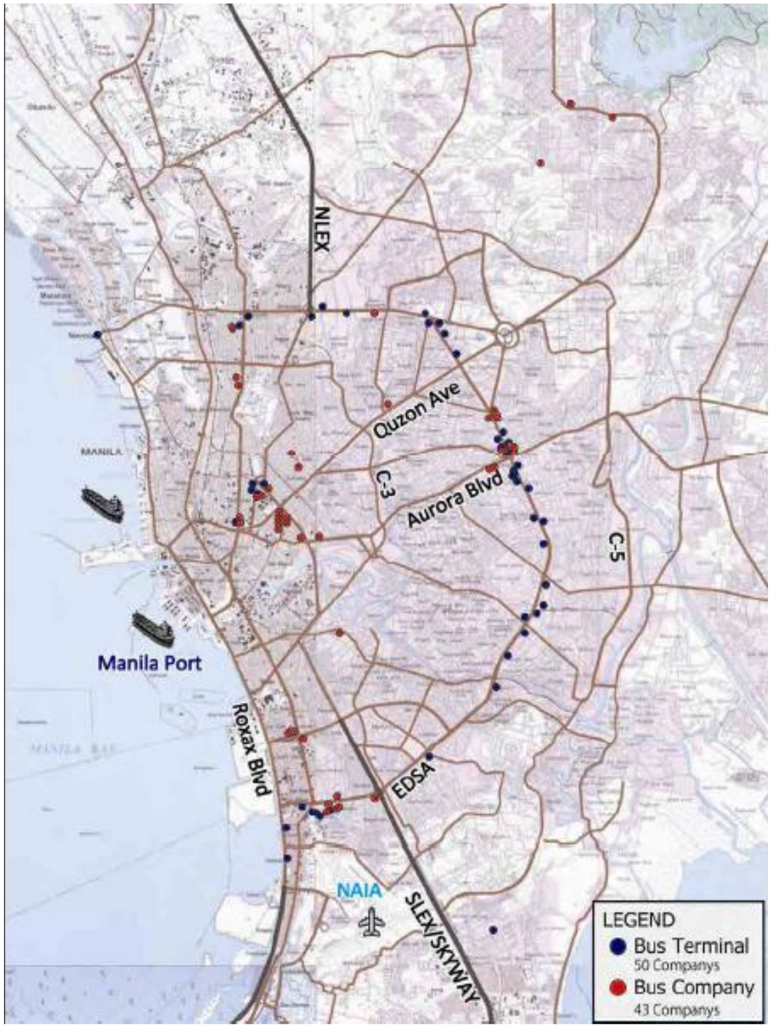

FIGURE 3 Location of bus terminals and companies in Metro Manila (JICA, 2013).

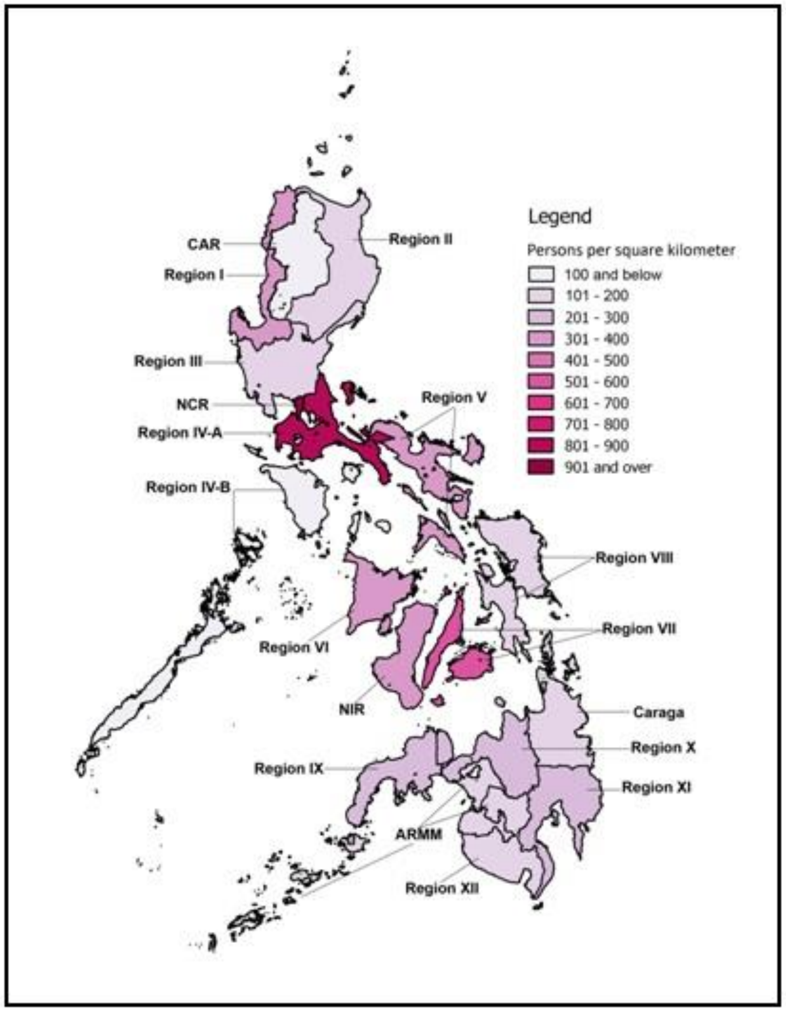

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FIGURE 5 Population density of the Philippines (PSA, 2015).

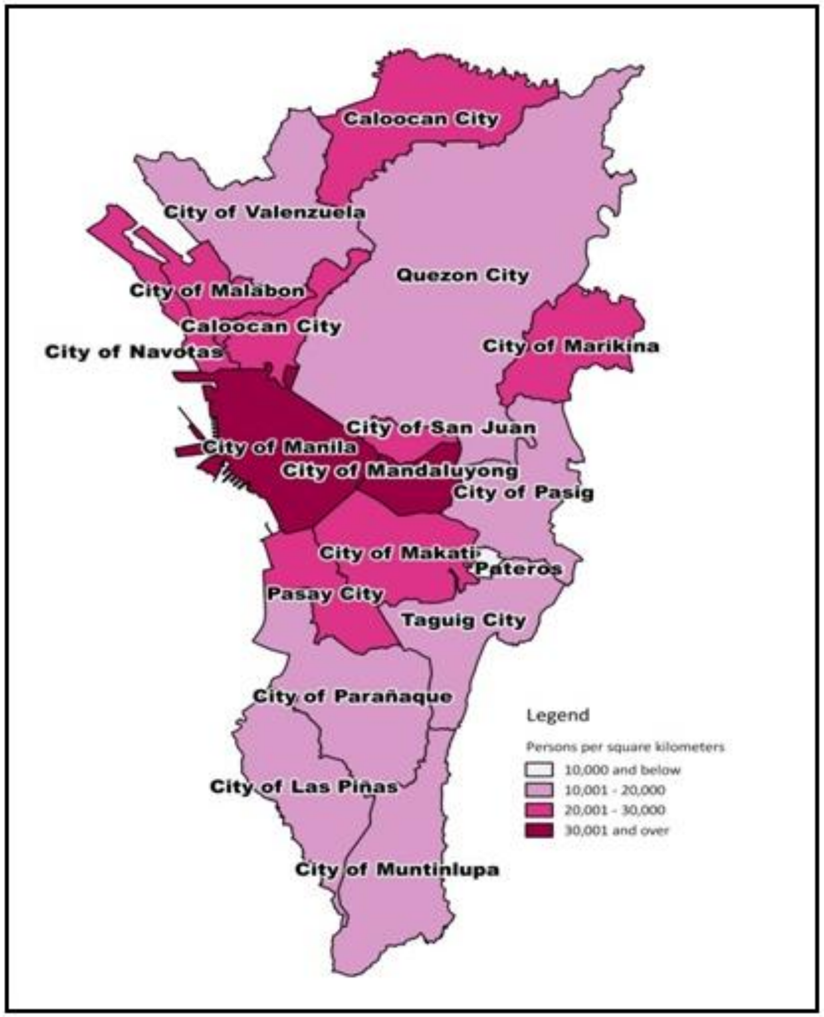
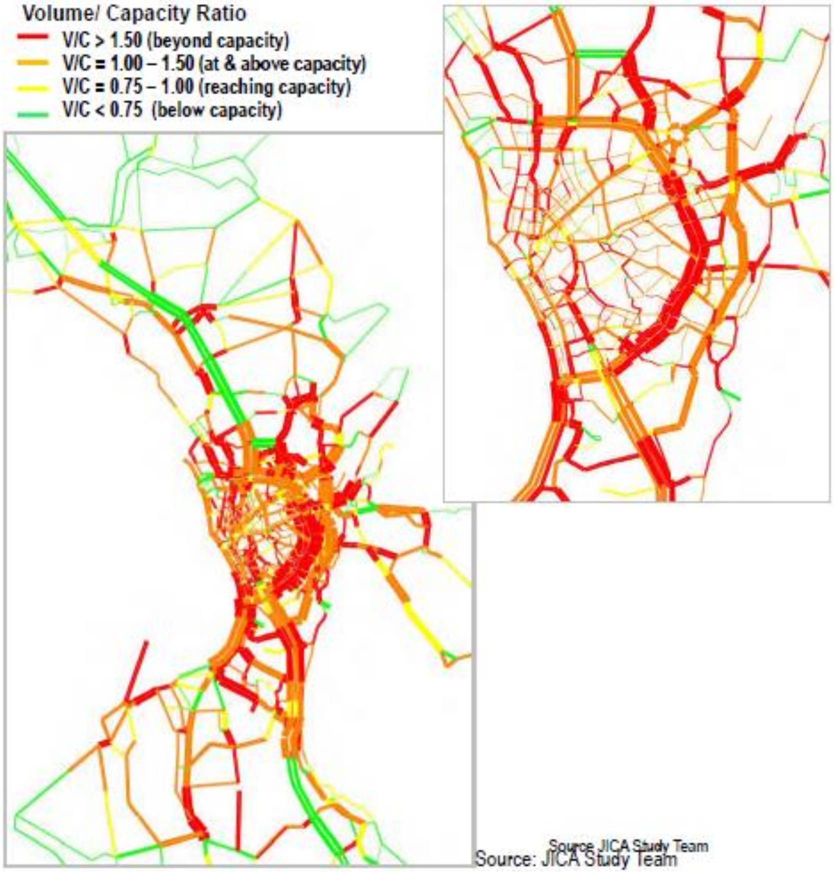


FIGURE 6 Population density of Metro Manila by Municipality (PSA, 2015).



Source: JICA Study Team

Source JICA Study Team

FIGURE 7 Traffic situation on Metro Manila Roads without intervention, 2030 (ALMEC Corporation, 2014).

In an economic perspective, road congestion accounts for 2-5% of the GDP in Asia (Division for Sustainable Development Goals, 2016). In Metro Manila alone, transport cost of road users including vehicle operating cost and time cost is PhP 2.4 billion a day which will increase to PhP 6.0 billion a day in 2030 in a do-nothing scenario (Almec Corporation, 2014).

TABLE 1 Traffic demand and impacts without interventions (Almec Corporation, 2014)

		2012	**2030**	**2030/2012**
Traffic Demand (mil. Trips/day)	Metro Manila	12.8	14.5	1.13
	BRLC	6.0	8.0	1.33
Public transport share in total demand		69%	69%	1.00
Occupancy of road space by private vehicles		78%	78%	1.00

Transport Cost (PhP billion/day)	Metro Manila		2.4	6.0	2.50
	BRLC		1.0	3.5	3.50
Air quality (million Tons/year)	Metro Manila	GHG	4.79	5.72	1.19
		PM	0.014	0.019	1.36
	BRLC	GHG	3.20	4.49	1.40
		PM	0.005	0.010	2.00

To address congestion issues, various measures such as increasing capacity or managing demand have been made to achieve the possibility of faster journeys leading to more longer trips made by road users which were deterred by the probability of time delays (Metz, 2018). Due to worsening traffic condition, government agencies around the world have been focusing their attention on policies that aim to increase the operational efficiency of urban streets (Castro & Delos Reyes, 2010). These transport policies, however, focused more in mobility based on motorized transport and improving traffic speed (Division for Sustainable Development Goals, 2016).

Same with developing cities within the Association of South East Asian Nations (ASEAN) region, the government are facing problems caused by rapid motorization and deteriorating public transport systems. Among the urban growth patterns that can be observed is sub-urbanization leading to an increase in the number of person-trips and trip distances. Another is the spread of informal settlers in the city center as well as the creation of commercial centers along EDSA (Mijares, 2014).

The traditional approach in solving traffic congestion and environmental problems is increasing transportation supply by expanding existing roads and constructing new highways. However, this has repeatedly failed due to the consistent increase in vehicles causing traffic congestion occurring soon after the intervention (Castro & Delos Reyes, 2010). Moreover, increasing attention has been directed towards policies designed in improving operational efficiency of urban streets (Castro & Hyodo, 2003).

In Metro Manila some of these policies, include the restriction of trucks within the city since they are perceived as slow-moving and occupy a large amount of road space hampering the smooth flow of traffic, especially during peak-periods. The intention of the policy introduced in 1978 was for buses and other public transport modes not to compete on the limited road space. Overall, the additional restrictions significantly increase the total vehicle kilometers, total-vehicle hours, and total pollutant emissions translating to increased transportation cost (Castro & Hyodo, 2003).

Moreover, with the implementation of the Philippine Clean Air Act of 1999 in 2000, several emission standards were enforced on motor vehicles starting 2003 by national government agencies and some local governments (Vergel & Tiglao, 2005). Travel demand management (TDM) strategies were designed to control demand for transportation system sources. The Unified Vehicular Volume Reduction Program (UVVRP) was enacted in 1996 by the Metro Manila Development Authority (MMDA) to regulate the operation of certain motor vehicles in all national, city, and municipal roads in Metro Manila (Gueta & Gueta, 2013).

The MMDA refined it to the number coding scheme (NCS) banning vehicles from plying to all the streets of Metro Manila on specific days of the week 9am to 5pm based on the last digit of the plate number of each vehicle. Some cities observe window hours from 10am-3pm, while others do not implement number coding scheme. The MMDA claims that there is a 20% reduction on the major streets and highways in Metro Manila but as of 2011, there is no existing study to support the claim (Gueta & Gueta, 2013).

A new rerouting scheme for buses was introduced recently to solve the heavily congested EDSA in Metro Manila. The memorandum circular released by the Metro Development Authority (MMDA) last June 21, 2018 aims to alleviate the traffic congestion along EDSA from Pasay City to Cubao, Quezon City in both the northbound and southbound directions by regulating the operations of the provincial buses in the said routes.

In a recent interview with the Traffic Engineering Center last 14 March 2019, provincial buses will no longer be allowed to enter the city and instead passengers need to transfer at designated interim terminals: the Valenzuela Gateway Complex in the north and at SM Sta. Rosa in the south. These terminals will be operational for the next 3-5 years and will be replaced by a permanent terminal in the future: at Ciudad de Victoria (CDV) in Bocaue, Bulacan and the Food Terminal, Inc. (FTI) in Taguig for the north and south, respectively.

There are numerous bus routes along EDSA due to the presence of office and commercial areas (JICA, 2013). As of 2017, there are 12,595 buses operating within Metro Manila as well as from neighboring provinces to Metro Manila. Of this, 3,711 operate the Manila-EDSA route. Excluding from this number are buses operating without franchise (called "colorums") which are estimated to be around 4,000 to 5,000 buses along EDSA alone (Llanto, 2017). The speed of these buses average from 16.3-19.4 km/hr during the day (Almec Corporation, 2014). Heavy vehicles like urban buses move frequently throughout the day and are mostly powered by heavy-duty diesel engines. Thus, their energy and environmental impacts should not be ignored (Wang, Ye, Yu, & Wei, 2018). In addition, Castro & Delos Reyes mentioned in their study that roads often pass close to populated areas, and thus like freight traffic, buses also potentially possess a public health risk.

1.2 Significance of the Study

At a global scale, urban growth is poorly planned or managed, resulting to sprawl and inadequate transport and infrastructure (Division for Sustainable Development Goals, 2016). Urban population growth in Metro Manila is increasing at a very rapid rate, resulting to the growth spilling over nearby towns and cities within a 30 to 50-kilometer radius of the metropolis. This densification has led many people to reside in the adjoining BRLC provinces, a large percentage of whom commute to Metro Manila daily (Almec Corporation, 2014).

Environmental awareness and sustainable development are some of the major concerns in both developed and developing countries (Wang, Ye, Yu, & Wei, 2018). Sustainable development depends in the successful management of urban growth especially in low-income and lower-middle-income countries. Urban growth is related to three dimensions of sustainable development: economic, social, and environmental (United Nations, 2018).

Moreover, numerous previous studies have already researched the deterioration of air quality from traffic source. Congested traffic corridors in dense urban areas are some contributors that lead to the degradation of urban air quality (Wang, Ye, Yu, & Wei, 2018). In a study conducted by the World Health Organization (WHO) in 2016, in all regions apart from high income Americas the populations are exposed to levels of fine particulate matter air pollution ($PM_{2.5}$) exceeding the annual mean value of 10 μg/m^3 stipulated in the WHO air quality guideline (AQG). As shown in Figure 8, the population-weighted exposures of urban areas in both low- and middle-income countries belonging in the Western Pacific region are over three times the WHO AQG value.

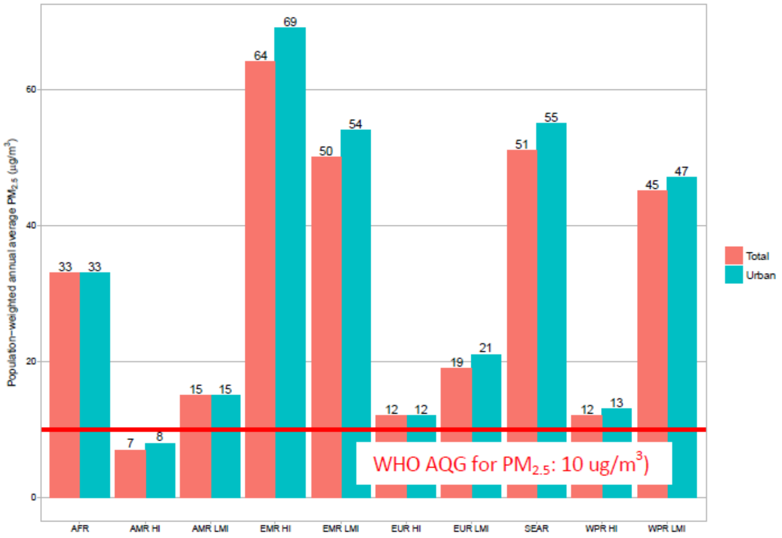


FIGURE 8. Annual average (population-weighted) exposure to $PM_{2.5}$ in μg/m^3 by region, 2016 (World Health Organization, 2018).

Note: AFR (Africa), AMR (America), EMR (Eastern Mediterranean), EUR (Europe), SEAR (Southeast Asia), WPR (Western Pacific), LMCI (Low- and middle-income countries), HIC (High-income countries)

Moreover, in most regions, the urban annual average exceeds that of the total annual average due to urban areas producing a disproportionate amount of road traffic emissions compared to their geographic size. Further, it has been known that tailpipe emissions from vehicles on urban roads have damaging impacts which has been worsened by the congestion issues. (Grote, Williams, Preston, & Kemp, 2016).

As highlighted by the Japan International Cooperation Agency (JICA) study in 2015, one of the problems with urban transportation is the pollution that has become a serious impediment to the quality of life and eventually to the health of the urban population. The United Nations also mentioned the urgent need for action in addressing the social environmental, and economic costs with the 'business as usual' scenario. Specifically, 3.5 million people die prematurely due to outdoor pollution including transport sources every year with 23% of energy-related greenhouse emissions from transport (Division for Sustainable Development Goals, 2016).

Further, as cited by Yai and Vergel in their 2002 study, as far back as 2000 there is already a growing consensus among more than 70% of the people in Metro Manila about the effects of motorized vehicle emissions on their health and air pollution (Vergel & Tiglao, 2005). Several studies revealed that vehicle emissions are still a serious issue in Metro Manila (Castro & Delos Reyes, 2010).

Studies conducted by the Philippine National Emission Inventory in 2008 revealed that 65% of total emission comes from mobile sources. These emissions contribute to total emissions of particulate matter (PM), volatile organic compounds (VOC), carbon monoxide (CO), and nitrogen oxides (NOx). The transport sector has also been found to be a large contributor to GHG emissions which are projected to still increase in the coming years due to increase in motorization. Air quality in Metro Manila is worse compared to other major Asian cities aside from Bangkok (Almec Corporation, 2014).

The WHO has estimated in 2014 that 7 million people die prematurely every year due to air pollution (Division for Sustainable Development Goals, 2016). PM 2.5 poses more harm, if inhaled, due to the possibility of reaching peripheral regions of the bronchioles and interfere with gas in the lungs. Moreover, there has been a high number of lower respiratory infections among the youngest members of society due to air pollution. Potentially productive members of society are affected by poor air quality during their formative years which will eventually affect the productivity of the labor force in the future. From an economic and social perspective, there is a need to improve traffic management to limit emissions (Almec Corporation, 2014).

It has been long recognized that there is a need to effectively integrate transport and land use policy by approaching land use and transport planning as two sides of the same coin (Division for Sustainable Development Goals, 2016). However, one of the key challenges in the integration of land use and transportation is the lack of integrating planning models capable of addressing air pollution, transportation, and health issues to aid in the decision-making for a comprehensive planning process (Almec Corporation and Oriental Consultants Co., 2015).

As early as 2008, traffic estimation estimates have been utilized in allowing decision makers to effectively manage local air quality (Nejadkoorki, Nicholson, Lake, & Davies, 2008). Local Government Authorities (LGAs) have the responsibility in facilitating the mitigation of emissions. Thus, it is crucial that LGAs can assess impacts on transportation interventions on road traffic emissions for an entire network (Grote, Williams, Preston, & Kemp, 2016). As governments continue to introduce new polices when it comes to alleviating traffic congestion, they should also consider its effects on the environment and thus, on the people affected as well. In encouraging transportation interventions, it is critical that decision makers can assess environmental impacts along with the impact on road traffic emissions. To do this, there is a need to quantify the intervention's effect on emissions (Grote, Williams, Preston, & Kemp, 2016).

Similar to the study of Nejadkoorki et al in 2008, the estimation and modelling of emissions can be a powerful tool for air quality managers and environmentalists in examining the impact of different transport plans such as the reduction of personal mobility, restructuring urban areas and switching low carbon vehicles. They also identified the growing need of examining how overall emissions can be managed by local decision makers in reducing its impact as a greenhouse gas.

Hence, this paper can aid traffic managers and local policy makers in the understanding of the effects of policies not only in the traffic perspective. The study can be used as a tool in investigating impacts on the environment of transportation decisions. Moreover, the importance in utilizing available data to LGAs in the estimation of network level emissions and informing effective policy is a relatively new research area (Grote, Williams, Preston, & Kemp, 2016). Thus, this paper can add to existing literature.

1.3 Formulation of the Research Question and Sub-Research Questions

The hypothesis is that with the newly implemented rerouting scheme there would be an improvement in traffic condition along EDSA but there is an effect on the vehicle emissions and traffic conditions along the rerouted path.

Thus, this study attempted to answer the question: Is there a significant improvement in terms of traffic and vehicle emissions with the proposed rerouting of public buses along EDSA?

To achieve the research question, the following sub-research questions were also listed:

1. What are the kilometers covered, average speed, and estimated vehicle emissions for the 2020 base traffic condition, 2025 without policy condition and 2025 with policy condition?
2. Is there an improvement in terms of traffic condition and vehicle emissions in Metro Manila between the 2020 base traffic condition, 2025 without policy condition and 2025 with policy condition?
3. Is there an improvement in terms of localized traffic and environmental impacts with the introduction of the policy along the proposed rerouting scheme for the year 2025?

1.4 Scope and Limitation of the Study

The study area includes the entire Metro Manila traffic model, similar to the 2015 MUCEP study. However, the road networks only include the affected routes for the proposed policy: NLEX, Paso de Blas, EDSA, SLEX, and San Pedro National Highway.

Policy in this study only concerned the proposed rerouting ban along EDSA. However, policies concerning other modes of transport was not be covered. Moreover, to test whether there is an improvement with the introduction of the policy, the existing traffic conditions were compared to their respective alternative scenarios for each year.

Buses in this study only focused on those using the EDSA route, both the intercity and the provincial buses. Moreover, to see whether there was an effect in localized traffic and environmental impacts with the introduction of the policy, the scenarios was also tested in two spatial areas: network and specific roads.

In terms of emissions, the UP-NCTS emission factors were used. Only vehicle types which have corresponding emission factors were included in the computation. Percentage distribution of fuel sources were based on the records available from LTO and PSA.

Moreover, other routes that do not use EDSA was not analyzed but was still covered in the traffic model. Further, the effect of modal shift from public transport to private transport caused by the introduction of the policy was not covered in this study. In terms of road network, small local streets that will not be affected by the ban were not included as seen in the road network.

2. REVIEW OF RELATED LITERATURE

2.1 Vehicle Emissions

Buses contribute to pollution levels through direct emissions from the vehicles and by the resulting chemical reactions from the emitted pollutants with each other or with the materials in the atmosphere (Wang, Ye, Yu, & Wei, 2018). These vehicle emissions can be subdivided into different groups depending on their chemical composition.

2.1.1 Particulate Matter

Particulate matter or PM consists of a complex mixture of solid and liquid particles of organic and inorganic substances suspended in the air. Major components include: sulfate, nitrates, ammonia, sodium chloride, black carbon, mineral dust and water. Depending on the size of the particle, it can affect the areas in which it can affect the human body. Particles with a diameter of 10 microns or less ($\leq \mathrm{PM}_{10}$) can penetrate and lodge deep inside the lungs. Whereas, particles with a diameter of less than 2.5 microns ($\leq \mathrm{PM}_{2.5}$) can penetrate the lung barrier and enter the blood system. Exposure to these particles may contribute to the risk of the development of cardiovascular and respiratory diseases (World Health Organization, 2018).

2.1.2 Volatile Organic Compounds

Volatile organic compounds or VOCs are a large group of organic chemicals that include any compound of carbon. They are important since during photochemical reactions, airborne VOCs together with airborne nitrogen oxides, and sunlight, contribute to ozone formation. They also play a role in the formation of secondary organic aerosols found in airborne particulate matter. Lastly, they are known to be harmful to human health although it varies per pollutant. There are several sources of VOCs such as motor vehicles, chemical manufacturing facilities, refineries, factories, consumer and commercial products, and natural sources among others (Environmental Protection Agency, n.d.).

2.1.3 Carbon Monoxide

Carbon Monoxide or CO forms primarily when carbon fuels are not burned completely, a majority of which is accounted by mobile sources. Specifically, these sources include both on-road (e.g. cars, trucks, buses) and non-road vehicles (farm equipment, construction equipment, aircraft). High concentrations of CO generally occur in areas with heavy traffic congestion (Environmental Protection Agency, n.d.).

2.1.4 Nitrogen Oxides

Nitrogen Oxides or NOx represent a family of seven compounds formed by reacting with the chemical element nitrogen. The diatomic molecular nitrogen N_2, a relatively inert gas makes up about 80% of the air in the atmosphere. The chemical element nitrogen (N) as a single atom can be reactive to form several different oxides such as nitrous oxide, nitric oxide, dinitrogen dioxide, dinitrogen trioxide, dinitrogen trioxide, nitrogen dioxide, dinitrogen tetroxide and dinitrogen pentoxide. Specifically, nitrogen dioxide (NO_2) the most prevalent of NOx in the atmosphere reacts in the atmosphere to form ozone (O_3) and acid rain. NO_2 reacts in the presence of air and ultraviolet light (UV) in sunlight to form ozone and nitric acid NO. The NO then reacts with free radicals in the atmosphere, which are also created by UV that acts on VOCs. The free radicals then recycle to NO to NO_2 ,creating a cycle that produces ozone multiple times. Acid rain, together with cloud and dry deposition, severely affects certain ecosystems and directly affects parts of the economy. Thus, there is an obvious need to reduce NOx emissions (Environmental Protection Agency, 1999). Major sources of NO_2 include are combustion processes such as heating, power generation, and engines in vehicles and ships (World Health Organization, 2018).

2.2 Emission Models

The study of Grote, Williams, Preston, and Kemp in 2016 presented a review of literature regarding road traffic data and its use by LGAs in emission models (EMs). However, their study was only limited to GHG emissions specifically carbon dioxide since it is the largest contributor to GHG transportation emission. Overall, their study focused on the review of estimation emissions for an urban road network.

The study identified several major factors that influence emissions. Tailpipe emissions such as fuel combusted inside the vehicle are usually estimated by multiplying activity data by emission factors (EFs). In this case, the distance travelled by a vehicle (vehicle kilometers, VKMs) has a large influence on emissions such that greater activity will lead to greater emissions. Moreover, vehicle speed is another major influence on emissions, since road traffic EFs are strongly dependent of speed. Lastly, vehicle category has a significant influence on emissions since they have corresponding EFs dependent on vehicle mass, fuel specification, engine size, aerodynamics, and emissions control technology (Grote, Williams, Preston, & Kemp, 2016).

Other factors in the study considered congestion which is defined as “the deterioration of smooth, free-flowing traffic conditions due to increased travel demand and/or reduced traffic movement by capacity”. It is typically assumed under stop-and-go conditions associated with congestion that there is an increase in the number of acceleration and deceleration activities by vehicles resulting to increased emissions. In several studies, it has recognized congestion as a major factor in the estimation of road traffic emissions ranking alongside VKMs, vehicle speed and vehicle category (Grote, Williams, Preston, & Kemp, 2016).

Other factors affecting emissions also include: driver behavior and gear-shift strategies; road gradient; cold starts; ambient temperature; increasing vehicle age or lack of maintenance; use of auxiliaries, and vehicles using alternative drive trains or fuels. However, it is emphasized to use congestion over other factors since the influences of the remaining factors are relatively smaller. But it is also acknowledged to include these remaining factors whenever applicable (Grote, Williams, Preston, & Kemp, 2016).

The main input required in EMs are road traffic data made available from several sources. Traffic counts (manual or automatic) record the number of vehicles passing a location and can include vehicle category data. Automatic Number Plate Recognition (ANPR) cameras read vehicle license plates that allows the determination of vehicle category, and collection of journey time data from time taken for vehicles to travel between camera locations. Moving Car Observer (MCO) method uses observers in a test vehicle in deriving average journey times and traffic flow data. Queue length surveys manually record the number of queueing vehicles or queue length in meters, and often include corresponding delay times. These resources have limited use in the prediction of emissions, either due to restricted availability to few locations or involvement in resource-intensive data acquisitions, or both (Grote, Williams, Preston, & Kemp, 2016).

National vehicle category data are usually available from fleet models typically provided by a country’s government or a delegated authority. Measurements of the characteristics of the road network itself provide another useful source of traffic data such as: link length, number of lanes, link curvature intersection layouts, number of intersections per kilometer, speed limits, signal timings or roadside land use (Grote, Williams, Preston, & Kemp, 2016).

Lopez-Martinez et al (2017) mentioned that there are several methodologies developed in the estimation of vehicle emissions. These can then be classified into two groups: a macro-scale approach and a micro-scale approach (Nejadkoorki, Nicholson, Lake, & Davies, 2008). While the study of Grote, Williams, Preston, & Kemp in 2016 identified several types of EM models to estimate EFs dealing in order of complexity from simpler EMs to more complex EMs as shown in Figure 10.

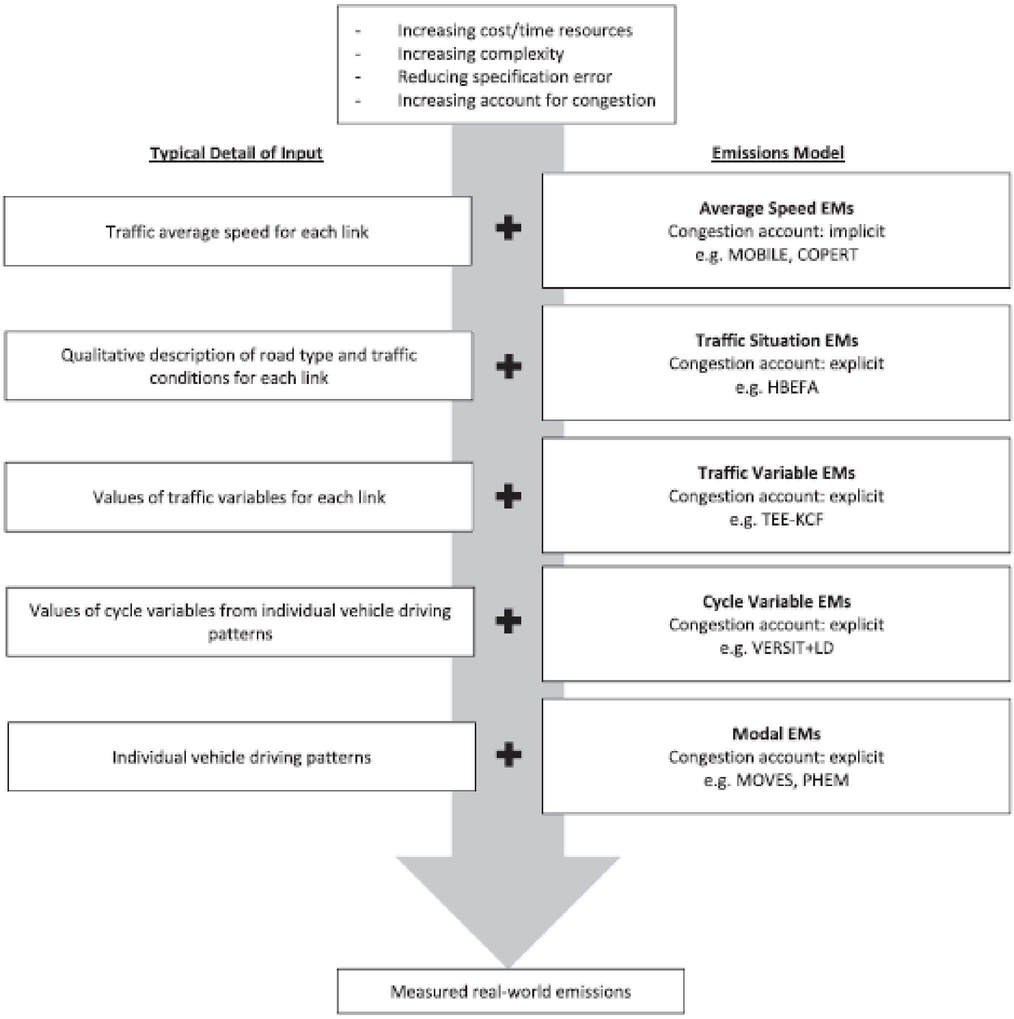


FIGURE 9 Emissions model classification (Grote, Williams, Preston, & Kemp, 2016).

The first approach identified by Lopez-Martinez et al evaluates emissions in large geographical areas, countries, regions or others, which takes into account the number of vehicles moving in the identified areas. This usually considers weight, technology incorporated (particularly the power train), fuels used and other variables affecting consumption and emissions. It is a type of methodology that looks at the problem at a macro level that factor in infrastructures as well as speed and among other variables, type of road, terrain and vehicle (Lopez-Martinez, et al., 2017).

The estimations at this level cannot be precise since the sources of the average values of the variables such as speed for each vehicle type depend on the degree up to which the said data can be further broken down. Along with the vehicle estimations, emission factors of each vehicle type are required which are usually from databases that required these factors to be adapted to local traffic situations and fleet composition thus further reducing the uncertainty of the calculations. If not performed properly, approximations in the computed values would have questionable error level.

But this method is still acceptable for emission inventory purposes (Lopez-Martinez, et al., 2017).

The second approach provides a more precise knowledge when it comes to emissions of a smaller vehicle population or vehicle fleets that operate in environments that are easier to identify. Moreover, this provides an opportunity in obtaining real data on vehicle emissions as well as operating conditions with the use of on-board measuring equipment. In this case, the methodology looks at the problem at a micro or local level (Lopez-Martinez, et al., 2017). Further, the estimates from this approach can be integrated over time and space providing estimates on a regional scale (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

As mentioned by Namdeo et al in 2002 (as cited by Nejadkoorki, Nicholson, Lake, & Davies, 2008), the use of a micro-scale approach is preferable in the prediction of emissions in urban areas due to the significant variation of traffic densities and speeds over relatively short distance and time scales. It is also important to note that this approach gives a chance for the impact of changes in local infrastructure and patterns to be investigated which can eventually identify potential alternative options in the reduction of emissions like changing fleet composition, low emission zones, and congestion charging (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

Looking at a more specific perspective, there are several EMs available in calculating EFs as previously mentioned. Average speed emission models calculate EFs for each vehicle category as a function of traffic average speed (space-mean-speed). A significant number of EMs are presently based on average speed since for larger urban networks, readily available data are limited to estimates of average traffic speed for each link. However, one limitation of this approach is that they consider that trips with different vehicle operation characteristics all have different emissions but will lead to the same average speed. This would be a problem for low average speeds like congested urban areas where there is a high possibility of a wide range or operational characteristics for a given average speed. But eventually this would average out on a network level. For example, the increase in emissions due to a stop-and-go condition at particular locations (model under-estimating) will be offset by decrease in emissions from free-flowing conditions at other locations (model over-estimating) (Grote, Williams, Preston, & Kemp, 2016).

Moreover, Average Speed EMs indirectly accounts for congestion influence due to driving cycles that are used in vehicle emission tests generating data wherein EMs are developed resulting to a dynamic speed-time profile. Some examples of these EMs are COPERT (Europe), MOBILE and EMFAC (USA), and TRL EFs 2009 (UK) (Grote, Williams, Preston, & Kemp, 2016).

Traffic Situation EMs correlate the parameters of emission tests and their associated average EFs to specific traffic situations resulting in each traffic situation being referenced to an average EF. Traffic situations differ on their characteristics by road type such as a speed limit, and a qualitative description of congestion, for example, either free-flowing or a stop-and-go. Using this model, the user identifies the traffic situation and then weights the appropriate average EFs for different vehicle categories according to traffic composition. An example of this EM is the HBEFA widely used in Europe. However, the model is designed for traffic situations representative of traffic conditions in specific European countries and limits its applicability to other countries (Grote, Williams, Preston, & Kemp, 2016).

Traffic Variable EMs predict EFs based on variables aggregated for the traffic as a whole. In this way, the congestion influence is allowed to account for explicitly and quantitatively. Traffic variable is defined here to cover network characteristics due to their influence on traffic movement capacity. An early example is provided by the Traffic Energy and Emissions-Kinematic Correlation Factor (TEF-KCF), which attempted to overcome the limited ability of Average Speed EMs in accounting congestion using KCF.

Cycle variable EMs calculate EFs for individual vehicles as a function of variables derived from a vehicle's driving cycle i.e. number of stops per km, average speed, maximum acceleration, idle time, etc. In this model, the vehicle's driving pattern is required as an input, meaning congestion influence is explicitly included. However, the necessary driving patterns for each vehicle can only be acquired from micro-RTM (Road Traffic Model) or vehicles equipped with a GPS device. One example of this model is the VERSIT + LD (for Light Duty Vehicles) originally developed as a Cycle Variable EM and consisting of statistical models that were constructed using multiple linear regression analysis of emissions test data to find an empirical relationship between EF and driving cycle variables for each vehicle category. Later changes to this model led it to be more related to the next type of EM (Grote, Williams, Preston, & Kemp, 2016).

Modal EMs calculate EFs for individual vehicles as a function of vehicle or engine operating mode. This typically requires the vehicle's driving pattern as an input meaning congestion as an influence is included. The recent version of this model predicts EFs for operating modes at high time resolutions typically termed as Instantaneous EMs (IEMs). The EPA has the Motor Vehicle Emission Simulator (MOVES) characterized by operating modes of a combination of vehicle speed and VSP, divided into bins with each speed-VSP having their respective EF. Another example is the Passenger car and Heavy-duty Emissions Model (PHEM) which uses a vehicle driving pattern, vehicle characteristics data, and a model of gear shift behavior, in computing instantaneous values of engine power and engine speed which in turn is used in determining the associated EF (Grote, Williams, Preston, & Kemp, 2016).

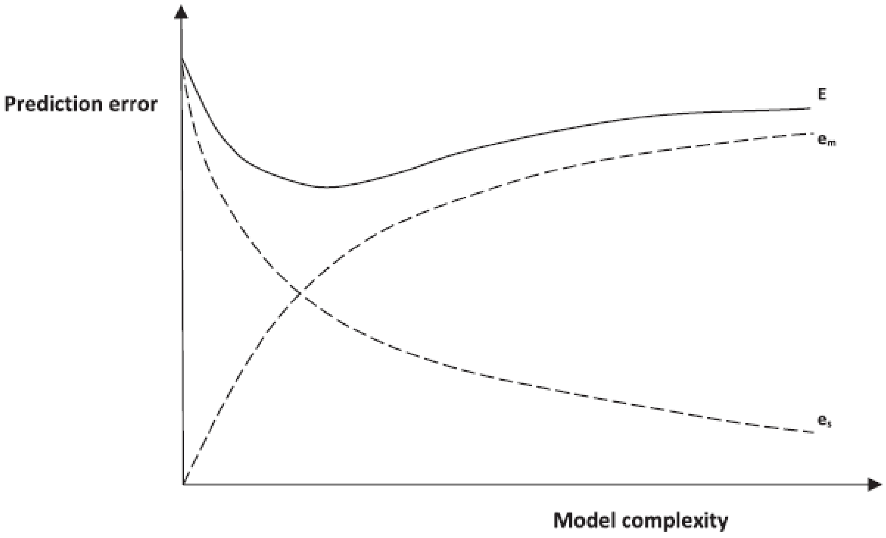
Existing methodologies for network emissions estimation that are based on traffic variables usually have limitations. Smit et al mentioned in 2006 and 2010 that it is unrealistic in measuring real-world emissions at road network level due to the large number of vehicles and traffic conditions involved. (Grote, Williams, Preston, & Kemp, 2016). For either macro or micro scale emission model, a basic issue must be resolved: the determination of the emission of vehicle types of the vehicle fleet while considering the fuel for each driving cycle (Lopez-Martinez, et al., 2017).

EMs must strike a balance such that they must not be too simplistic and end up failing to capture the majority of the emissions impact of potential interventions, but as well as not be too complex entailing more time and expertise in building and running models and collecting necessary input data (Grote, Williams, Preston, & Kemp, 2016). Several studies also highlighted that finely detailed input data are susceptible to errors in estimation, measurement or assumptions meaning that lack of quality input data may offset any accuracy gained in increasing model complexity. Alonso in 1968, identified two error sources: specification error arising due too models being simplified representations of real-world phenomena; and measurement errors in input data. By summing both errors, we obtain the total model error. Figure 10 shows the optimal model complexity wherein the total prediction error is minimized (Grote, Williams, Preston, & Kemp, 2016).

It is evident that whatever the approach used, the values computed are dependent on how representative the emission factors are, which are an adjusted description of the vehicle type and the driver cycles tested. For this reason, aside from the in-laboratory experiments to compute emission factors, real-world condition measurements are also taken such as tunnels, remote-sensing, on-road and on-board measurements, which are all possible with the use of Portable Emission Measurement Systems (PEMS) (Lopez-Martinez, et al., 2017).

As identified by Lopez-Martinez et al (2017), there two basic characteristics of emission measurements in real world cycles:

1. real emissions are an unrepeatable experiment since the data is provided in the absence of a standard test cycle;
2. this experiment includes all sources of variability such as environmental conditions and traffic, driver behavior, or highly transitory operation or the variable operating conditions of the vehicle.



- E is total prediction error.
- e_m is measurement error.
- e_s is specification error.
- Source: adapted from Alonso (1968).

FIGURE 10 Model complexity and prediction error (Grote, Williams, Preston & Kemp, 2016).

At both local and international level, several studies have been conducted that focus on vehicle emissions, its impact and ways on how to conduct such as study. For example, the study conducted by Lopez-Martinez et al (2017), presented a methodology for calculating fuel consumption and emissions of vehicle fleets that operate in urban areas (CEFLOUR) which was developed by the University Institute for Automobile Research, Technical University of Madrid (INSIA) and then applied to the Madrid Municipal Transport Company (EMT) bus fleet. This fleet comprised approximately 2000 buses with 20 different bus types including the drive system and fuel used. The methodology was developed to assess the effect of substituting groups of vehicles for another group of different propulsion technologies and fuels in specific groups of routes or the entire network.

The methodology includes: characterizing and grouping the EMT bus fleet into clusters; calculating the fuel consumption and emission models of the different pollutants based on tests with on-board equipment and their subsequent modelling; specifying the operational characteristics of a representative sample of the bus lines (about 167 within the city) using on-board equipment tests and subsequent analysis including other variables such as the gradient of the various routes and occupancy levels.

Moreover, a calculation program was developed to perform a generalized calculation of the fleet and routes as a whole by considering the data related to the journeys of the vehicles on the route. The results were then validated by taking the fuel consumption estimation of the mode which was the only variable that have data outside the calculation model, resulting to an acceptable fit.

The CEFLOUR methodology considers of the vehicles actually used in the transport service and their respective actual operating conditions. It comprises of three fundamental calculation blocks which are denoted as M-1, M-2 and M-3, respectively. A summary of the CEFLOUR methodology is illustrated in Figure 11.

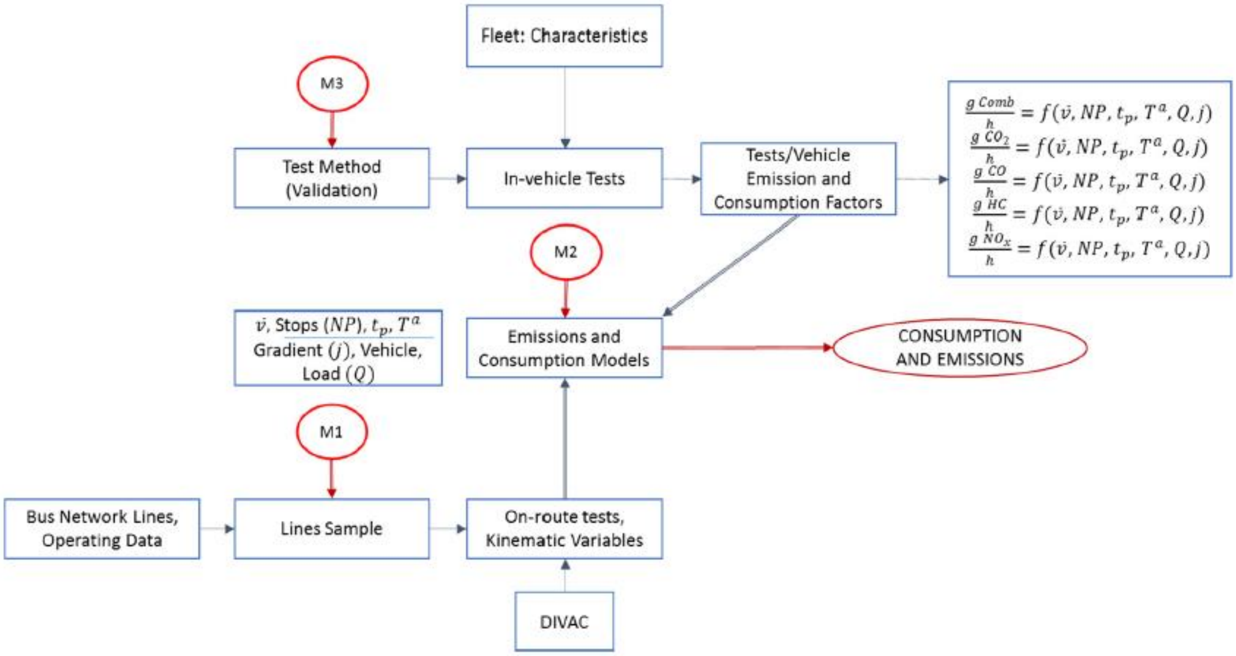


FIGURE 11 CEFLOUR methodology (Lopez-Martinez et al, 2017).

The first calculation M-1 is the calculation of the vehicle fleet emission and consumption models. In reality, a vehicle fleet is made up of groups of vehicles that use different technologies, years of manufacture and emission standards used for homologation and fuels. In this calculation, the first step is to characterize the different vehicle types and group them on terms of the characteristics on consumption and emissions. The second step would be the selection of the test samples for each group with similar characteristics and testing in accordance with protocol to determine records of consumption and emissions under conditions representative of actual use within the various routes of operation by EMT: different acceleration-deceleration-stop cycles; different route profiles and different occupancy levels.

The second calculation M-2 is the determination of the operating conditions of vehicles that influence on fuel consumption and emissions. To reduce the number of tests, a set of representative operating lines within the city of Madrid were selected. Routes having similar characteristics of average speed parameters, number of stops, etc. were divided into clusters. Afterwards, a sample was chosen and tested using a kinematic variables recorder (DIVAC) that was designed and built for the study.

The third calculation M-3 is the estimation of the total fuel consumption and emissions of an urban operated vehicle fleet. The values computed in the previous calculation blocks were incorporated to a calculation program wherein the data on the set of transport routes were entered to their respective cluster programming. With the help of the program, the total fuel consumption and emissions of the fleet can be estimated for the entire routes under operation. The CEFLOUR program was then applied to the study area using the workplan methodology as the first three steps shown in Figure 12.

The next step in the procedure was the emissions measurement. In this step, the CO_2 data and regulated emissions like CO, THC, NOx and fuel consumption in vehicles and routes under real-world conditions were collected using the on-board Horiba OBS 2200 system that used by the authors in previous studies. Moreover, particle measurement was collected using the DPMS-04 instrument from the MAHA Company. The fuel consumption was accurately determined from mass emission of CO, CO_2, and THC.

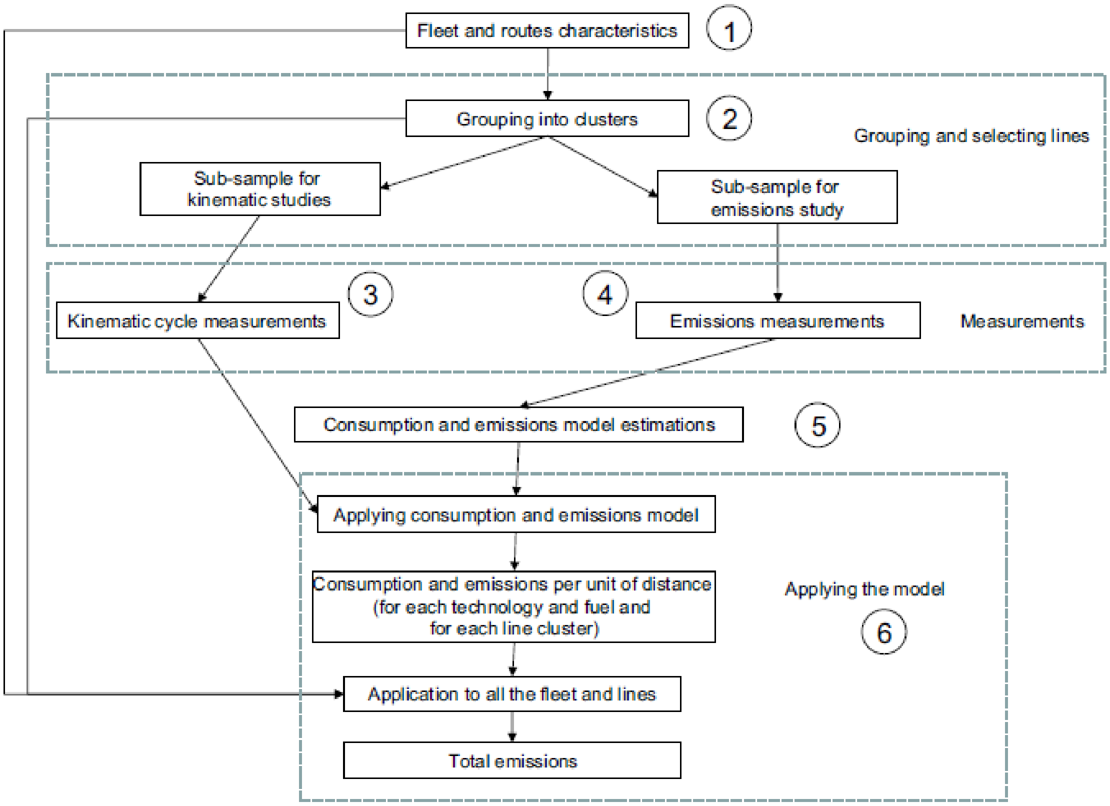


FIGURE 12 Workplan methodology (Lopez-Martinez et al, 2017).

After the emissions measurement, fuel consumption and emissions model were estimated. In the emissions model used, the test results were analyzed separately for the stationary and movement cycles with the consideration of respective variables. For the stationary interval, wherein the bus is halted, the fuel consumption and emissions were modelled using average values (grams/second) considering only the stop time. Meanwhile, for the movement cycles, wherein the vehicle speeds were greater than 5km/hr, the kinematic variables such as average speed, maximum speed, acceleration process and cycle duration; fuel, occupancy, and the geography of the section were considered.

Models were developed using general regression models for the three urban routes covering most driving situations in the city. These models were then experimentally validated such that the error committed in the estimation of consumption and emissions along the entire journey within a route with respect to the actual experimental measured values were adjusted. In this case, two driving routes aside from those used in the development of the models were travelled.

Finally, the model was then applied to the study area with four different renewal scenarios: buses using diesel fuel and then changed to biodiesel B100 without modifying bus-types regarding Euro standard; all diesel and biodiesel buses are replaced by a fleet of vehicles meeting Euro IV standards and are biodiesel-driven, gas vehicle fleet is not changed; entire bus fleet is made up of vehicles that meet Euro IV standard, and are bio-diesel driven; and the entire bus fleet is made up of natural gas-driven (CNG) vehicles.

In this study, it was found that the first alternative situation leads to slight reductions in HC, CO and particles, that however leads to slight increases in CO_2 and NOx. The second alternative scenario lead for more significant reductions in HC, CO and PM and increases in NOx. The third scenario were even more favorable in the reduction of HC, CO, and PM although there was an increase in NOx. Lastly, the fourth alternative scenario lead to increases in HC and CO emissions, but lead to a significant reduction of NOx emissions and a complete reduction in PM.

Significant highlights in the study by Lopez-Martinez et al includes the determination of the kinematic operating cycles of the vehicles with the use of low-cost on-board equipment, development of emission models and fuel consumptions according to respective variables in the operating cycle, load state or the geography of driving route, using measurements by on-board instrumentation, a calculation method that allows fuel consumption and emission values to be estimated for the entire route or for a single route in particular.

Compared to the study of Lopez-Martinez et al, wherein the emission rates were collected using an on-board equipment, the study of Wang et al in 2010, used two methods in collecting emission rates: a laboratory driving cycle and a testing vehicle on actual on-road driving conditions. Emissions from traffic interrupted transport microenvironments were determined by developing the composite line source emission (CLSE) model in the evaluation of the of the particle number concentrations along a platform with the construction of a single representative line source. The method used was driving a vehicle through standard driving cycles in a laboratory (Wang, Ye, Yu, & Wei, 2018).

However, the emission rate used for this study was a limitation since it was from a dynamometer test and was used to estimate estimations during driving conditions regardless of the speed or acceleration or deceleration. This only shows that test conditions limit the accuracy of the estimates since they may not represent real-world conditions. To improve this limitation, the second method of estimating emissions was developed.

In this case, emissions are measured directly from testing vehicles that are situated on actual on-road driving conditions. For example, a second-by-second GPS data which includes latitude, longitude, time, and speed, was used in the estimation of vehicle specific power (VSP) and bus emissions near bust stops in the study of Li et al in 2012. The use of Portable Emission Measurement System (PEMS) in recent years have become a crucial method in the field of vehicle real-world emission research since it has the ability to obtain real-time characteristics straight from the tail-pipe for real-world driving conditions as cited by Yu et al in 2016 (Wang, Ye, Yu, & Wei, 2018).

Further, Unal et al hypothesized in 2003 (as cited by Wang, Ye, Yu, & Wei, 2018) that a study can be designed and executed to collect, analyze, an interpret real-world on-road emissions data which uses a comparison associated with a change in traffic control. In this study, it was found that congestion conditions affect total emissions such that total emissions for NO, Com and HC were higher in congested situations compared to uncongested situations (Wang, Ye, Yu, & Wei, 2018). This also supports Grote et al's statement that congestion is a major influence on emissions.

In the study, two primary objectives were presented: to compare the changes in bus speed, acceleration and emissions between stops, intersections, and road sections by applying statistical methods; and to develop a VSP-based artificial neural network (ANN) model to estimate the emissions of CO, HC, NOx, and CO_2 for four different fuel types. The fuel types include gas-electric hybrid electric buses (GEHE bus), compressed natural gas buses (CNG bus), EURO 4 heavy-duty diesel engine buses (EURO IV bus), and EURO 5 heavy-duty diesel engine buses (EURO 5 bus).

VSP is defined by Jimenez-Palacios et al (1998) as "the instantaneous power per unit mass of the vehicle generated by the engine used to overcome the rolling resistance and aerodynamic drag and to increase the kinetic and potential energy of the vehicle". Compared to a stochastic approach, the ANN makes no prior assumptions with the data distribution and is particularly suitable for modelling multifactor, uncertainty and non-linearity. Thus, it has increasingly been applied and evaluated for regression analysis and the forecasting of air pollutant emissions (Grote, Williams, Preston, & Kemp, 2016).

To achieve the first objective of the study, the following steps were utilized:

1. testing differences in emissions of CO, CO_2, HC, and NOx – (Based on collected emission data, statistical analysis was conducted to test differences between stops, intersections, and road sections for the four types of buses);
2. bus emission estimation using a VSP-based artificial neural network ANN model – (Numerous models adopted VSP as a primary parameter due to its direct physical interpretation and strong statistical correlation with emissions.

Moreover, ANN models do not require prior relationships between the independent and dependent variables and was found to be a consistent alternative method for analyzing relationship between output results and explanatory variables.)

To test the significance of the differences between two means from two different samples, the Student's t-test is often used (Wang, Ye, Yu, & Wei, 2018). Consider μ_1 and μ_2, and s_1 and s_2 to be the mean and variance at two different sites, respectively. The null hypothesis states that both means are equal:

$$H_0: \mu_1 = \mu_2$$

versus

$$H_1: \mu_1 \neq \mu_2$$

H_0 can be rejected if

$$Z^* = \frac{(x_1 - x_2) - (\mu_1 - \mu_2)}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}} \geq Z_{\propto/2}$$

where

$n_1$and n_2	the sample sizes for two different samples
ɑ (ɑ=0.05)	the significance level
$Z_{\propto/2}$	the 100(1-ɑ/2) % percentile of standard normal distribution (Wang, Ye, Yu, & Wei, 2018).

As cited by Wang et al in the same study, Qi et al in 2004 mentioned that vehicle emissions relate to vehicle operation in the current and immediate past time periods. Thus, not only are bus emissions a function of current operation condition (VSP), but they are also a function in the immediate past time period, expressed as acceleration and speed in the past one second:

$$emission_{\delta}^{\tau} = f\ (VSP, a^*, v^*)$$

where

$emission_{\delta}^{\tau}$	the different pollutant emissions for different types of buses
δ	the pollutant emissions including CO, HC, NOx, and CO_2
τ	the different types of buses including the GEHE bus, CNG bus, EURO 4 bus, and EURO 5 bus
a^* and v^*	the acceleration and speed of the bus in the immediate past one second, respectively

Among the ANN systems the most common is the back-propagation neural network (BPNN), which is a layered network consisting of an input layer (I), an output layer (O), and at least one hidden layer (H). These layers are composed of several neurons and interconnected by sets of correlated weights (Chen, 1990 as cited by Wang et al, 2018). In this model, the error at the output layer will propagate backward to the input layer using the hidden layer and then generate the final desired outputs. The gradient descent method calculates the weight of the network and then adjusts the weight of interconnections to minimize the output error.

The field data collected for this study was for four fuel types of buses as previously mentioned. The characteristics of the buses selected were homogenous in terms of vehicle age, load, and size to exclude other confounding factors on bus emissions. The second-by-second by second gaseous exhaust emissions were measured using an AUTOplus automotive gas emission analyzer. Moreover, a global positioning system receiver was used for the collection of vehicle speed and acceleration on a second-by-second basis. Prior to each individual test, standard calibration gases were used for the verification of the accuracy of the system. Lastly, to avoid potential influence of adverse weather, data collection was conducted under good weather condition.

Around 6000 samples were collected for each of the fuel types and were divided into two parts, the first part was used for modelling and the rest was for estimation and comparison. Based from the t-test results, there was no significant difference among the GEHE, CNG, EURO 4, and EURO 5 buses, for the speed and acceleration values. This indicates that the difference in fuel types had little to no impact on the bus operation. However, in terms of bus emissions, CNG buses tend to have lower CO and NOx emissions but have higher CO_2 and HC emissions. For both EURO 4 and 5 buses, CO and NOx levels were quite high. In general, GEHE buses performed the best with the lowest emissions for CO_2, CO, and NOx.

Further t-tests also reveal that there was no significant difference between bus stops and intersections for bus emissions of CO, CO_2, HC and NOx. This can be attributed to the similar operation modes of bus stops and intersections. As mentioned by Tong et al in 2000 (cited by Wang et al, 2018), there are four standard driving modes defined as follows: 1) idling mode: zero speed and acceleration; 2) acceleration mode: positive incremental speed changes of $> 0.1\, m/s^2$; 3) cruising mode: absolute incremental speed changes of less than or equal to $0.1\, m/s^2$; 4) deceleration mode: negative incremental speed changes of $> 0.1\, m/s^2$.

Moreover, differences in emissions between bus stops and road sections, and intersections and road sections were statistically significant. Compared with road sections, bus stops and intersections required drivers to perform a complete stop for boarding and alighting passengers and wait for traffic signals. In this case, drivers need to be in cruising mode, deceleration mode, idling mode, acceleration mode and then back to cruising mode. Likewise, results also showed that there were significant effects of fuel types on bus emissions which indicates the necessity and feasibility of estimating emissions with respect to the different fuel types of buses.

The utilization of the ANN model to conduct the estimation and analysis was performed after the calculation of the VSP from instantaneous bus operation data. Subsequently, several measures of effectiveness (MOEs) including mean absolute percentage error (MAPE) was selected to evaluate the performance of the proposed method. The lower 10% of absolute percentage error (Lower -10% APE) was also chosen which indicates that the mean absolute percentage error has accuracy higher than 90% when the computed value is lower than 10%.

Based from Figure 13, road sections have more accurate estimations (8.2% MAPE on average) compared to the bus stop and intersection (with 10.1% and 10.5% of MAPE on average, respectively) locations. In this case, emission predictions may be affected by more factors compared to road sections like speed changes and excessive delays. Moreover, among the four fuel types, EURO 4 performed the best with MAPE values in all locations lower than 10% and averaging at 7.8%. Thus, it can be deduced that differences in emissions between different locations and different fuel types of buses were all statistically significant.

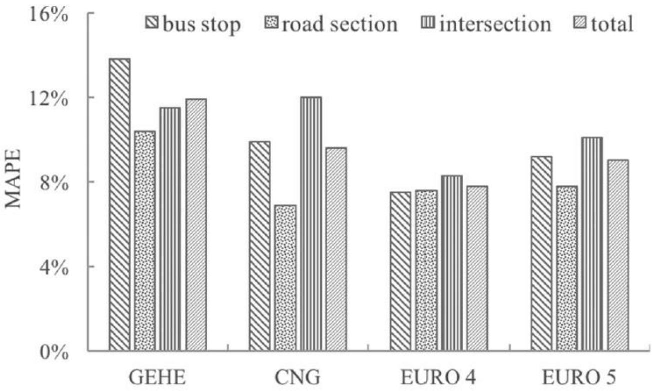


FIGURE 13 MAPE values at different locations for different fuel types of buses (Wang et al, 2018).

In another study, Nejarkoorki et al in 2008, they have demonstrated how the road traffic model using Simulation and Assignment of Traffic in Urban Road Network (SATURN) which adopts a micro-scale approach can be used with a programing software MATrix LABoratory (MATLAB) in the prediction of CO_2 emissions in an urban area. Moreover, Geographic Information System or GIS (ArcGIS) was incorporated in the study to spatially display the results of the study. This study also highlights how emissions are affected by different management strategies in the small city of Norwich, UK.

The modelling approach in this study is shown in Figure 9. This approach incorporates three modelling components: the first approach incorporates the traffic modelling component which determines the road traffic characteristics (SATURN); the second approach utilizes the output from the model in providing the estimates of the CO_2 emissions for the urban area; and the last approach illustrates the model output.

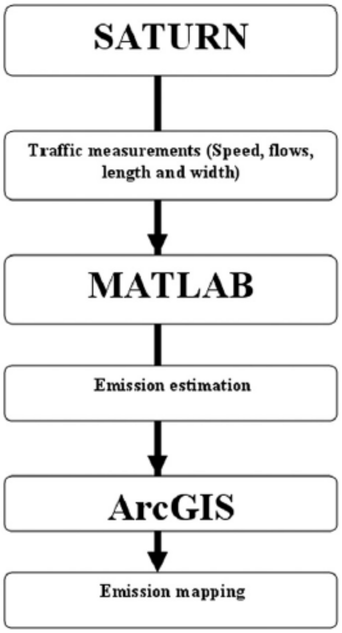


FIGURE 14 Modelling approach (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

Road traffic modelling in general is mainly based on models simulating real-world traffic flow and conditions which are then used to monitor and resolve road traffic issues such as the prediction of the effect of new roads or developments, and the prediction of areas of congestion. Outputs from these models are usually expressed in terms of vehicle speeds and traffic flow at peak hour periods for a given length of the road (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

The SATURN traffic model was developed at the Institute for Transport Studies (ITS), University of Leeds, UK. As early as 1998, it has been used by around 80 local authorities in the UK. The software was selected for this study due to its widespread acceptance and use. It requires input of two data types: a trip matrix and a road traffic network.

Moreover, the study is divided into areas of similar land use called traffic analysis zones (TAZs). Traffic demand in this case is expressed in Passenger Car Units (PCUs) and represented by the number of journeys needed to be made between each TAZ per unit time (usually hour time periods). They are coded as a matrix which consists of rows and columns representing journeys leaving zones and journeys coming to zones, respectively.

On the other hand, traffic networks are coded and based on information for junctions such as roundabouts and signaled junctions, and individual roads such as free flow speed and road length. SATURN's use of network is based on the Institute of Transport Studies' (2003) Wardrop's second principle: "drivers choose routes such that, equilibrium (i.e. in the long term) for each origin-destination movement, the cost of travel (i.e. average travel time) on all used routes is equal and minimum, and no greater than that on any unused route". Output from the program show the number of vehicles on the road, vehicle distances travelled, and net speeds and delays, for each individual road (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

Both the matrix and the network are put into a road choice model wherein the total flows along the links in the network are estimated and the corresponding network costs are calculated. However, one of the limitations of the model is its failure to include minor roads in the network. Moreover, the network files used for the model may not compatible to other models. This may lead to the exclusion of emissions that may have built up areas like minor roads (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

The next modelling tool used is MATLAB to estimate the road traffic emissions. The estimates for each road section was computed by using the output from SATURN on traffic density (number of vehicles per kilometer), length of the road its corresponding vehicle speed. Specific information regarding the fleet composition on the road such as vehicle and fuel type, and engine size, as well as its respective emission factors according to speed was also incorporated into MATLAB.

The total emissions (ET_c) can be computed using the following equation:

$$ET_c = \sum_{1}^{N} F_{sv} \times D_{sv} \times C_{sv}$$

where

ET_c total CO_2 emission (g) for the entire study area for a given vehicle type v
F_{sv} number of street segments (s)
D_{sv} traffic flow on a segment of road by a given type of vehicle
C_{sv} the CO_2 emission factor (g/km) on a segment of road for a given vehicle type and speed

Data such as traffic flow, speed, and road length from SATURN are imported to MATLAB to estimate emissions for a given road segment and then put together to estimate the entire city's network. The initial output for this computation is in hourly time resolution which is then extrapolated to arrive at the annual estimates of CO_2 emissions.

The third modelling tool used is the ARCGIS is used to appropriately visualize the values computed in the previous models. This is essential for helping decision makers to better understand issues on emissions and in enabling easier identification of areas that need attention. There have traditionally been two methods in the generation of data enabling data visualization of road traffic emissions. The first is based on the interpolation of measurements on stationary sites with the use of meteorological and topographical data which is useful for pollutants such as NO_x, SO_3, O_3, CO, and PM_{10}, due to their detrimental effects on health. The second method is the visualization of emissions as line sources with a line (either with varying thickness or color representation) representing pollution levels. However, the disadvantage of this method is its lack of ability to represent air concentrations at intermediate points between roads.

In this study, the focus is more on the emissions rather than the spatially distributed air concentrations. This method is useful in the management and monitoring of air pollution. Similarly, it is practical to show emissions on a fine resolution on urban areas since road traffic is a significant source of pollutants. This enables the provision of emission maps according to zones and streets and which could help in informing local authorities for their plans in reducing emissions thru either alternative forms of transport or by modifying traffic infrastructure.

The study area considered was Norwich which is a major city in eastern England and has a population of 121,650 at the time of the study. Many roads in the city are heavily congested especially at peak hour periods leading to pollution hotspots. In this study, the city was divided into TAZs for analysis. Moreover, since SATURN provides estimates in PCUs at peak periods, there was a need to convert the said data to daily statistics for all vehicle types using 24-hour traffic counter measurements on selected roads.

If possible, traffic fleet composition should be made available to each road in the network. Thus, for easier computations, it was assumed that the vehicle composition is the same for all roads within the network. This was one of the limitations for this study and was acknowledged as one possible source of error. Another limitation in the study was the assumed traffic speed on the main at off-peak periods was the free-flow speeds. Moreover, for minor roads a constant speed of 17.7 km/h was assumed due to lack of data. It was also assumed that all the vehicle types travelled at the same speed.

Emission rates were also divided between three types: hot, cold, and evaporative. Whereas, hot emissions are produced after the engine has reached its working temperature, cold emissions are produced during warm up. Evaporative emissions comes from parts of the car aside from exhaust emissions and was not considered for this study.

Hot emission rates were categorized according to vehicle type and speed which were derived from rolling-road tests. The vehicle speeds were dependent on traffic density and which in turn strongly affects vehicle emissions. Further, these coefficients were derived from the TRL dataset and then used to determine the emission factors in the following equation:

$$E_f = k + av + bv^2 + cv^3 + \frac{d}{v} + \frac{e}{v^2} + \frac{f}{v^3}$$

where

E_f CO_2 emission factor (g/km)

v average speed (km/h)

k, a, b, c, d, e, f coefficients for each vehicle type

This equation is valid for speed of 5km/h to 130 km/h.

Cold emission rates are usually accounted with the use of an excess emission over the hot emission rate. De Vlieger in 1997 found that cold start hydrocarbons emissions were 40% higher than hot emissions. Cold emission rates on average during the first 5.9 km of a vehicles journey and since most intra-city journeys in the study area were below this value, all journeys were assumed to have a cold excess emission and were thus included in the computation.

The importance of including cold emissions in the computation was that it revealed that majority of the 50% of all journeys originating from outside the study area were short journeys close from zones close to the city's boundary. Moreover, petrol cars were identified to be the source 69% of all movements in the city which was symmetrical to the vehicle composition. The spatial distribution of the results of the emissions estimation for the city of Norwich is presented in Figure 10.

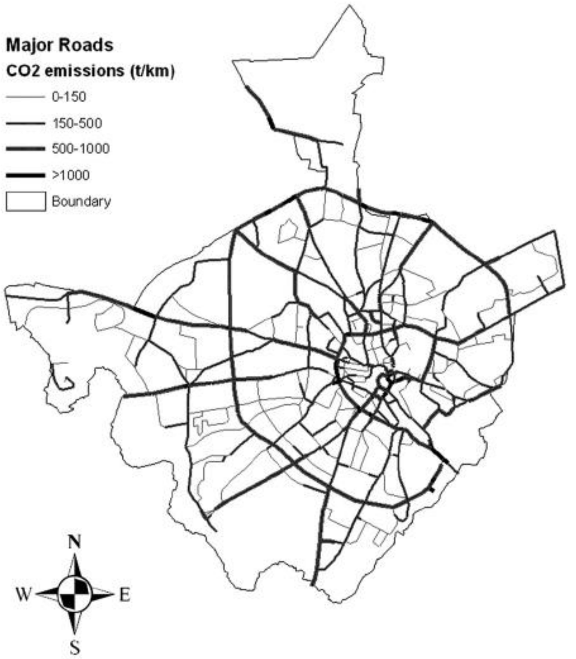


FIGURE 15 2003 CO2 emissions in Norwich, t/km (Nejadkoorki, Nicholson, Lake, & Davies, 2008).

It was expected that most polluted areas were the main arterial roads, ring roads and city center which were areas of high traffic activity. This was evident on the calculations which revealed that 85% of CO_2 emissions were from main roads and the remaining 15% was from minor roads. It was also found that cars were the major source comprising 72.5% of all CO_2 emissions, followed by light goods vehicles (LGVs) at 12.5%, heavy goods vehicles (HGVs) at 7.5%, buses at 6.5%, motorcycles at 1%.

By dividing the total annual emissions of 61, 900 tons with the city's population, it was calculated that about 586kg of CO_2 would have been emitted to each resident. Disaggregation of the total emission in a time dimension also revealed that 41% were during inter-peak periods (09:30-16:00); 18% were during PM peak period (16:00-

18:30); 17% were during AM peak period (07:30-09:30); 14% were during night period (24:00-07:30); and 11% were during the evening period (18:30-24:00). This is crucial since transportation planning studies usually focus on peak period where highest congestion occurs and thus, significant emissions of CO_2 also occur.

Comparing the results to a macro-scale approach from a subsequent study revealed significant differences in the computed values. Whereas the 2003 micro-scale value was 61,900 tons, the 2004 macro-scale value was 115,000 tons. Possible sources of differences were identified such as the difference in study area, collection of road traffic data, and systematic differences in the averaging times of time flow data. But overall, the values are still in reasonably good agreement.

Validation of the input data in SATURN can also be done by regressing the output values against observed traffic counts for selected roads. In this case, there were uncertainties of around 6.5%-9% for the morning peak periods and around 9%-12% for the afternoon peak period. This was around the same estimates with that of a similar road network in the city of Manchester.

Some notable highlights in this study include the use of TAZs in urban areas with a potential of enabling local pollution management as well as the use of traffic modelling in assessing emissions in relation to greenhouse gases. This is essential with traffic generated emissions which can be an opportunity to reduce total emissions thru urban restricting, development of road networks, and changing traffic demands. Moreover, the use of ARCGIS can be a user-friendly format in illustrating urban road traffic emissions to planners and decision-makers alike. These modelling approaches are a useful tool in the examination of future scenarios of traffic related emission thru simulations.

2.3 Emission Studies in the Philippines

At the local level, the study of Vergel and Tiglao in 2005 was conducted to review several project studies and researches, and national government plans and scenarios to develop the policy scenarios for environmental assessment. The study aimed to develop environmental strategies for Metro Manila to reduce air pollution and evaluate the effectiveness of the strategies in terms of reduction in particulate matter emissions. Aside from quantifying policy PM emissions, baseline emissions of present and future years were also estimated to establish a more accurate emissions inventory from mobile or transport sources.

In the study, policy scenarios were developed by reviewing past project studies and researches conducted by various local and international organizations. These scenarios included the business-as-usual scenarios and three general policy scenarios based on a framework for selecting instruments by the World Bank in 2001: reducing vehicle-kilometers, reducing fuel used per vehicle kilometer, and reducing emissions per unit of fuel used. The transportation demand was forecasted for 2005, 2010 and 2015 using the existing main transportation network in 2005.

Policies under the reducing vehicle-kilometers category included demand restraint using administrative instruments such as limitation on vehicle use and increase in share of public transport by expanding the urban rail network. For reducing fuel used per vehicle kilometer, policies included the assessment on the promotion of non-motorized transport such as construction of bikeways. The last category included several policies such as the implementation of the Motor Vehicle Inspection System (MVIS), replacement of 2-stroke with 4-stroke motorcycles for tricycles (4STC), diesel particulate trap for buses and jeepneys, compressed natural gas (CNG) for buses (CNGB), coco-methyl ester (CME) for jeepneys (CMEJ). Moreover, a combination of all these policies was also included in the review.

To model and estimate the transportation demand, the study area was established covering Metro Manila and the BRLC and was used to form the traffic analysis zones. These traffic zones required a database of aggregated socio-economic characteristics derived from the 1996 household interview survey (HIS) of the Metro Manila Urban Transportation Integration Study (MMUTIS) database. These values were forecasted to the different years using growth rates based on the same study. Further, data on transportation network consisting of roads and public transport lines were also included which also utilized the MMUTIS transportation network in 1996. The networks made up nodes and links were encoded in a digital map in JICA System for Traffic Demand Analysis (STRADA) format.

The 4-step model was used in the estimation of the transportation demand for the baseline scenarios in 2005, 2010 and 2015. This included the trip generation/ attraction, trip distribution, modal split and the traffic assignment, the outputs of the JICA STRADA traffic assignment are the link traffic volumes per day, link average traffic speed per day, link volume-to-capacity ratios per day and link trip lengths per day.

In the estimation of PM emissions, the study adopted the locally developed VECP Project by the Asian Development Bank (ADB) in 1992 for the 6-vehicle fuel types according to traffic speeds. The emission factors were patterned after the speed-specific and emission specific factors provided by the MMUTIS Technical Report No. 10 by JICA in 1999. The average speed output of the 4-step travel demand forecasting model estimated in the JICA STRADA for each zone was used to identify the corresponding EF in the table below:

TABLE 2 PM emission factors (g/veh-km) (derived from 1992 VECP project and 1992 MMUTIS emission factors as cited by Vergel and Tiglao, 2005)

Fuel Type	Vehicle Type	Idling	~10km/h	10-20km/h	20km/h
Gasoline	Car	0.15	0.12	0.10	0.10
	Jeepney	0.17	0.14	0.13	0.12
	Tricycle (2-stroke)	2.05	2.01	2.00	2.02

Diesel	Car	1.73	2.03	0.90	0.90
	Jeepney	1.59	1.89	0.99	0.90
	Bus	1.60	2.40	1.60	0.90

The daily PM emissions for each traffic analysis zone was calculated using the following equation:

$$PM = \sum_{i=1}^{6} d_i \times EFexhaust_i(v) + \sum_{i=1}^{6} T_s \times d_i \times EFidle_i$$

where

PM	PM emissions per traffic analysis zone (g)
d_i	travel distance of vehicle type *i* (veh-km) per zone
v	average travel speed per zone (km/h)
$EFexhaust_i(v)$	exhaust emission factor of vehicle type *i* as a function of travel speed (g/veh-km)
T_s	idle or stopping time (min/veh-km) per zone
$EFidle_i$	idle emission factor of vehicle type *i* (g/min)

The stopping or idle time per zone was obtained from the Two-Fluid Model by MMUTIS. Together with the travel time (min/km) output from the travel demand estimation in each zone, the stopping time is calculated using the equation of the Two-Fluid model shown below:

$$T_s = T - T_m^{\frac{1}{n+1}} T^{\frac{n}{n+1}}$$

where

T_s	stopping time per unit distance (min/km)
T	trip time per unit distance (min/km)
T_m	average minimum trip time per unit distance = 1.966 min/km for Metro Manila
n	1.889 for Metro Manila

In a different study by Castro and delos Reyes in 2010, they examined the traffic and environmental impacts of various scenarios of freight restrictions in the major streets of Metro Manila. The objective of the study was to determine the best truck regulation scenario in helping and reducing vehicle traffic congestion and emissions.

Traffic flow in the road network was approximated with the User Equilibrium Traffic Assignment Model which assumes that each user tries to minimize travel time without considering its impact or consequences to other users in the network. A stable condition is attained when no user can improve their travel time by changing their route. This is eventually lead to the link flows satisfying the user-equilibrium criterion when all the origin-destination demand has been appropriately assignment (Sheffi, 1985 as cited by Castro & Delos Reyes, 2010). The model allows the estimation of traffic patterns (volume, speeds, etc.) on each link of the road network as well as the share of total travel demand serviced by each mode (Castro & Delos Reyes, 2010).

The model requires transportation data such as transportation network, traffic analysis zones, link-based traffic volumes and travel speeds, and interzonal travel demand. These are then used as input in the traffic assignment model stored in a GIS. Traffic demand characteristics are expressed in terms of the origin-destination (O-D) matrix of road vehicles wherein a suitable zoning of the entire urban area is required. Once the traffic demand data is provided, it is possible to reproduce traffic flow behavior within each link of the network. In this study, the O-D matrices for Metro Manila were generated from a sampling survey of 3,815 freight vehicles conducted in MMUTIS which were grouped into 28 zones. In parallel, the truck driver roadside interview questionnaire included questions regarding the origins, destinations, loading capacities, commodity types and loading factors was also conducted.

The sampling values were expanded to the population by adjusting it from traffic counts simultaneously conducted with the truck driver roadside interview survey, and the number of trips for each of the TAZ was obtained for the morning peak, off-peak, and afternoon peak hours. Once the traffic flows on each link have been assigned by the traffic model the relative mean speed along with the split in vehicle fleet can be determined. This will lead to the estimation of pollutant emissions over the entire network.

There were three types of pollutant emissions estimated in this study: CO, NOx, and SPM, based on existing vehicle composition in Metro Manila. At the time of the study, 70% of the registered vehicles in Metro Manila were gasoline-fueled while the remaining 30% are diesel-fueled. Vehicles on the road are normally modeled as a line source approximating the effects of numerous vehicles moving along a road as a line which emits a defined amount of pollution, per unit of time, along its length. The amount of emissions can be determined by multiplying the number of vehicles by a per-vehicle emission factor. The emissions were generated on each link of the road network for the different time periods using the following equation:

$$E_{ai} = \frac{F_a L_a EF_{ai}}{1 \times 10^3}$$

where

E_{ai} estimated pollutant *i* on link *a* (kg)
F_a number of vehicles on link *a* (veh)
L_a length of link *a* (km)
EF_{ai} emission factor of pollutant *i* (g/km/veh)

Single measure policies such as MVIS and the switch to 4-stroke tricycles resulted to higher reduction in emissions form 11-16 tons/day in 2010 to around 12-16 tons/day in 2015, followed by the railway network expansion with a reduction of 11 tons/day in 2015 and installation of DPTs in public transport vehicles. Since air pollutant emissions are affected by vehicle movements such as stop-and-go, vehicles in the traffic stream were divided into moving and stopped vehicles. The stopped vehicle class includes vehicles stopped due to congestion, traffic signals, stop signs, and loading and unloading. The two fluid-model (Herman & Prigogine, 1979 as cited by Castro & Delos Reyes, 2010) represents movements in the traffic network to improve the performance of the traffic assignment model. It is found to represent remarkably well the behavior of traffic during congested periods.

Emission factors calculated by MMUTIS study were utilized to estimate the total amount of pollutants setting a factor on vehicle characteristics such as type and size of vehicle, fuel type, and speed. It should be noted that emission factors depend on a variety of factors such as operating or driving conditions, age of vehicle, environmental characteristics such as altitude and temperature, among others. At the time of the study, however, the MMUTIS data was found to be the most comprehensive dataset on emission factors for Metro Manila.

Various scenarios were also considered aside from the existing truck ban regulation. The current scenario required present traffic conditions and the estimated origin-destination demand. For the alternative scenarios, present conditions data together with traffic interventions in the form of freight regulations to the Metro Manila area, were considered. The scenarios covered alternative cases of truck regulation for the main arterial network including the abolition of the ban regulation, abolition of ban during off-peak period at the major circumferential road, abolition of truck ban at 10 major roads, and implementation of additional ban at 10 major roads.

After the traffic assignment, there is a need to compare model results with actual flows to establish the level of accuracy by which the model is representing real-life conditions. Thus, the model was validated to confirm flows resulting from the model to the actual flows on the road. Appropriate adjustments to the model parameters were made to validate counts in the field by comparing actual traffic counts from the MMDA at selected sites to the modelled traffic flows at equivalent cordon stations. Based from the output, most of the differences were less than 25% error level, warranting a reliable estimation of mobile emissions.

In terms of redistribution of flows, the alternative scenarios showed remarkable changes in the transport network. This was done by considering the entire Metro Manila region as the study area and determining the traffic impacts in terms of changes in total travel distance and total travel time for each scenario. Afterwards, environmental impacts in terms of the amount of pollutant emissions for CO, NOx, and SPM for the various scenarios were calculated.

In comparing the alternative scenarios with the existing scenario, the percentage changes of the identified traffic and environmental impacts were calculated using the following equation:

$$\Delta I_i = \frac{I_{ai} - I_{bi}}{I_{bi}} \times 100$$

where

ΔI_i percentage change of the traffic or environmental impact *i* (%)
I_{ai} impact for the "after" case (i.e. alternative scenario)
I_{bi} impact for the "before" case (i.e. existing scenario)

In the previous analysis, it focused on the impacts of various alternatives on freight regulation from a region-wide standpoint by considering the entire Metro Manila as the analysis area. However, at that standpoint, localized traffic and environmental impacts are not identified and not well-understood. Thus, an area-specific analysis was conducted.

In this analysis, Metro Manila was divided into three distinct zones, namely inner zone (old Manila), middle zone (seven cities adjoining the old Manila area), outside zone (remaining cities located at the distance from the old Manila area). Similar to the previous analysis, the percentage changes of traffic impacts for each zone with the existing scenario as the base condition was computed. It was found that different scenarios generated varied and mixed traffic impacts depending on the area. Moreover, the best alternative for Metro Manila in this case is a compromise solution such that a substantial amount of traffic and environmental benefits will be given to two out of the three analysis areas, and a slight negative impact for one remaining area. Thus, there is an observed trade-off relationship between the benefits and scope.

The results were an application to policy making and can be useful to policy-makers in determining how certain travel demand management measures such as large freight restrictions can impact and improve traffic flow and reduce emissions. Information on emissions is significant in the design of effective pollution control plans and strategies that are consistent with the provisions of the Philippine Republic Act (RA) 8749 of 1999 or the Philippine Clean Air Act.

Similar to the study of Castro and Delos Reyes, Castro and Hyodo also assessed the impact and effectiveness of the truck ban scheme in Metro Manila. The truck ban was originally introduced by the then Metropolitan Manila Authority (MMA) in 1978 to alleviate the worsening conditions of road traffic congestion which prohibits truck movements along eleven specific routes, mostly primary arterial roads. The two types of truck ban are: all-day truck ban which prohibits trucks from using the EDSA from 6am to 9pm during weekdays; and the peak-hour truck ban which prohibits trucks from using major 10 thoroughfares from 6am to 9am and 5pm to 9pm except Saturdays, Sundays and holidays.

To understand the transport characteristics of Metro Manila, the study identified possible changes and consequences of the truck ban scheme which includes: volume increase of truck-ban exempt trucks, reduction of truck-loading factors, increase of truck traffic at night, and changes in traffic distribution during ban and no ban periods. Thus, the traffic assignment was performed to estimate the probable effects of the truck ban in terms of vehicle-kilometers and vehicle-hours using the shortest path method. In this method, it assumes that the goal of the driver is cost minimization following the minimum cost path between the origin and the destination.

Afterwards, the environmental assessment was carried with the help of the traffic assignment identifying the truck volume, truck type, and average speed of vehicles at road links. The environmental emissions were then computed by multiplying traffic volume by the respective emission factors for each environmental pollutant. Lastly, the alternative truck ban schemes were compared with the existing truck ban to compute for the percentage changes in vehicle emissions.

The traffic assignment requires origins, destinations quantity of movements, details of the road network, and rules for the selection of paths. In this case, the minimum path rule for selecting the route due to its wide applications in real-life large-scale models. There are two major inputs in the model: the road network including link characteristics such as coordinates for the origin and the destination, distance, travel speed, and coordinates of the zone centroid; and the truck OD classified by truck type and time period.

For the node coordinates, small local streets were not included in the road network since freight trucks do not use them. Moreover, streets within exclusive villages and subdivisions were not considered. A list of street links that were affected by the ban in different time periods were also prepared which along with those due to the alternative ban were integrated in the final road network.

There were several alternative truck ban schemes studied for the truck ban scheme aside from the existing truck ban scheme: the without truck ban scheme, peak-hour only truck ban at all major roads (EDSA and major routes), all day EDSA truck ban only scheme, and all-day truck ban at EDSA and other major road scheme.

The environmental assessment was performed by aggregating the results of the traffic assessment by identifying the volume, type, and average speed of vehicles in each link. In this case, the environmental emissions were calculated by multiplying traffic volume by their respective emission factors for each of the environmental pollutant (CO, NOx, SOx, SPM). Since it was difficult to find a single data source containing all the factors for all conditions, the emission factors calculated by MMUTIS was used using Table 3 and was estimated using the following formula:

$$Pollutant\ (i) = travel\ distance\ \times emission\ factor\ at\ average\ speed$$

(veh-km) (g/veh-km)

TABLE 3 Emission factor (g/km) (Castro & Hyodo, 2013)

Pollutant Type	Vehicle Type		Average Speed		
			<10 km/hr	10-20 km/hr	>20 km/hr
CO	Gasoline	Car	27.57	23.5	18.7
		Small Truck	47.58	52.2	41.14
	Diesel	Car	7.85	6.54	5.94
		Small Truck	8.02	6.8	6.2

		Large Truck	8.12	7.11	6.5
NOx	Gasoline	Car	2.75	2.76	2.78
		Small Truck	4.7	3.59	3.53
	Diesel	Car	5.65	4.28	3.89
		Small Truck	8.95	7.66	7.01
		Large Truck	11.24	10.59	9.22
SOx	Gasoline	Car	0.013	0.011	0.011
		Small Truck	0.015	0.011	0.01
	Diesel	Car	0.14	0.08	0.07
		Small Truck	0.18	0.121	0.11
		Large Truck	0.2	0.15	0.1
SPM	Gasoline	Car	0.07	0.05	0.05
		Small Truck	0.07	0.06	0.05
	Diesel	Car	1.2	0.07	0.07
		Small Truck	1.8	0.9	0.81
		Large Truck	2.3	1.5	0.80

The table of emission factors indicates that lower vehicle speeds yield higher amounts of emissions, and that gasoline and diesel engines vary in emission profiles. Moreover, in the calculation of pollutant emissions, it was assumed that 50% were gasoline-powered small trucks and 50% diesel-powered small trucks. While large trucks were 100% diesel-powered.

Changes in performance measures were calculated by comparing alternative truck ban schemes with the existing truck ban schemes such as travel distance and pollutant using the following equations respectively:

$$\Delta D = \frac{D_a - D_b}{D_b}$$

$$\Delta E_i = \frac{E_a - E_b}{E_b}$$

where

D	travel distance
E	emission
a	“after” or “revised” ban scheme
b	“before” or “existing” ban scheme

Results showed that there is very little change in the amount of pollutant emissions for the four truck ban schemes. Moreover, considerable increases in pollutant emissions were observed for the all-day truck ban scheme at all major routes including EDSA. This may be due to an increase private car that are more gasoline-powered compared and thus emitting more CO. In general, gasoline engines produce more CO, but diesel-fueled trucks are a public health concern due to its high NOx and

SPM emissions, and in most cases emit more pollutants than gasoline engines. Based from existing literature diesel engines have been identified to have serious impacts on air quality and public health (Castro & Delos Reyes, 2010).

An accidental by-product of the truck ban implementation is switching to small trucks. Minimizing the switch can make the ban more successful, but these are done by companies to avoid restrictions of the ban. Although, the ban was designed to shift traffic out of the congested peak period to less congested daytime or nighttime off-peak periods, the noise generated from shipping and receiving may be unfavorable near residential areas. Overall, the additional restrictions significantly increase the total vehicle kilometers, total-vehicle hours, and total pollutant emissions translating to increased transportation cost.

Summarizing the related studies mentioned, several highlights were observed: existing methodologies for network emissions based on traffic variables have limitations leading to differences in estimate values; EMs must strike a balance between simplicity and complexity: too simplistic and it fails to capture the emission's impact or too complex and it requires more time and expertise; test conditions limit accuracy of estimates not representative of real-world conditions; congestion condition affect total emissions; road sections have more accurate estimations of vehicle emissions compared to bus stops and intersections; it is practical to show emissions on a fine resolution in urban areas since road traffic is a significant source of pollutants thus enabling local pollution management; most polluted areas are areas of high traffic activity; validation/calibration is needed to account for errors in computation; different scenarios generate varied and mixed traffic impact depending on the area; there is an observed trade-off relationship between benefits and scope of policy; lower vehicle speeds yield higher amounts of emissions; gasoline and diesel engines vary in emission profiles; and additional restrictions significantly increase the total vehicle kilometers, total-vehicle hours, and total pollutant emissions translating to increased transportation cost.

3. MATERIALS AND METHODS

In the evaluation of the proposed policy's effectiveness in terms of traffic conditions and emissions, the existing condition was compared to the alternative scenarios for each year of implementation: 2020 and 2025. This is based on the study of Castro and Delos Reyes in 2010. Moreover, environmental assessment was based on the study conducted by Castro and Hyodo in 2003 wherein volume, type and average speed of the vehicles for each link were aggregated to assess the impact and effectiveness of the proposed scheme. In this case, the aggregated values were multiplied to their corresponding emission factors for each pollutant. The pollutant emissions were assumed to be dependent on travel distance, speed, vehicle type, and fuel source. Figure 16 presents the proposed methodology for this study while Table 4 presents a summary of the required inputs for this study.

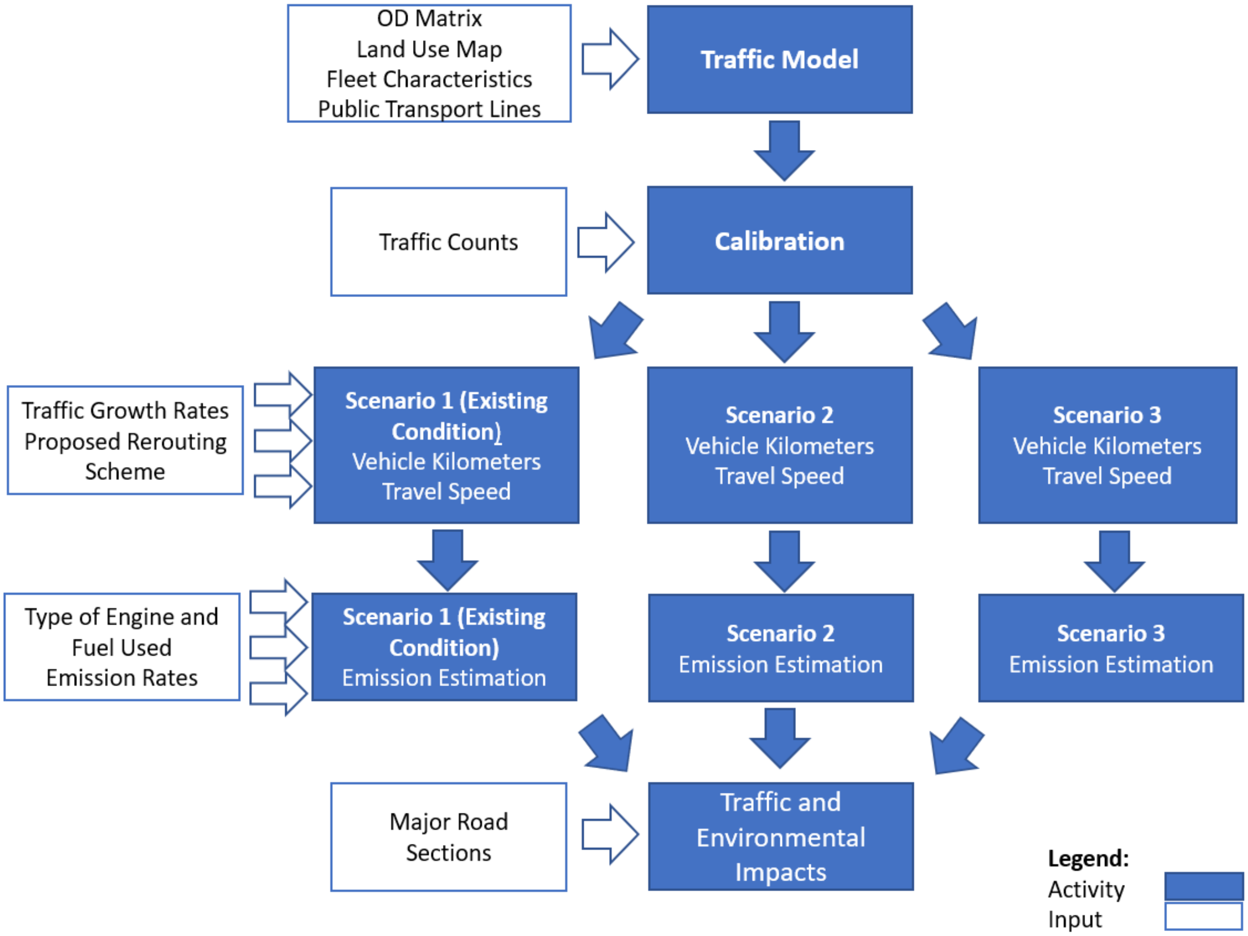


FIGURE 16 Proposed study methodology.

TABLE 4 Summary of required inputs in the study

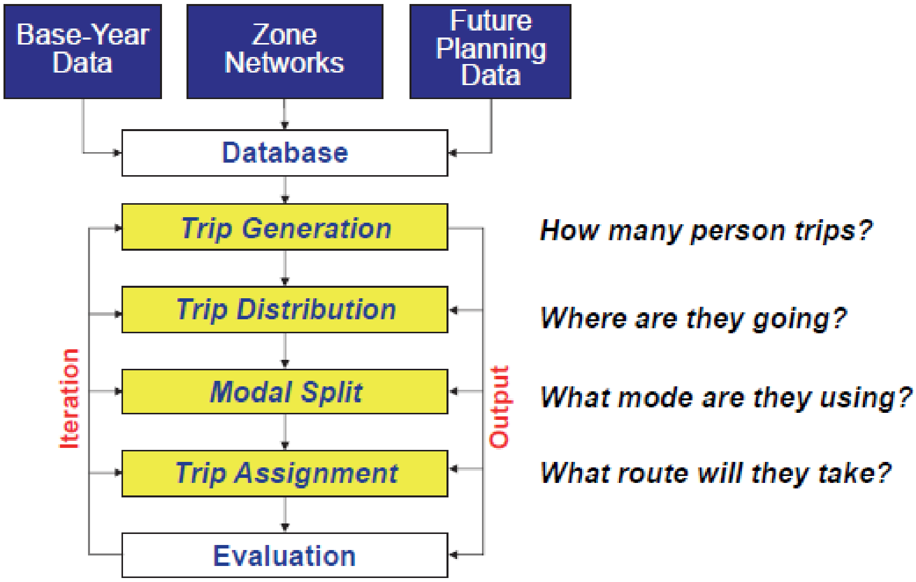
Input	Source
O-D matrix	MUCEP Study, 2015

Land Use Map	SDRP Consulting, Inc., 2018
Fleet Characteristics	MUCEP Study, 2015
Traffic Growth Rates	MMICP, 2012
Type of Engine and Fuel Used	LTO, 2017 and PSA, 2017
Emission Rates	Almec Corporation, 2014

3.1 Travel Demand Model

The travel demand model used in this study is from the recently concluded MMUTIS Update and Enhancement Project (MUCEP) in 2015 which includes the O-D matrix. Moreover, the highway network consists of a system of node and links, representing junctions and homogenous stretches of road between junctions, respectively. Specifically, the links are characterized by the following attributes: length, travel speeds (in speed-flow curves), link capacity (in PCU/hr), additional information, link classification, road width, number of lanes, turn penalties, type of junctions, and signal phasing. A subset of the nodes is associated with zone centroids while a subset of links is associated with centroid connectors.

The four-step model was used in the generation of travel demand forecasts as shown in Figure 17 and TAZs were organized in the zoning shown in Table 5 using small zones. The maximum speed was set according to the class of road and the lane capacity of each class of road was set based on Table 6.



Source: JICA Project Team

FIGURE 17 The 4-step model (Almec Corporation, 2015).

TABLE 5 Traffic analysis zones (Almec Corporation, 2015)

Zoning System	**Number of Zones**			
	MUCEP Study Area		Outside the Study Area	Total
	NCR	Provinces		

Small Zone	272	82	67	432
Medium Zone	24	51	14	89
Large Zone	1	4	3	8

Source: JICA Project Team

TABLE 6 Road Capacity and Maximum Speed by Road Category (Almec Corporation, 2015)

Area	Road Category	Carriageway Type	Capacity 1-way pcu/day/lane	Maximum Speed (km/hr)
Inside EDSA	Local Road	Single	2,200	30
	Secondary	Single	4,400	40
	Primary	Single	6,600	45
Outside EDSA Inside MM (including EDSA)	Secondary	Single	7,700	50
	Primary	Single	8,250	60
	Secondary	Divided	14,000	70
	Primary	Divided	16,500	80
Outside MM	Local Road	Single	8,000	30
	Secondary	Single	11,000	55
	Primary	Single	15,400	60
Urban/ Intercity	Access/ egress	Single	15,000	80
	Expressway	Single	17,000	80
	Expressway	Divided	20,000	100

Note: Based on MMUTIS and MUCEP updated by JICA Project Team where appropriate

Based from the 2015 MJUCEP study, the transit network data was converted from the STRADA transit network to the Cube Transportation Modelling Software which includes the city bus, jeepney, and rail route in Metro Manila and the BRLC. Traffic volumes by vehicle type was multiplied by their corresponding passenger car equivalent factors (PCEFs) to establish the traffic volume in terms of passenger car unit (PCU).

TABLE 7 Passenger car equivalent factors (Almec Corporation, 2015)

Vehicle Type	PCEF
Passenger Car/Van/AUV	1.0
Public Utility Jeepney (AUV)	1.5
Public Utility Bus (PUB)	2.5
Large Truck	2.5
Motorcycle	0.5

Source: JICA Project Team

Travel time changes due to congestion such that increase in traffic volume leads to a longer traffic time on the link. The concept link-cost function was used to incorporate speed reduction representing the volume-speed relationship as shown below:

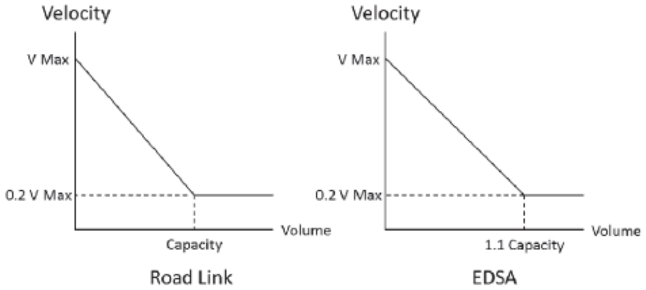


FIGURE 18 QV function (Almec Corporation, 2015).

The OD table was prepared based on the results of the HIS, while the 2025 OD was estimated using the MUCEP demand forecast model as summarized in the table below:

TABLE 8 Total trips by mode (Almec Corporation, 2015)

Year	Walk	Private Mode	Public Mode	Truck	Other
2014	10,910,100	6,467,516	11,092,775	275,327	7,189,171
2025	12,517,837	7,092,241	11,293,851	393,450	6,800,664
2035	13,764,329	8,748,371	12,091,295	581,391	7,473,246

Source: JICA Project Team

3.2 Bus Transport

At present, the bus transport sector is governed by the Department of Transportation through its line agencies, the Land Transportation Franchising and Regulatory board (LTFRB) and the Land Transportation Office (LTO). The former regulates the entry and exit of bus operators, as well as franchises for route operation and sets/ regulates the bus fares; while the latter helps implement the regulations through its registration and inspection functions (Domingo, Briones, & Gundaya, 2015).

Due to the complicated regulation and enforcement shared by several agencies, the bus market operates under a complicated system. Along with a confusing mix of liberal and conservative policy and selective enforcement, this resulted to implementation failures and regulatory capture. This is also manifested in the presence of illegal buses and the "*kabit*" system wherein a bus owner enters the market via an arrangement with an operator of an existing franchise. Market inefficiency is also exhibited with the excess number of buses and operators worsening traffic congestion issues (Domingo, Briones, & Gundaya, 2015).

In terms of compensation, the "boundary system" has been a major contributor to indiscipline of bus drivers on the road. In this system, the daily earnings of drivers are based on how well they compete with other bus drivers for passengers within the franchised routes (Domingo, Briones, & Gundaya, 2015). Due to poor monitoring, operators base compensation of the bus driver and the bus conductor (the person who collects the fare inside the bus) as a percentage of bus ticket sales leading to an incentive of doing whatever it takes to pick up as many passengers as possible and as time or road space would allow (Llanto, 2017).

Due to the easy entry of small operators and oversupply of buses, the present situation in EDSA has been chaotic. The competition of passengers was expected to lead to a more efficient transport service (Llanto, 2017). Table 9 presents the number of operators and buses within Metro Manila.

TABLE 9 Number of operators and buses in Manila bus routes (Domingo et al, 2015)

Route	Number of operators	Number of buses	Average no. of bus/ operator
Manila EDSA Route	266	3,711	14
Manila Non-EDSA Route	128	1,632	13
Manila-Provincial North Bound	371	3,684	10
Manila-Provincial South Bound	357	3,595	10
TOTAL	1,122	12,595	11
Alabang-Fairview	21	341	16
Baclaran-Novaliches	17	171	10

In 2006, Transportas Consulting estimated that around 75% of all daily total person trip in Metro Manila were serviced by public transport. There was also an excess of buses on 30 operational routes with below capacity load factors, except for short sections during morning peak hours. Load factors during the weekdays averaged around 51.3% while during weekends it was around 47.5%. The excess in supply of buses results to further congestion leading to time delays for public commuters as well as decreased revenue for bus operators.

TABLE 10 Mean Daily Supply and Demand Situation within the EDSA super corridor (Domingo, 2015)

Super Corridor	Daily Passenger Volume		Actual Bus Trips		Bus Trips		
	NB	SB	NB	SB	Required	Excess	Percent Excess
Magallanes-Ayala	115,652	128,554	4,156	4,216	7,005	1,367	0.16
Ayala-Guadalupe	120,272	112,181	4,156	4,216	6,668	1,705	0.20
Guadalupe-Aurora	113,177	101,839	4,156	4,216	6,168	2,205	0.26

Aurora-East Avenue	134,052	102,820	4,144	4,074	6,794	1,424	0.17
Magallanes-East Avenue (aggregate)	482,153	445,394	16,612	16,722	26,635	6,701	0.20

Note: passenger volume and bus trips are counted per major stop within the north bound (NB) and southbound (SB) routes

Considering the existing model of the MUCEP study, only the city buses are included: Metro Manila Routes and BRLC buses. To include trips from the surrounding provinces, an aggregate 16-hour traffic count of buses was conducted from 6am to 10pm last 19 and 21 March for the northbound and southbound buses, respectively. The counting stations were located at SM North EDSA and Magallanes Station. In addition to the bus count, the estimated occupancy for each bus were also included as shown in Table 11.

TABLE 11 Bus occupancy description for buses

Occupancy	Description	Load Factors
Empty	Bus is empty	0
Seated	Passengers are seated	0.5
Full	All seats are occupied	1.0
Standing	Some passengers are standing	1.5
Overloaded	Bus is already at standing capacity	2.0

Expansion factors were used to convert the 16-hour traffic volume to 24-hour volume and were based on the 2012 MMICP Study as shown in Table 12. The daily and seasonal factors were assumed to be 1.0 since the surveys were conducted on a weekday in ordinary season and not summer holiday season (Japan International Cooperation Agency, 2012). The adjusted 24-hour count was used as the AADT for the provincial and city buses as shown in Tables 13 and 14, respectively.

TABLE 12 16-Hour to 24-hour expansion factors (JICA, 2019)

Vehicle	Expansion Factor
Car	1.24
PUJ	1.22
PUB	1.32
Trucks	3.93
Motorcycle	1.2

TABLE 13 2019 AADT for provincial buses

	AADT	Occupancy	At Capacity	Excess
SM North – NB	1,746	70.79 %	1,236	29.21%

SM North – SB	1,667	64.25 %	1,071	35.75%
Magallanes – NB	975	56.63 %	552	43.38%
Magallanes – SB	1,096	56. 93 %	624	43.06%

TABLE 14 2019 AADT for city buses

	AADT	Occupancy	At Capacity	Excess
SM North – NB	2,255	106.79 %	2,408	-6.78%
SM North – SB	2,189	117.76 %	2,577	-17.72%
Magallanes – NB	2,932	91.83 %	2,692	8.19%
Magallanes – SB	2,919	101.24 %	2,955	-1.23%

Although the aggregate occupancy of the buses along EDSA are still acceptable at 89.47%, it should be noted that city and provincial buses operate differently. Thus, there is a need to observe the bus occupancies separately in order to compute for the additional trips of the city buses once the policy is implemented. Provincial buses have an average occupancy of only 63.51% compared to city buses with an average occupancy of 103.29%.

With the proposed rerouting scheme, provincial bus operations are cut and diverted to the assigned terminals and the passengers are forced to transfer to city buses. Moreover, only the closest routes are allowed to extend their route and accommodate affected passengers. In the case of the Sta. Rosa Interim terminal, the Pacita route city buses will be extended to Sta. Rosa via the San Pedro National Highway.

Thus, to accommodate these passengers, there should be at least 1,236 and 1,071 buses deployed daily for the northbound and southbound direction, respectively. Whereas, for the Valenzuela Interim Terminal, there are already two existing routes passing through the area. However, to accommodate affected passengers, there should be at least 552 and 624 buses deployed daily for the northbound and southbound direction, respectively.

It is obvious from these numbers that there is already a problem in the number of buses to be deployed along with the occupancy of the buses at present condition. With the existing scheme, there is already a shortage in the number of buses which cannot be shouldered by the existing bus franchise in the area.

FIGURE 19 2019 Existing condition bus route.

FIGURE 20 Proposed bus routes for scenarios 2 and 3.

Tables 15 to 17 present the projected bus counts for the future scenarios with the existing and the proposed bus rerouting scenarios, respectively. To adjust for the bus volumes, headways for the different routes were adjusted depending on the scenario. Table 16 accounts for the original proposed bus scheme while Table 17 accounts for the additional bus routes to accommodate the affected passengers.

TABLE 15 Projected bus counts for scenario 1

	2020		2025	
	Provincial	**City**	**Provincial**	**City**
SM North – NB	1,825	2,356	2,188	2,825
SM North – SB	1,742	2,287	2,089	2,743
Magallanes – NB	1,019	3,064	1,222	3,674
Magallanes – SB	1,145	3,050	1,373	3,657

TABLE 16 With bus-rerouting scenario 2

	2020	2025
SM North – NB	2,356	2,825
SM North – SB	2,287	2,743
Magallanes – NB	3,064	3,674
Magallanes – SB	3,050	3,657

TABLE 17 With bus-rerouting scenario 3

	2020	2025
SM North – NB	3,648	4,374
SM North – SB	3,406	4,085
Magallanes – NB	3,641	4,366
Magallanes – SB	3,702	4,439

Regarding bus stops, MMDA has designated stops along EDSA as shown in Table 18. However, based on on-site inspections, buses tend to not follow these stops and drop-off passengers at random points along EDSA as shown in Table 19. Aside from these stops, MMDA data also show that there a total of 47 terminals along EDSA: 31 terminals along the northbound direction and 18 terminals in the southbound direction. Thus, in modelling stops for Cube, it was assumed that buses stop randomly along EDSA such that the nodes were assigned as designated stops.

TABLE 18 Bus stops directory along EDSA

Northbound	Southbound
SM Mall of Asia	Ermin Garcia
Magallanes	Kamuning

Ayala Avenue	Arayat Cubao
Buendia Avenue	Main Avenue
Estrella	VV Soliven
Guadalupe	POEA Ortigas
Pioner/ Boni	Connecticut
Shaw Boulevard	Shaw Starmall/ Pioneer / Boni
SM Megamall	Estrella
Ortigas Avenue	Guadalupe
Boni Serrano	Estrella
Cubao Farmers	Buendia
Main Avenue	Ayala
Ermin Garcia	Mantrade
Baliwag/ Star	Taft

TABLE 19 Non-designated stops along EDSA

Northbound	Southbound
Diosadado Macapagal Avenue and EDSA ext. Intersection	GLC Truck and Equipment beside MRT North Avenue
Dragon Point Mall	PWU-JASMS
Roxas Boulevard and EDSA Intersection	Merced Bakehouse and Restaurant
Metropoint Mall	Quezon Avenue and EDSA Intersection
Cabrera Footbridge (Malibay, Pasay)	MRT Quezon Avenue
Evangelista Footbridge (Malibay, Pasay)	Mother Ignacia Street
Diosadado Macapagal Avenue and EDSA ext. Intersection	Scout Borromeo Street
Dragon Point Mall	MRT Kamuning
Roxas Boulevard and EDSA Intersection	GMA Intersection and EDSA Intersection
Metropoint Mall	JAM Bus Liner
Petron Station along Antonio Arnaiz Avenue	Kamuning and EDSA intersection
Mckinley Road and EDSA Intersection	Police Station 10 Kamuning
MRT Buendia	Aurora Boulevard and EDSA Intersection
Estrella Footbridge	P. Tuazon and EDSA Intersection
MRT Guadalupe	Main Avenue Footbridge
MRT Boni	Ford EDSA
Reliance Street	MRT Ortigas
Ortigas Provincial Bus stop	MRT Shaw Boulevard
White Plains Drive	Sultan Street, Mandaluyong

Corinthian Gardens II	Domingo Guevarra Street, Mandaluyong
MRT Santolan	Caltex EDSA (Boni Avenue)
Boni Serrano and EDSA Intersection	MRT Guadalupe
P. Tuazon Intersection	SM Makati
Five Star Terminal	UCPB Malibay, Pasay
Kamias and EDSA Intersection	Cabrera Footbridge (Malibay, Pasay)
JAC Liner	Paasay Rotunda Intersection
Manuel Quezon University (besides MRT Kamuning)	Roxas Boulevard and EDSA Intersection
National Irrigation Administration (NIA)	Jollibee along EDSA Extension
Eton Centris	Diosadado Macapagal Avenue and EDSA ext. Intersection

3.3 Traffic Modelling

The use of models is important when it comes to future transportation plans and investments. Moreover, they can be used to estimate number of trips which are the basis in the analysis of major investments are well as environmental impacts (Almec Corporation and Oriental Consultants Co., 2015). Similar with any other modeling software, it requires data input such as zonal data and matrices, in different file formats. The software then computes the lowest-cost path for each vehicle unit depending on departure time, and computes interactions between vehicle units while travelling the network.

The software can also integrate other modelling systems such as a network, highway, and public transport. Moreover, it provides direct access to and from ArcGIS compatible with the ESRI standards including GIS functions (Citilabs, 2016). This can be very useful in terms of loading the shapefiles for the road network and public transit network as well as the land use maps needed in the comparison of the two spatial scenarios: the regional and the area-specific areas.

With the use of the software, it is possible to generate performance measures for each specified time segment such as: traffic volumes on a road link, total traffic in queue, link operating speed and travel time, link occupancy/utilization, and intersection LOS and operating conditions (Citilabs , 2019).

Cube is a dynamic equilibrium assignment model that tracks the movement of vehicle packets (from an individual vehicle up to platoons of 20 or more vehicles) along the highway network by using an iterative process to calculate optimal network conditions. Cube blends macroscopic traffic assignment methods together with traffic progression and time periods typical to microscopic models (Citilabs , 2019).

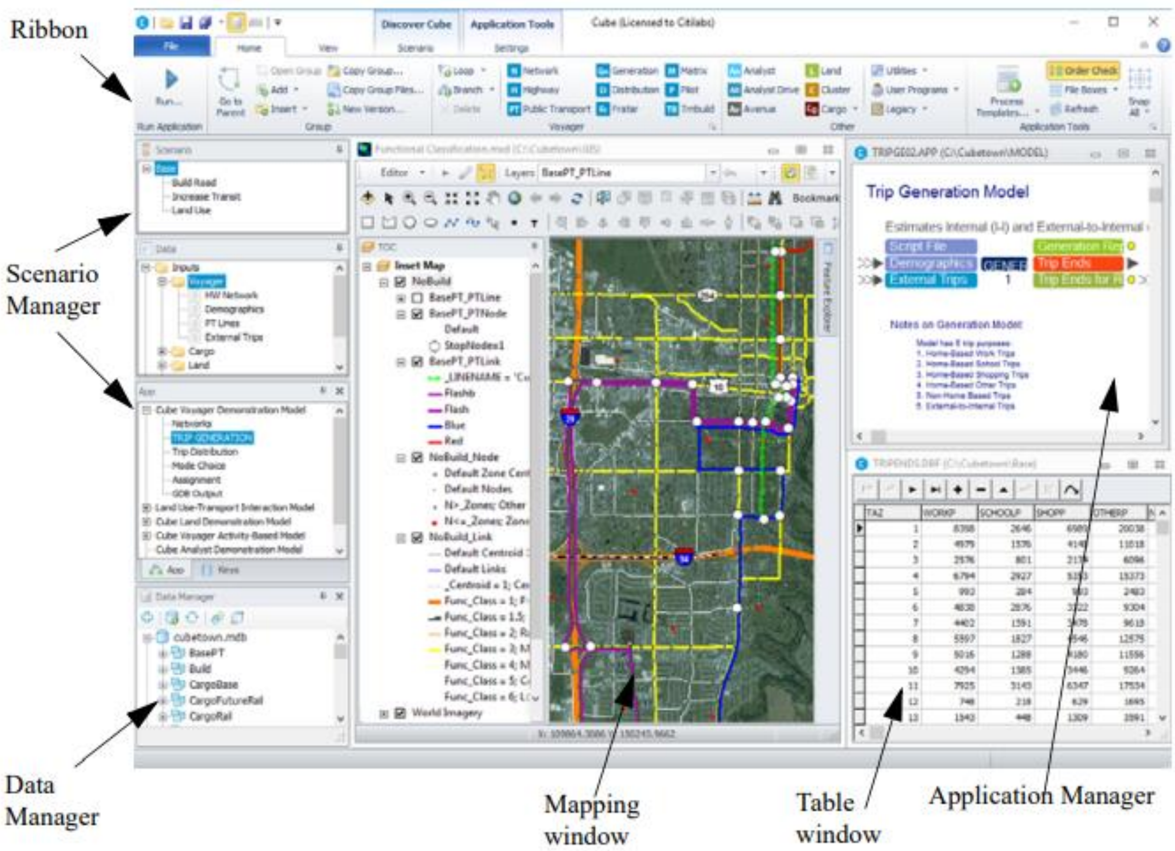
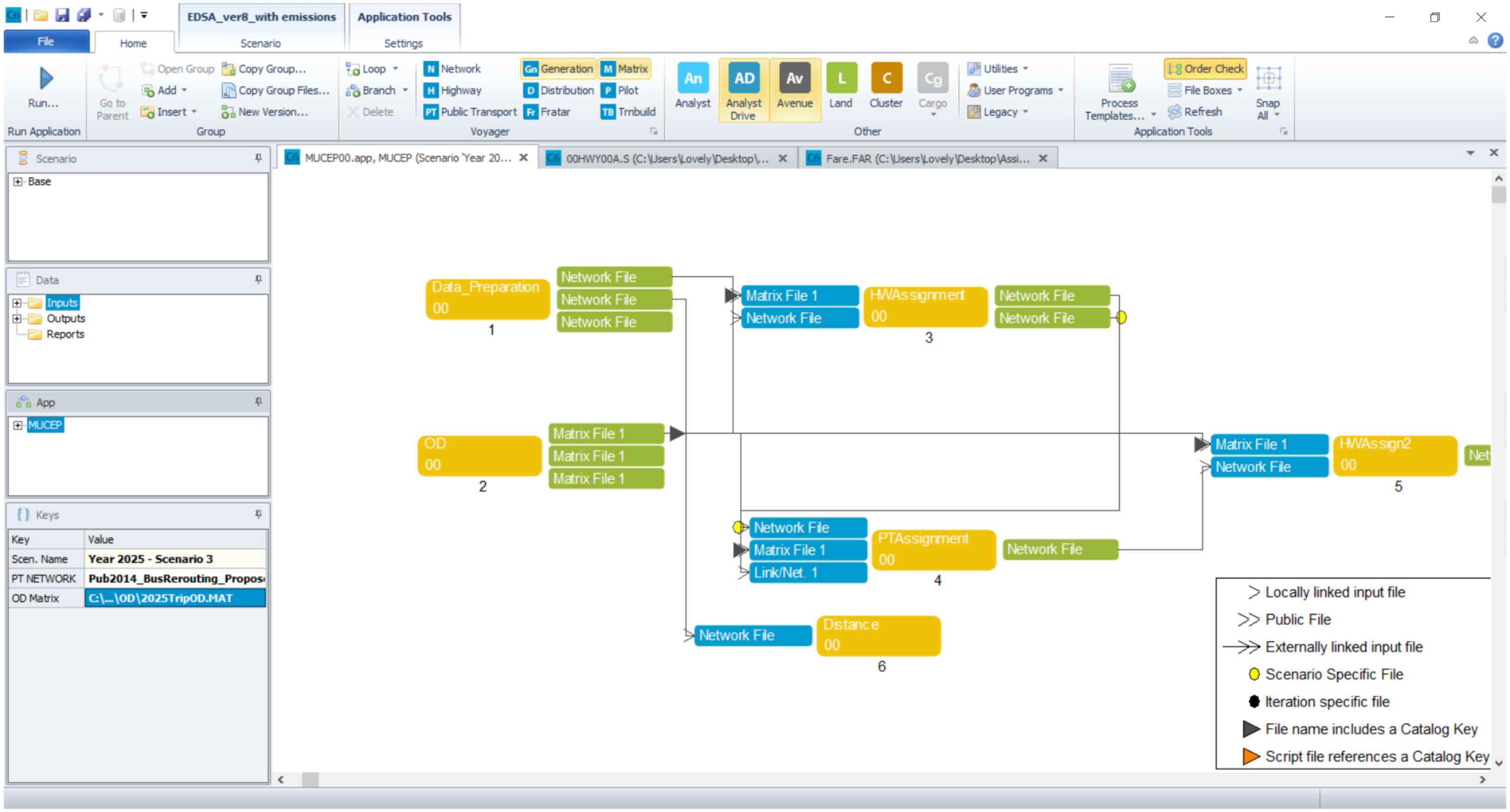


FIGURE 21 Cube user interface (Citilabs, 2016).

In this study, the traffic model application from the 2015 MUCEP study was used as shown in Figure 22. The application follows the 4-step model shown earlier in Figure 17. The first step is to create the traffic network generated (Figure 26) from the link and node files from GIS. The GIS files have attribute properties that is used in the running the model as shown in Table 20.

TABLE 20 Input GIS files attributes from model

Information	GIS Type	Attributes
Link	Polyline	Link name Link classification (rail, road) Link distance Link velocity Link capacity Fare
Node	Point	Node name Node coordinates



Key	Value
Scen. Name	Year 2025 - Scenario 3
PT NETWORK	Pub2014_BusRerouting_Propos
OD Matrix	C:\...\OD\2025TripOD.MAT

FIGURE 22 MUCEP study application.

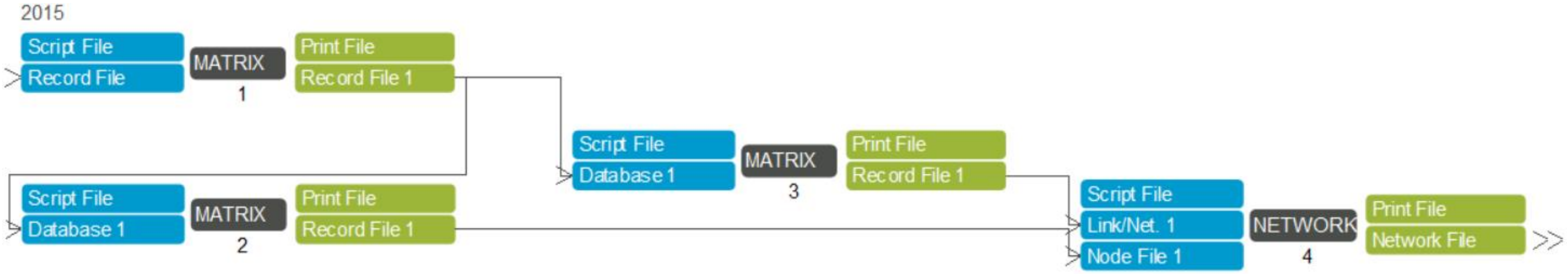


FIGURE 23 Network program from Cube.

FIGURE 24 Highway assignment from Cube.

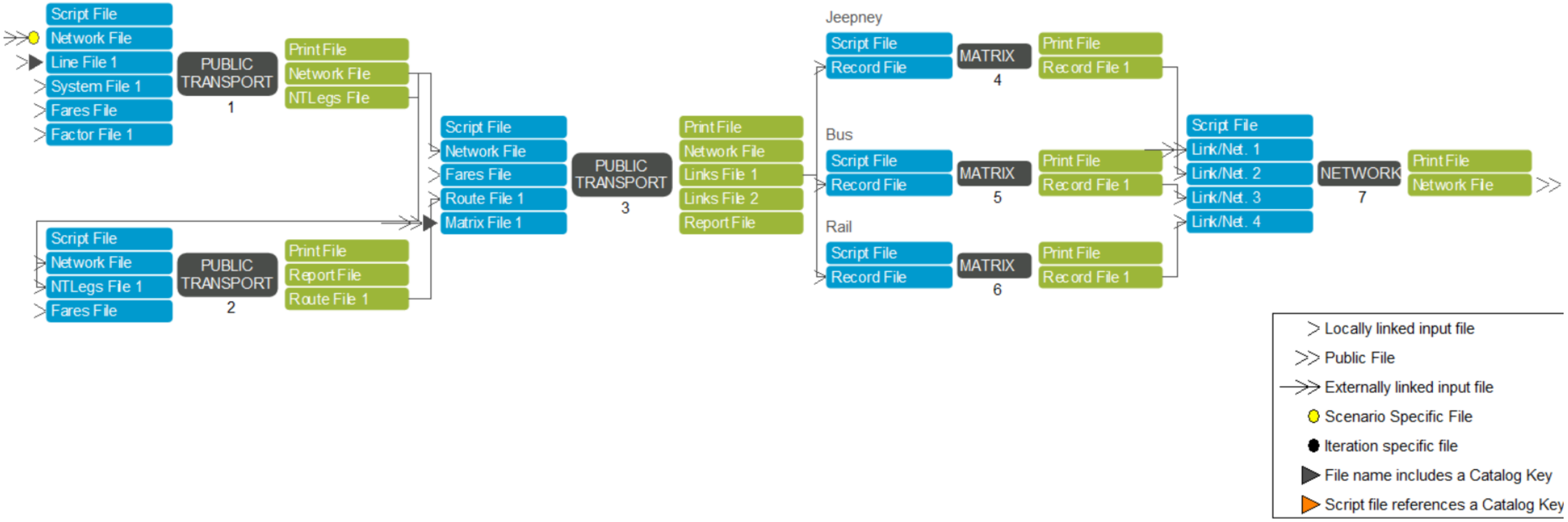


FIGURE 25 Public transportation program.

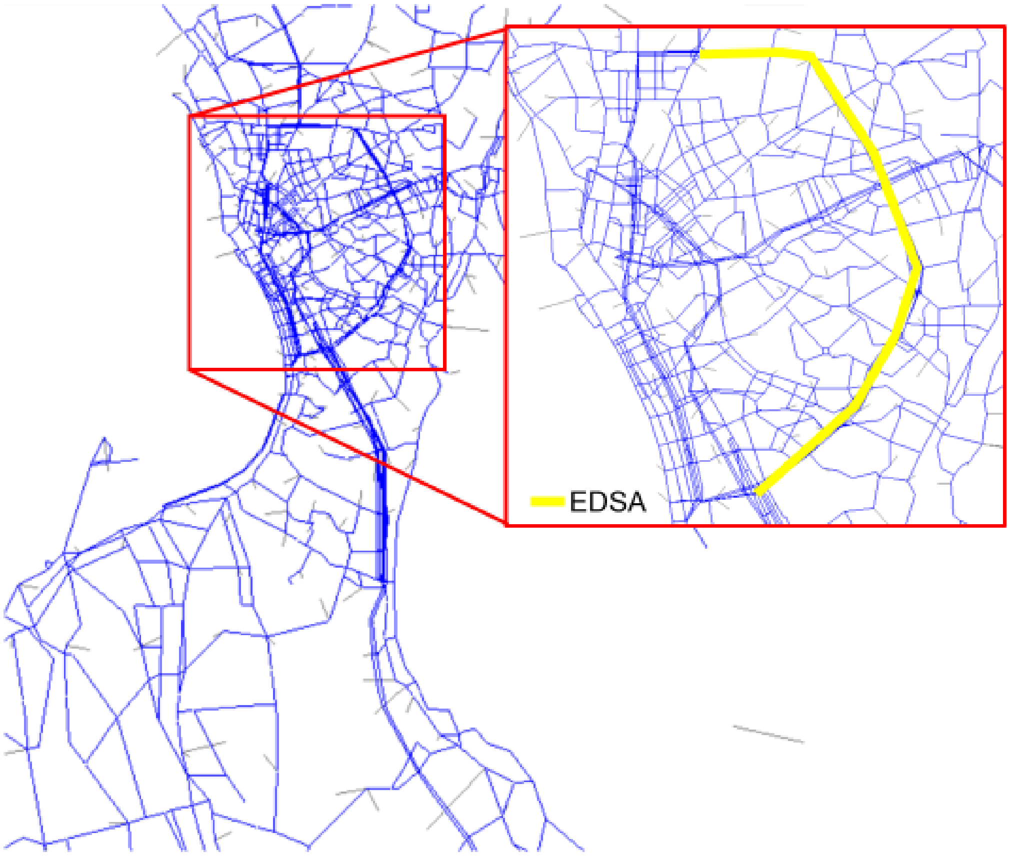
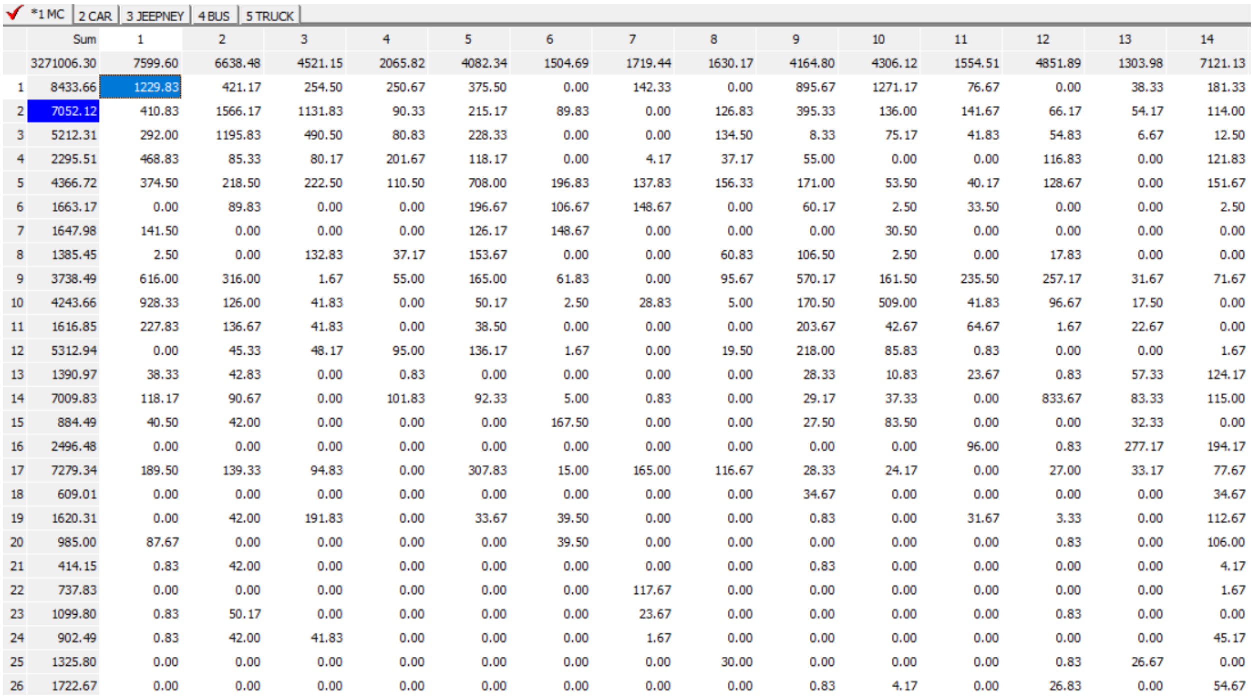


FIGURE 26 Metro Manila Cube network model.

The second step in the model is the trip generation and distribution which is based on the O-D matrix provided by the same study. These O-D matrices are already divided based on the mode used: motorcycle, car, jeepney, bus, and truck as shown in Figure 27 which was also used in the highway assignment step of the model.

Specifically, the MUCEP study has utilized a link-cost function for the traffic assignment as shown in Figure 28. In this case, an initial path is generated in the empty network, with the shortest distance. An initial time is then generated based on the link's distance and assigned velocity. This initial time along with the value of time and assigned fare is used to compute for the cost which is then used to generate a path with the least cost. Afterwards, the volume along this path is then computed and the congested time is calculated. This process is repeated until the least cost along the network is determined to generate the final traffic assignment.

The network step of the Cube model processes the highway networks from the previous step and generates a data record for each node and link found in input highway network file. The public transportation step of the program assigns the public transport routes present in the network. Information gathered from the bus transport system was utilized in this step such as the bus routes, headways, and bus occupancy.



	Sum	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	3271006.30	7599.60	6638.48	4521.15	2065.82	4082.34	1504.69	1719.44	1630.17	4164.80	4306.12	1554.51	4851.89	1303.98	7121.13
1	8433.66	1229.83	421.17	254.50	250.67	375.50	0.00	142.33	0.00	895.67	1271.17	76.67	0.00	38.33	181.33
2	7052.12	410.83	1566.17	1131.83	90.33	215.17	89.83	0.00	126.83	395.33	136.00	141.67	66.17	54.17	114.00
3	5212.31	292.00	1195.83	490.50	80.83	228.33	0.00	0.00	134.50	8.33	75.17	41.83	54.83	6.67	12.50
4	2295.51	468.83	85.33	80.17	201.67	118.17	0.00	4.17	37.17	55.00	0.00	0.00	116.83	0.00	121.83
5	4366.72	374.50	218.50	222.50	110.50	708.00	196.83	137.83	156.33	171.00	53.50	40.17	128.67	0.00	151.67
6	1663.17	0.00	89.83	0.00	0.00	196.67	106.67	148.67	0.00	60.17	2.50	33.50	0.00	0.00	2.50
7	1647.98	141.50	0.00	0.00	0.00	126.17	148.67	0.00	0.00	0.00	30.50	0.00	0.00	0.00	0.00
8	1385.45	2.50	0.00	132.83	37.17	153.67	0.00	0.00	60.83	106.50	2.50	0.00	17.83	0.00	0.00
9	3738.49	616.00	316.00	1.67	55.00	165.00	61.83	0.00	95.67	570.17	161.50	235.50	257.17	31.67	71.67
10	4243.66	928.33	126.00	41.83	0.00	50.17	2.50	28.83	5.00	170.50	509.00	41.83	96.67	17.50	0.00
11	1616.85	227.83	136.67	41.83	0.00	38.50	0.00	0.00	0.00	203.67	42.67	64.67	1.67	22.67	0.00
12	5312.94	0.00	45.33	48.17	95.00	136.17	1.67	0.00	19.50	218.00	85.83	0.83	0.00	0.00	1.67
13	1390.97	38.33	42.83	0.00	0.83	0.00	0.00	0.00	0.00	28.33	10.83	23.67	0.83	57.33	124.17
14	7009.83	118.17	90.67	0.00	101.83	92.33	5.00	0.83	0.00	29.17	37.33	0.00	833.67	83.33	115.00
15	884.49	40.50	42.00	0.00	0.00	0.00	167.50	0.00	0.00	27.50	83.50	0.00	0.00	32.33	0.00
16	2496.48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	96.00	0.83	277.17	194.17
17	7279.34	189.50	139.33	94.83	0.00	307.83	15.00	165.00	116.67	28.33	24.17	0.00	27.00	33.17	77.67
18	609.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	34.67	0.00	0.00	0.00	0.00	34.67
19	1620.31	0.00	42.00	191.83	0.00	33.67	39.50	0.00	0.00	0.83	0.00	31.67	3.33	0.00	112.67
20	985.00	87.67	0.00	0.00	0.00	0.00	39.50	0.00	0.00	0.00	0.00	0.00	0.83	0.00	106.00
21	414.15	0.83	42.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	0.00	0.00	0.00	0.00	4.17
22	737.83	0.00	0.00	0.00	0.00	0.00	0.00	117.67	0.00	0.00	0.00	0.00	0.00	0.00	1.67
23	1099.80	0.83	50.17	0.00	0.00	0.00	0.00	23.67	0.00	0.00	0.00	0.00	0.83	0.00	0.00
24	902.49	0.83	42.00	41.83	0.00	0.00	0.00	1.67	0.00	0.00	0.00	0.00	0.00	0.00	45.17
25	1325.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	30.00	0.00	0.00	0.00	0.83	26.67	0.00
26	1722.67	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.83	4.17	0.00	26.83	0.00	54.67

FIGURE 27 Sample matrix from Cube.

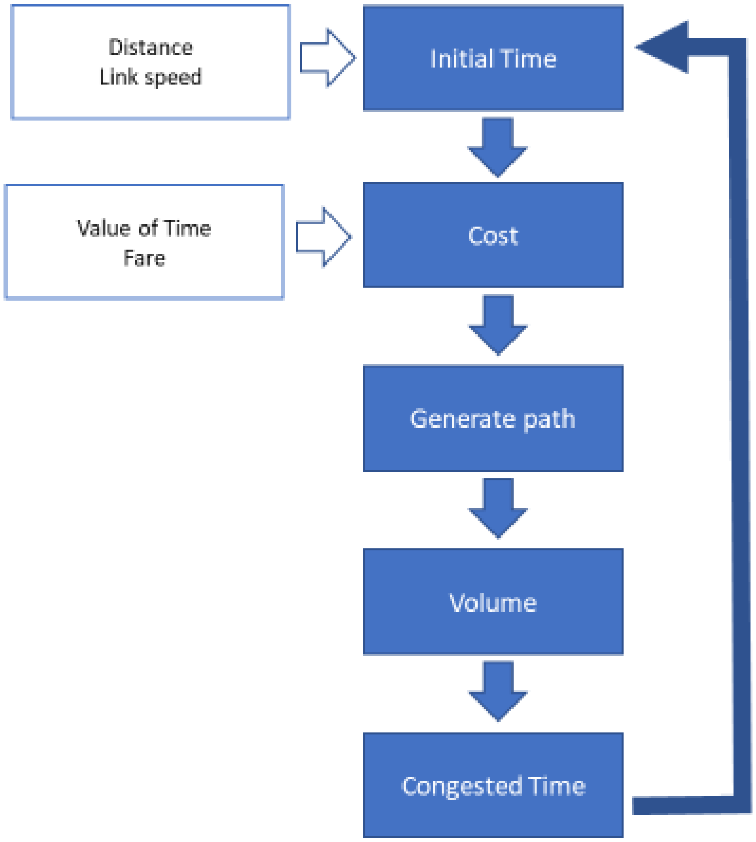


FIGURE 28 Simplified highway assignment process.

3.4 Validation of Flows

After initial running of the program, there is a need to compare model results with actual traffic flows to check the accuracy of the model in representing real-life conditions (Castro & Delos Reyes, 2010). Thus, the model was validated to confirm the flows which resulted from the model and then compared to actual flows on the roadways. Specifically, bus counts from the recently counted survey and some traffic counts along EDSA as late as 2018 were used. Adjustments in the parameters of the model were then made to validate these counts.

3.5 Emissions Estimation

As mentioned by Nagendra et al. in 2002, vehicles on the road are normally modeled as a line source which estimates the effects of many vehicles moving along a road as a line. This means that the vehicles emit a defined amount of pollution per unit of time along its length. Thus, emissions can be determined by multiplying the number of vehicles by a per-vehicle emission factor (Castro & Delos Reyes, 2010).

The impacts of the overall transport roadmap programs on air quality improvement and climate change mitigation can be estimated thru two approaches: top-down and bottom-up approach. The former is used for fuel consumption in a city or a region, while the latter is based on cumulating all vehicle emission in a target city or region (Almec Corporation, 2014).

Specifically, top-down approach is most suitable for programs targeting specific values such as the introduction of a new fuel-source. Whereas, bottom-up approach can be applied to programs that include traffic flow improvements and is more appropriate to estimate vehicle emissions (Almec Corporation, 2014). In this study, the bottom-up approach will be used in the estimation of emissions. The following equation will be used in the estimation of the vehicle emissions on each link:

$$E = \sum_{k} \sum_{i} (D_k \times T_{k,i} \times EF_{k,i})$$

where

i	vehicle type
k	link number
D_k	link length (km)
$T_{k,i}$	traffic volume by vehicle type by link (vehicles/day)
$EF_{k,i}$	emission factor by vehicle type by vehicle speed (g/km)

Emission estimation required several variables such as the length of the link, traffic volume, and emission factors by vehicle type and vehicle speed. The first two variables can be taken from the traffic model. In the 2014 report by Almec Corporation, the emission rates used was from the "Reference Emission Factors" developed by UP-NCTS as shown in Table 21. Compared to other existing vehicle emission factors in Metro Manila, this was found to have a more accurate calculation compared to previous tables since it includes a sufficient number of speed classes. In this study, six types of pollutant emissions were estimated, CO2, NOx, PM, CO, SOx, and HC based on the existing vehicle composition in Metro Manila.

TABLE 21. Reference emission factors developed by UP-NCTS (Almec Corporation, 2014)

	Speed Classes/ Speed of Representative (km/hr)							
	Vehicle Type	3 to 5 4	5 to 10 7.5	10 to 15 12.5	15 to 25 20	25 to 40 32.5	40 to 60 50	60 to 80 70
CO2	Gas car	447.6	363.7	327.5	306.3	292.0	282.5	277.3
	Diesel utility vehicle/jeepney	643.7	544.6	501.8	476.7	459.9	448.7	442.5
	Diesel truck/bus	1182.9	1083.9	1041.1	1016.0	999.1	987.9	981.7
NOx	Gas car	5.512	3.656	2.998	2.700	2.456	2.462	2.424
	Diesel utility vehicle/jeepney	4.212	2.356	1.698	1.400	1.246	1.162	1.124
	Diesel truck/bus	15.312	13.456	12.798	12.500	12.346	12.262	12.224
PM	Gas car	2.912	1.056	0.398	0.100	0.100	0.100	0.100
	Diesel utility vehicle/jeepney	3.712	1.856	1.198	0.900	0.746	0.662	0.624
	Diesel truck/bus	3.712	1.856	1.198	0.900	0.746	0.662	0.624
CO	Gas car	52.312	50.456	49.798	49.500	49.346	49.262	49.224
	Diesel utility vehicle/jeepney	5.312	3.456	2.798	2.500	2.346	2.262	2.224
	Diesel truck/bus	15.212	13.356	12.698	12.400	12.246	12.162	12.124
Sox	Gas car	2.823	0.967	0.309	0.011	0.011	0.011	0.011
	Diesel utility vehicle/jeepney	2.933	1.077	0.419	0.121	0.121	0.121	0.121
	Diesel truck/bus	3.186	1.330	0.672	0.374	0.220	0.136	0.098
HC	Gas car	8.812	6.956	6.298	6.000	5.846	5.762	5.724
	Diesel utility vehicle/jeepney	3.512	1.656	0.998	0.700	0.546	0.462	0.424
	Diesel truck/bus	6.512	4.656	3.998	3.700	3.456	4.462	3.424

Source: JICA Study team

Note: Dr. Karl N. Vergel of UP-NCTS updated existing Manila emission factors (1992, 1996) upon request of study team as a reference.

3.6 Vehicle and Fuel Types

It can be noticed from Table 20 that the vehicle types were further subdivided to type of fuel used. Thus, information on the list of vehicle type and type of fuel used was also needed for the calculation which was taken from the data of the Land Transportation Office and the Philippine Statistics Authority as shown in Table 22. As observed from the table, there are two major fuel types used in the country: gas and diesel. Alternative sources such as CNG, LPG, and LEV, were not included since they are too few to pose any significant effect on the overall traffic flow. Looking into specific vehicle type, 98.50% of cars are fueled by gas, while 99.57% of buses are fueled by diesel, 96.58% of trucks are fueled by diesel and 65.76% of jeepneys are fueled by diesel. This is consistent with the available emission factors shown in Table 21. Thus, for the emission estimations, it was assumed that 100% of cars are fueled by gasoline and the rest are 100% fueled by diesel.

TABLE 22 Vehicle registration by fuel type in Metro Manila, 2014 (LTO, 2017 and PSA, 2017)

Fuel Type	Vehicle Type				
	Cars	UV/ SUVs	Trucks	Buses	Trailers
Gas	455, 833	273,819	2,569	53	19,234
Diesel	6,948	525,867	72,595	12,168	
CNG	0	2	2	0	
LPG	91	25	0	0	
LEV	5	53	2	0	
Others	3	10	0	0	

3.7 Traffic Growth Rates

Traffic growth rates from the 2012 Metro Manila Interchange Construction Project (MMICP) was used in adjusting the traffic volumes from the 2020 condition to the 2025 condition as shown in Table 23. After 2015, traffic growth rate is expected to decrease considering a decreasing trend in the growth rate estimated by DPWH. The estimated traffic growth rates were obtained by deducting rates of 1.9% and 0.8%, respectively (Japan International Cooperation Agency, 2012).

TABLE 23 Traffic growth rate (Japan International Cooperation Agency, 2012)

Period	Annual Growth Rate
2011-2015	6.4%
2015-2020	4.5% (-1.9%)
2020-2028	3.7% (-0.8%)

Source: JICA Study Team

3.8 Scenarios

Aside from the present traffic condition and the proposed bus ban wherein the northbound and southbound trips are cut at Valenzuela and Sta. Rosa Interim Terminals, respectively, an additional alternative scenario - wherein the required city buses were added, was also included in the study. Specifically, the following scenarios were investigated:

- *2019 Scenario 1:* In this scenario, the 2019 existing bus route is implemented wherein the provincial buses are allowed to access EDSA without any restrictions.
- *2020 Scenario 1:* In this scenario, the 2020 existing bus route is implemented wherein the provincial buses are allowed to access EDSA without any restrictions. The results from this condition was the baseline for comparison from the other scenarios for this year.
- *2020 Scenario 2:* In this scenario, the 2020 proposed bus route is implemented wherein the provincial buses are not allowed to access EDSA but are instead redirected to the north and sound interim terminals. The selected city buses were extended to accommodate affected passengers with no additional buses deployed.
- *2020 Scenario 3:* In this scenario, the 2020 proposed bus route is implemented wherein the provincial buses are not allowed to access EDSA but are instead redirected to the north and sound interim terminals. The selected city buses were extended to accommodate affected passengers with additional buses deployed.
- *2025 Scenario 1:* In this scenario, the 2025 existing bus route is implemented wherein the provincial buses are allowed to access EDSA without any restrictions. The results from this condition was the baseline for comparison from the other scenarios for this year.
- *2025 Scenario 2*: In this scenario, the 2025 proposed bus route is implemented wherein the provincial buses are not allowed to access EDSA but are instead redirected to the north and sound interim terminals. The selected city buses were extended to accommodate affected passengers with no additional buses deployed.
- *2020 Scenario 3:* In this scenario, the 2025 proposed bus route is implemented wherein the provincial buses are not allowed to access EDSA but are instead to the north and sound interim terminals. The selected city buses were extended to accommodate affected passengers with additional buses deployed.

3.9 Data Analysis

Changes in performance measures such as total distance travelled as well as reductions in emissions was calculated by comparing the proposed bus ban scheme with the existing scenario and the alternative scenarios in both regional and local levels using the following equations:

$$\Delta T_j = \frac{T_a - T_b}{T} x\ 100\%$$

$$\Delta VC_j = \frac{VC_a - VC_b}{VC_b} x\ 100\%$$

$$\Delta E_i = \frac{E_a - E_b}{E_b} x\ 100\%$$

where

T percent change in travel time

V percent change in vehicle-kilometers travelled

E percent change in emission for pollutant *i*

a “after” or alternative scenario

b “before” or existing condition scenario

4. RESULTS AND DISCUSSION

4.1 Region-wide Analysis

Traffic impacts in terms of changes in total travel time and total travel distance were determined for each scenario as shown in Table 24. For the year 2020, scenario 1 has the least total travel time of 429,739.72 vehicle-hours. Whereas, for the year 2025, scenario 1 has the least total travel time with 566,623.26 vehicle-hours. This is also consistent for the total travel distance, with scenario 1 being the lowest for both years 2020 and 2025.

In can be noted that in scenario 2, the provincial buses have a shorter route due to the ban and thus have reduced travel times. Whereas, for scenario 3 selected city buses have a slightly longer route and thus have longer travel times and distances than scenario 2. For the Valenzuela Interim terminal, there are 1,236 and 1,071 additional bus trips for the northbound and southbound direction, respectively. While for the Sta. Rosa Interim terminal, there are 552 and 624 additional bus trips for the northbound and southbound direction, respectively.

A spatial presentation of the results for the travel speed, v/c ratio, and emissions of existing and alternative scenarios are presented in Tables 28 to 43.

TABLE 24 Traffic impacts for the existing and alternative scenarios

Scenarios	Veh-Hr	Veh-km
2019 - Scenario 1	313,614.88	9,581,526.83
2020 - Scenario 1	429,739.72	11,935,051.82
2020 - Scenario 2	441,048.33	12,436,367.20
2020 - Scenario 3	438,647.25	12,383,307.38
2025 - Scenario 1	566,623.26	12,265,752.55
2025 - Scenario 2	585,414.32	12,825,476.06
2025- Scenario 3	581,492.21	12,747,347.89

Environmental impacts in terms of the amount of pollutant emissions for CO2, NOx, PM, CO, SOx, and HC for the various scenarios were calculated as shown in Table 25. Based on the results, the emission estimations vary depending on the pollutants considered. For CO2, PM, and SOx, scenario 2 has the highest amount of emissions. While for NOx, CO, and HC, scenario 1 had the highest amount of emissions.

TABLE 25 Amount of emissions for the existing and alternative scenarios (in kg/day)

Scenarios	CO2	NOx	PM	CO	SOx	HC
2019 - Scenario 1	1,441,707.33	15,652.69	1,352.89	187,048.27	297.91	23,221.48
2020 - Scenario 1	2,041,615.50	22,592.06	1,828.80	282,935.02	492.75	34,866.74
2020 - Scenario 2	2,235,085.43	22,182.67	2,147.10	274,548.61	560.39	33,889.20

2020 - Scenario 3	2,213,802.04	22,082.07	2,121.67	272,866.77	557.37	33,679.70
2025 - Scenario 1	2,342,440.98	26,030.63	2,045.77	324,088.35	510.62	40,309.67
2025 - Scenario 2	2,565,826.34	25,569.91	2,440.48	315,622.68	571.41	39,345.85
2025- Scenario 3	2,532,860.10	25,595.34	2,387.47	315,443.21	565.59	39,315.00

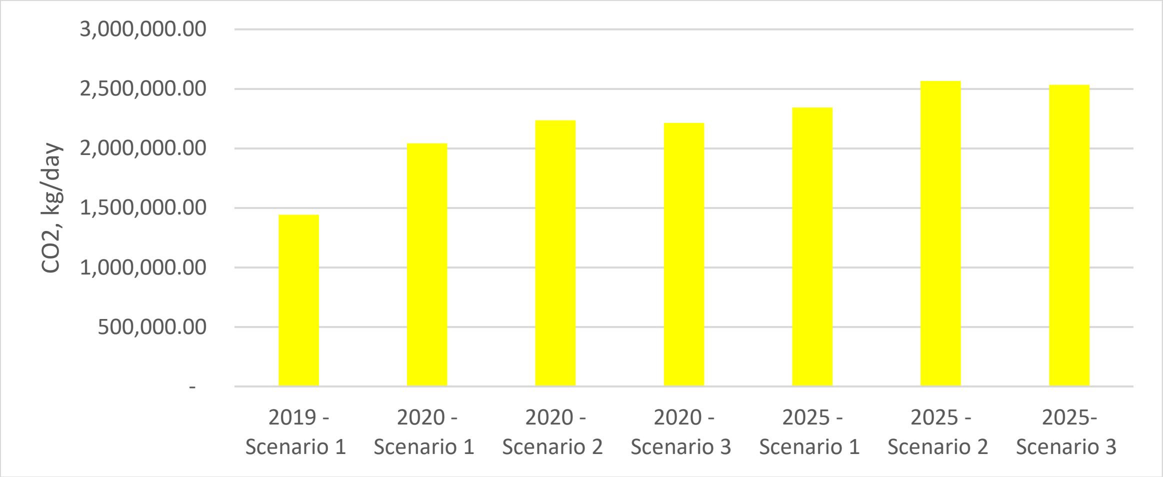


FIGURE 29 CO2 emissions for the existing and alternative scenarios.

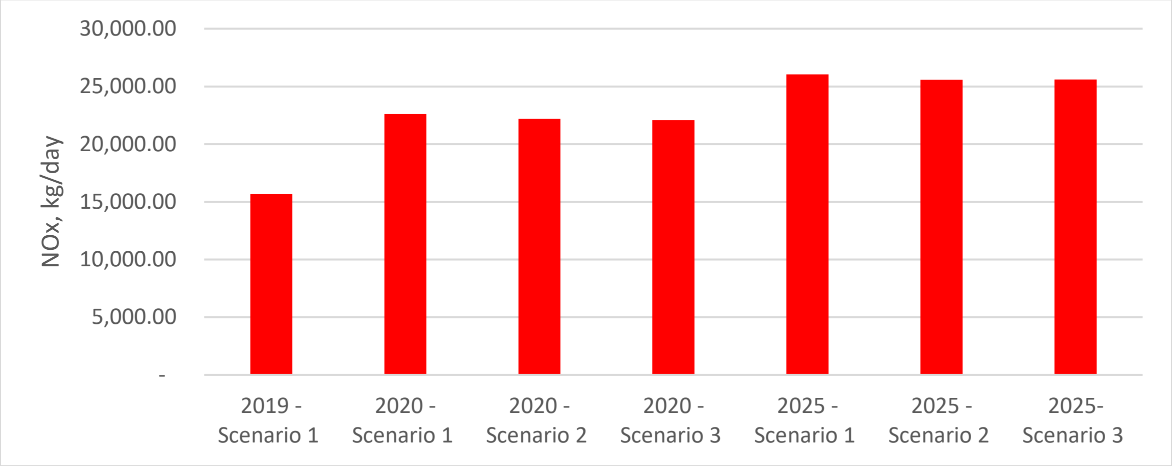


FIGURE 30 NOx emissions for the existing and alternative scenarios.

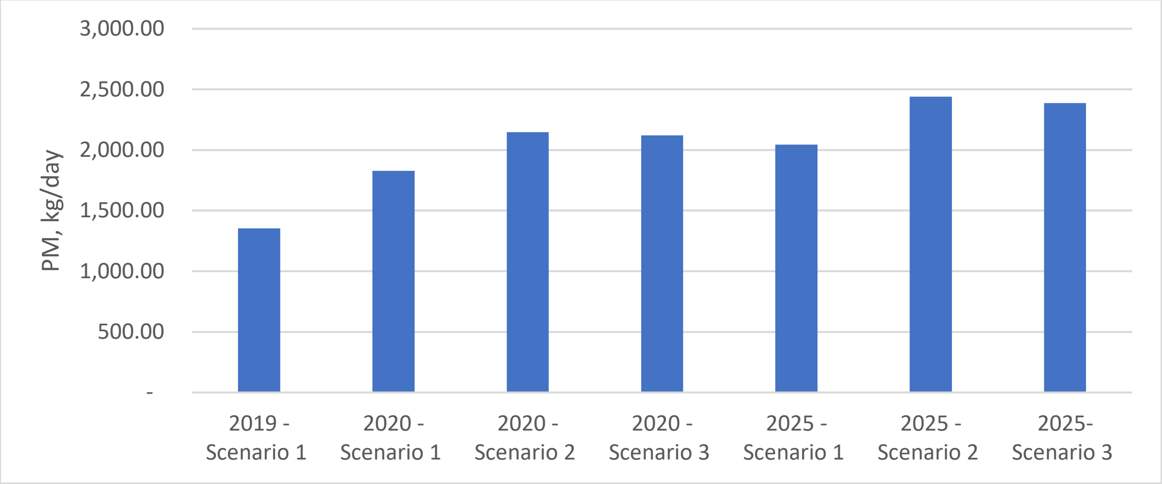


FIGURE 31 PM emissions for the existing and alternative scenarios.

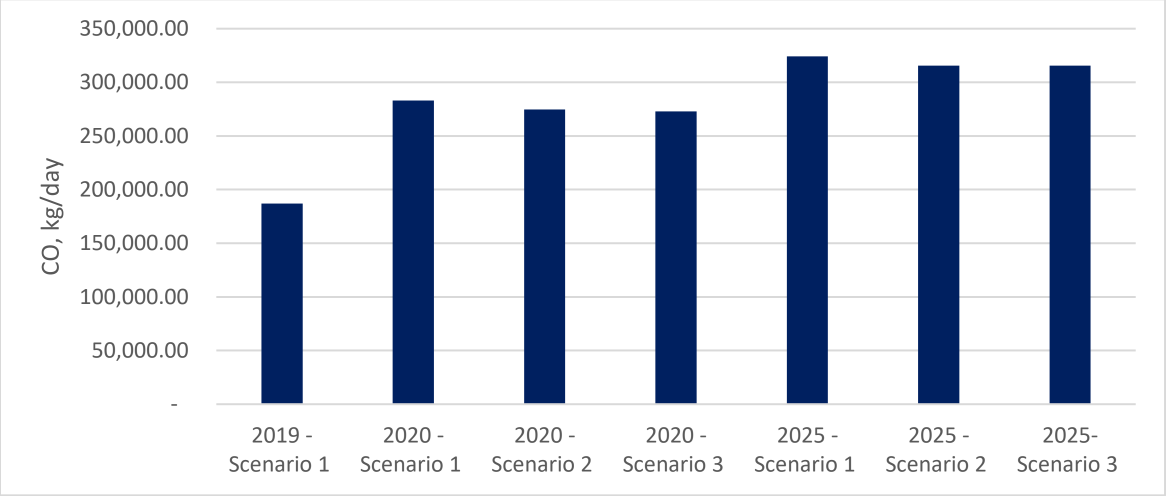


FIGURE 32 CO emissions for the existing and alternative scenarios

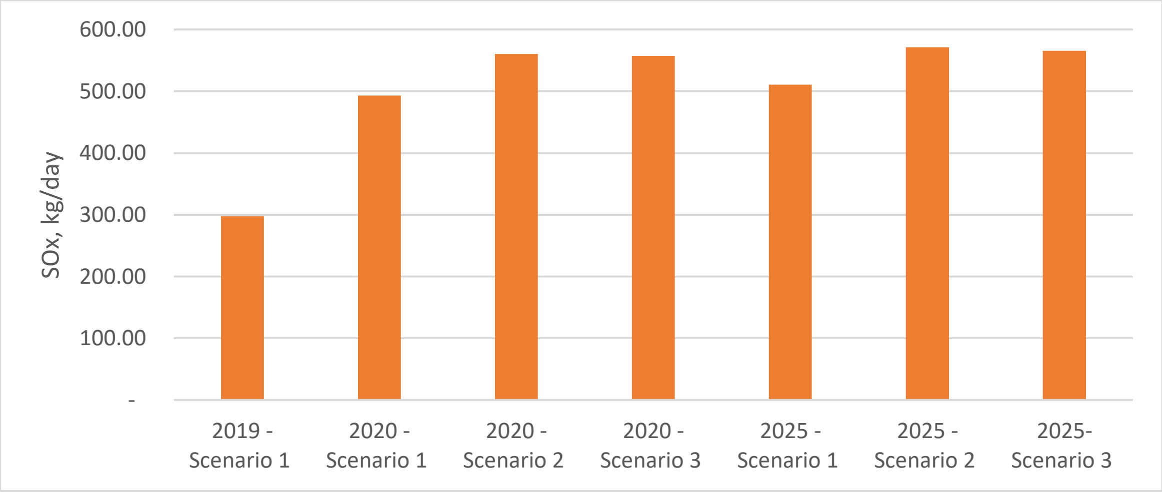


FIGURE 33 SOx emissions for the existing and alternative scenarios.

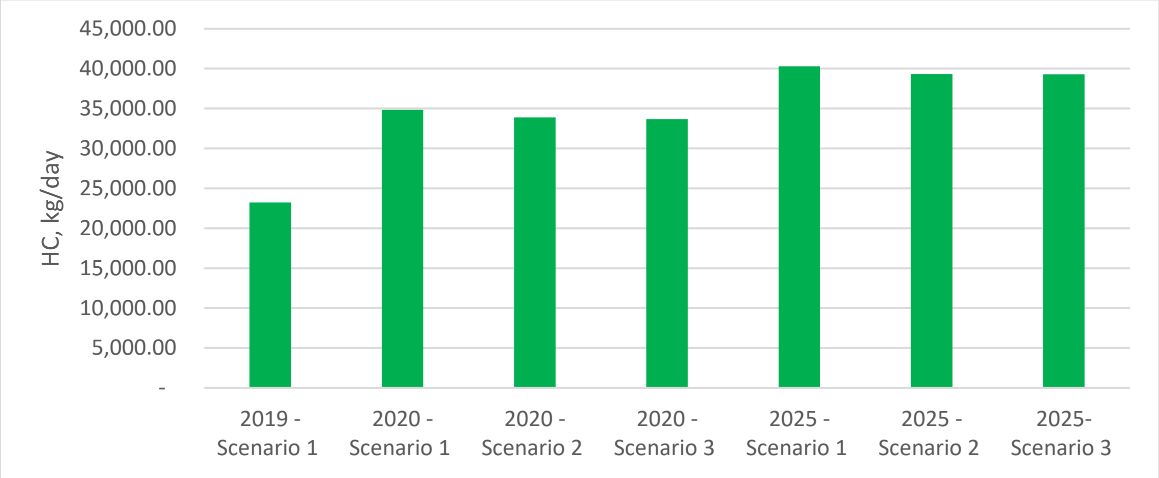


FIGURE 34 HC emissions for the existing and alternative scenarios.

To compare the alternative scenarios with existing scenario, percentage changes of the traffic and environmental impacts were computed as shown in Table 26.

TABLE 26 Percentage changes with the implementation of alternative scenarios

Scenarios	Veh-Hr	Veh-km	CO2	NOx	PM	CO	SOx	HC
2020 - Scenario 2	2.63%	4.20%	9.48%	-1.81%	17.40%	-2.82%	13.73%	-2.76%
2020 - Scenario 3	2.07%	3.76%	8.43%	-2.26%	16.01%	-3.40%	13.11%	-3.37%
2025 - Scenario 2	3.32%	4.56%	9.54%	-1.77%	19.29%	-2.63%	11.90%	-2.18%
2025- Scenario 3	2.62%	3.93%	8.13%	-1.67%	16.70%	-2.68%	10.77%	-2.26%

The existing condition for the year 2020 scenario is still a better option compared to the proposed alternative scenarios, since both scenarios generated increased travel times and distances. Similarly, the v/c ratio in the network got slightly worse with the implementation of the bus rerouting scheme. Moreover, emissions in the network got mixed results. Whereas, the NOx, CO, and HC emissions improved in both alternative scenarios, CO2, PM, and SOx emissions increased.

This is also similar for the year 2025, with both scenarios having increased travel time and distance indicating that the original scenario is still the best option. Considering emissions, CO2, PM and SOx emissions increased but with a reduced NOx, CO, and HC emission.

In general, the different scenarios got mixed results in terms of traffic and environmental impacts. Although the alternative scenarios did generate an increase traffic congestion and CO2, PM and SOx emissions, it however decreased NOx, CO and HC emissions.

CO, NOx and PM have been identified as criteria air pollutants by most environmental protection agencies and departments from different countries due to their severe adverse effects on humans and the environment (Wang, Szeto, Han, & Friesz, 2018). By considering this in the decision-making process, it can be concluded that scenario 3 is a better option it terms of reducing vehicle emissions.

The building up and expansion of public transport infrastructure is one strategy in the reduction of travel times, road congestion and emissions (Bel & Holst, 2018). By doing the opposite in reducing the public bus routes, the policy has led to longer travel times, congestion and emissions at some degree. Specifically, road space vacated by the buses provided a cheaper path for cars to occupy, thus, the observable increase in car composition. With the general increase in the traffic volume, however, traffic conditions along the study area have worsened with reduced travel speeds and increased travel time.

As shown in Table 18, the emission factors depend on the speed the vehicles are traveling along the link. Based on the results shown in Table 28, the average speed along the study area for 2019 is 37kph. With the increase in travel demand for the years 2020 and 2025, the average travel speed slowed to 36 and 27 kph, respectively. In some areas, the link speed is much lower corresponding to a higher emission factor which further led to higher emissions.

Vehicle composition also affects the emission estimation since emission factors vary depending on the vehicle classification. Table 24 presents the varying vehicle composition for the different scenarios. It can be seen scenario 2 shows a lower bus percentage since the provincial bus routes a cut at Valenzuela and Sta. Rosa, preventing them in accessing other road segments. Meanwhile, Scenario 3 has a slightly higher percentage since the city buses with extended routes are allowed to travel in a higher frequency to accommodate affected passengers. Although buses have higher emission factors for these emissions, the increase in the number of cars which also had affected the increase of the CO2, NOx, and CO emissions.

Although gasoline engines emit more CO, diesel-fueled vehicle are a concern to public health due to high emissions of NOX and SPM, and in most cases emit more of these pollutants compared to gasoline engines (Castro & Delos Reyes, 2010). Moreover, by replacing diesel-fueled buses with gas-fueled cars along the study area there was a significant reduction in emissions along the affected network.

TABLE 27 Traffic Composition for the existing and alternative scenarios

Scenarios	Motorcycle	Car	Jeepney	Bus	Truck
2019 - Scenario 1	11%	58%	13%	10%	8%
2020 - Scenario 1	1%	66%	11%	10%	11%
2020 - Scenario 2	1%	62%	17%	8%	11%
2020 - Scenario 3	1%	63%	16%	9%	11%
2025 - Scenario 1	2%	69%	12%	8%	10%
2025 - Scenario 2	2%	65%	18%	6%	10%
20205- Scenario 3	2%	65%	17%	7%	10%

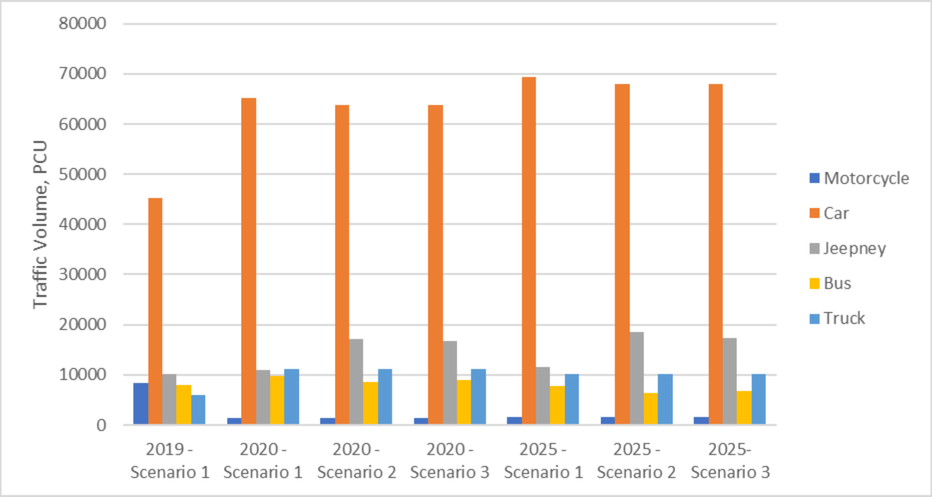


FIGURE 35 Traffic composition for existing and alternative scenarios

TABLE 28 Travel speed of the existing and alternative scenarios of regional network

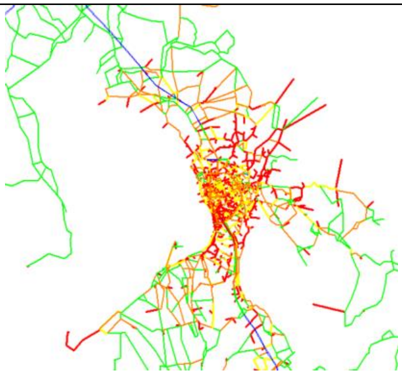
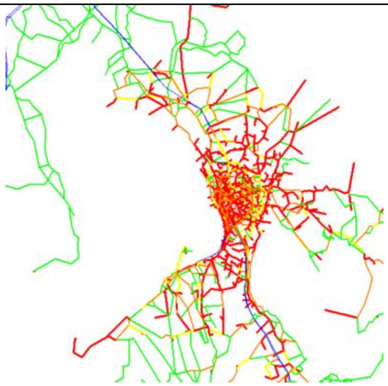
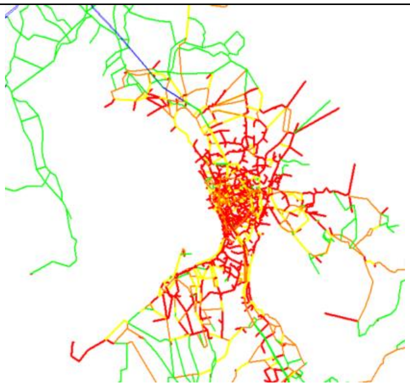
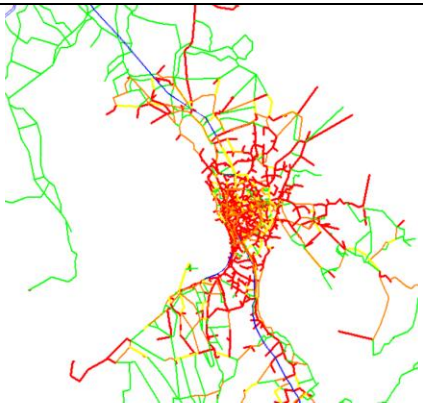
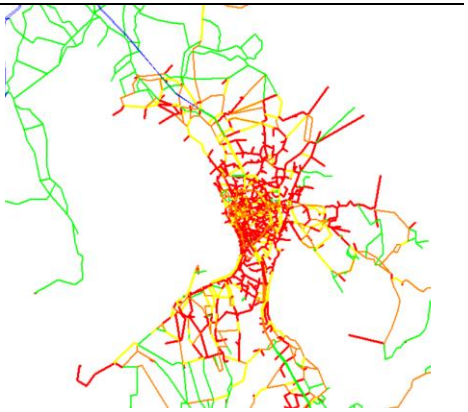
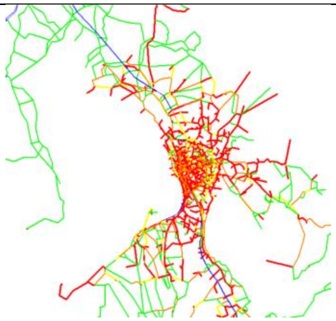
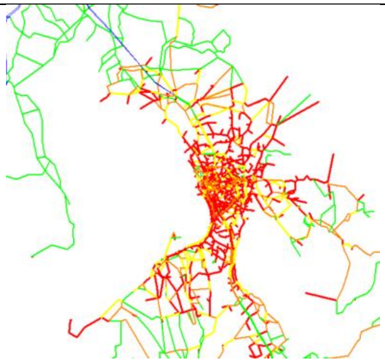
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟥 0 – 15 kph 🟨 15 kph – 25 kph 🟧 25 kph – 40 kph 🟩 40 kph – 60 kph 🟦 >60 kph		

TABLE 29 Travel speed of the existing and alternative scenarios of EDSA

Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟥 0 – 15 kph 🟨 15 kph – 25 kph 🟧 25 kph – 40 kph 🟩 40 kph – 60 kph 🟦 >60 kph		

TABLE 30 V/C ratio of the existing and alternative scenarios of regional network

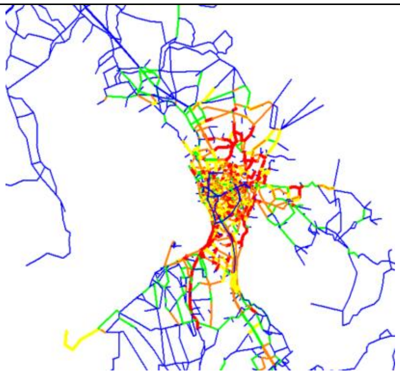
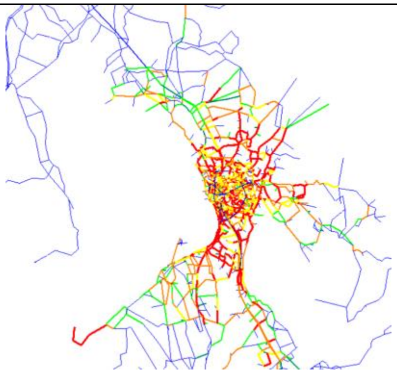
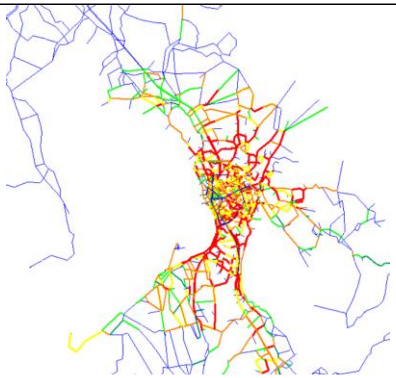
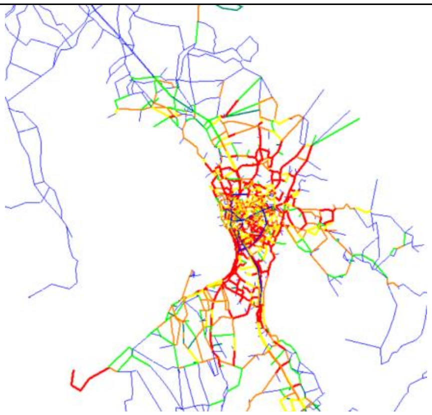
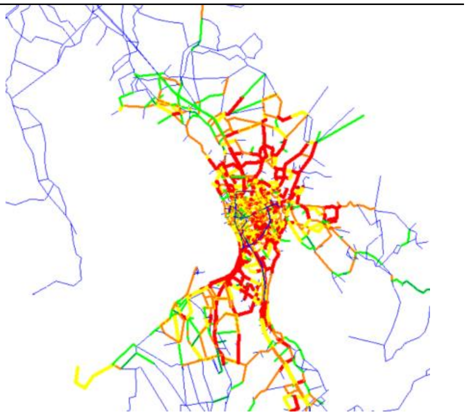
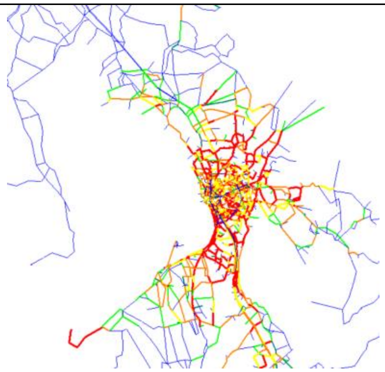
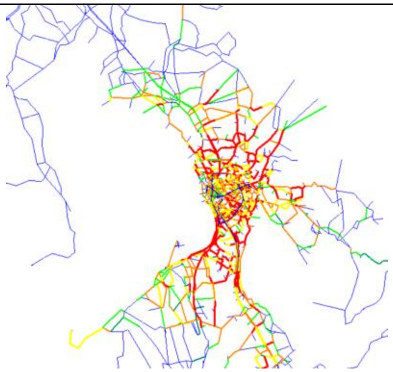
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 0.3 🟩 0.3 – 0.5 🟧 0.5 – 0.8 🟨 0.8 – 1.0 🟥 >1.0		

TABLE 31 V/C ratio of the existing and alternative scenarios of EDSA

Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 0.3 🟩 0.3 – 0.5 🟧 0.5 – 0.8 🟨 0.8 – 1.0 🟥 >1.0		

TABLE 32 CO2 emissions of existing and alternative scenarios of regional network

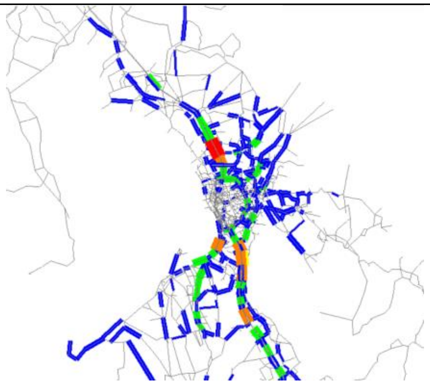
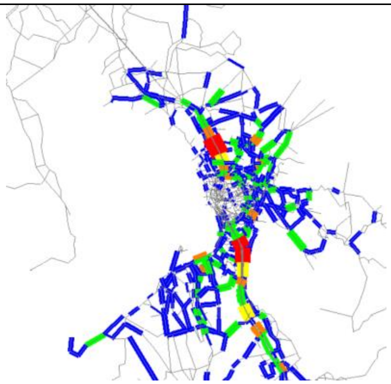
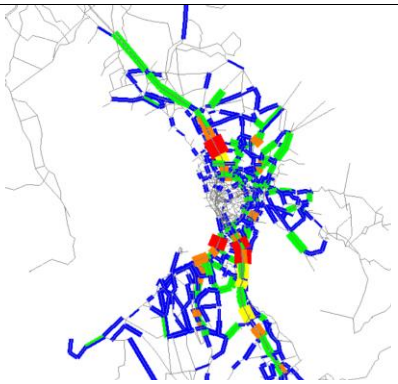
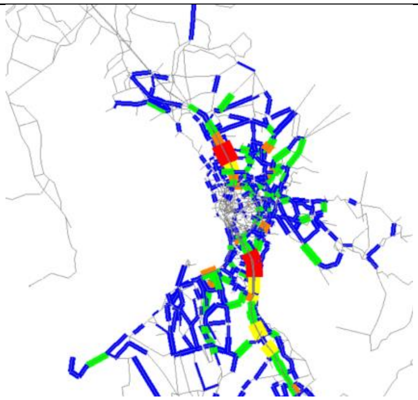
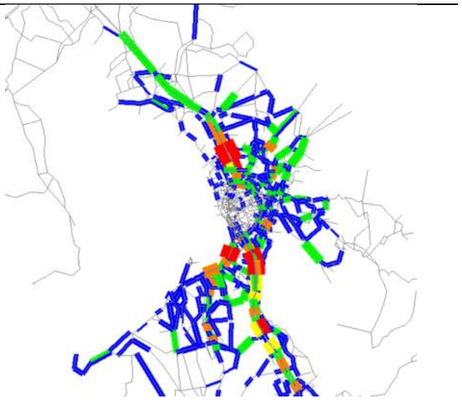
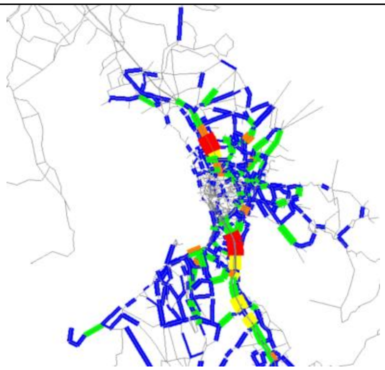
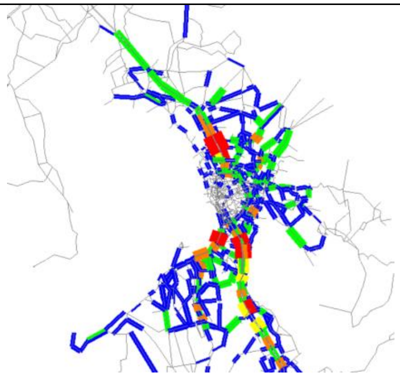
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 20,000 kg 🟩 20,000 kg – 40,000 kg 🟧 40,000 kg – 60,000 kg 🟨 60,000 kg – 80,000 kg 🟥 >80,000 kg		

TABLE 33 CO2 emissions of existing and alternative scenarios of EDSA

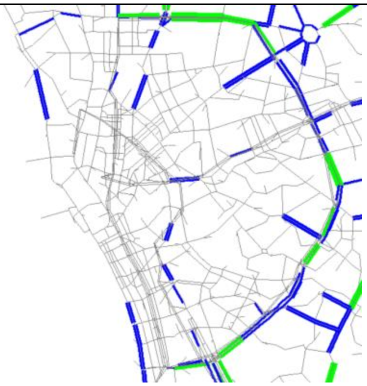
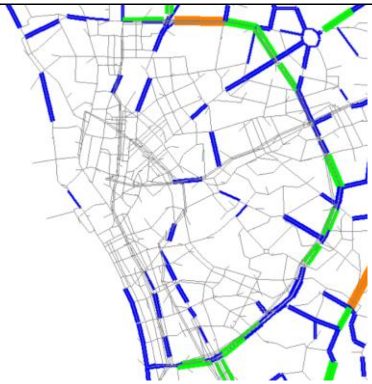
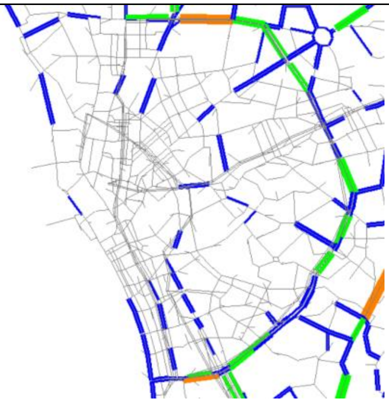
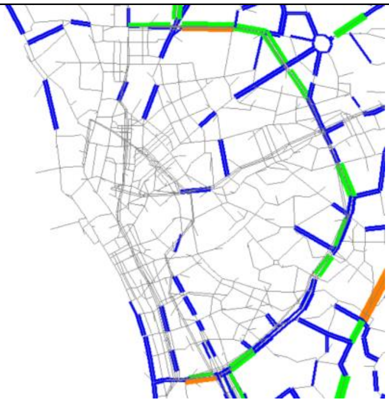
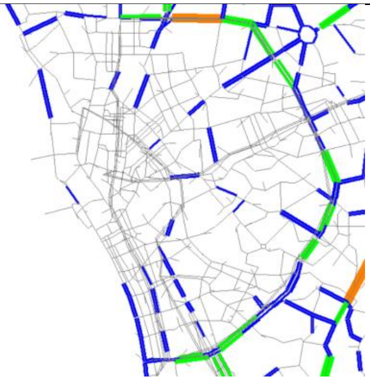
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 20,000 kg 🟩 20,000 kg – 40,000 kg 🟧 40,000 kg – 60,000 kg 🟨 60,000 kg – 80,000 kg 🟥 >80,000 kg		

TABLE 34 NOx emissions of existing and alternative scenarios of regional network

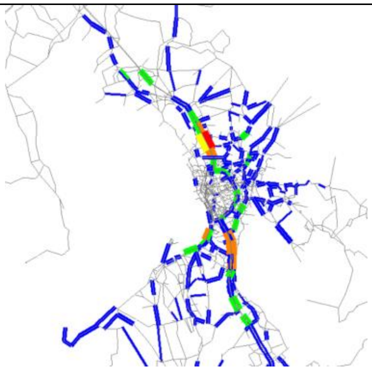
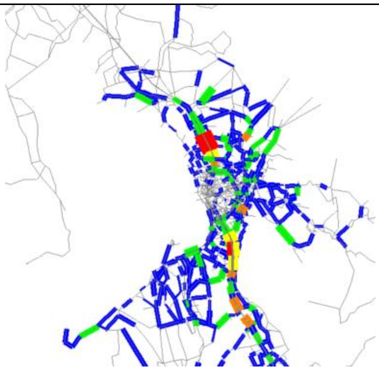
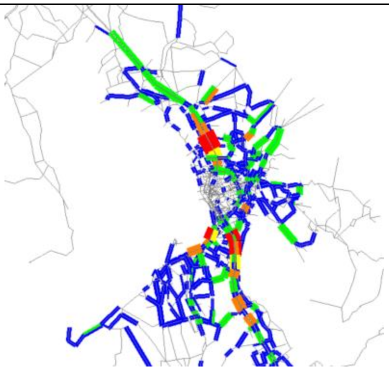
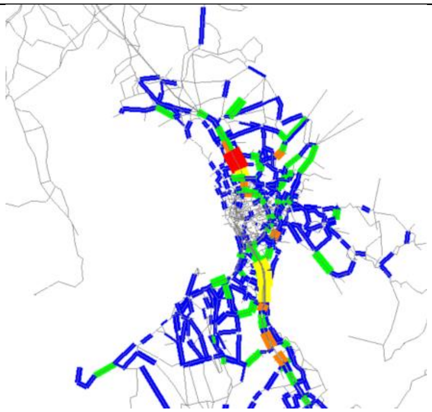
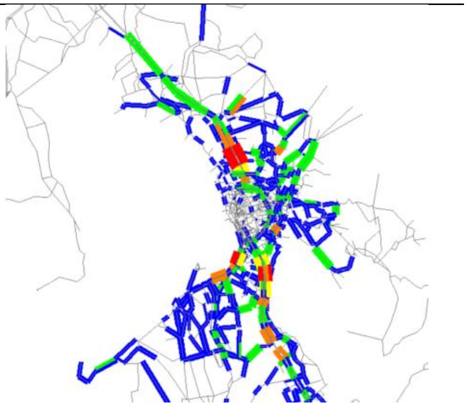
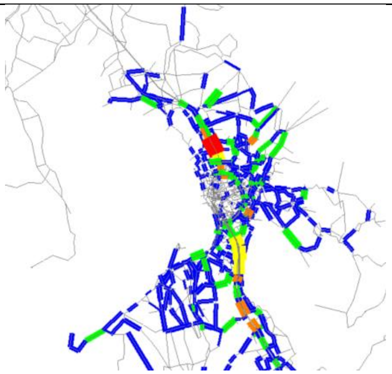
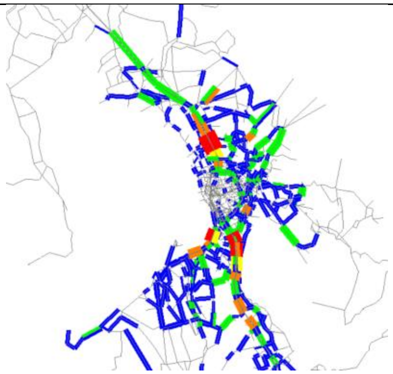
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 200 kg 🟩 200 kg – 400 kg 🟧 400 kg – 600 kg 🟨 600 kg – 800 kg 🟥 >800 kg		

TABLE 35 NOx emissions of existing and alternative scenarios of EDSA

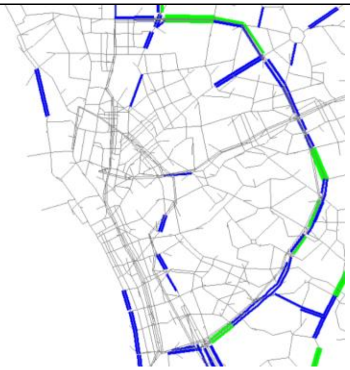
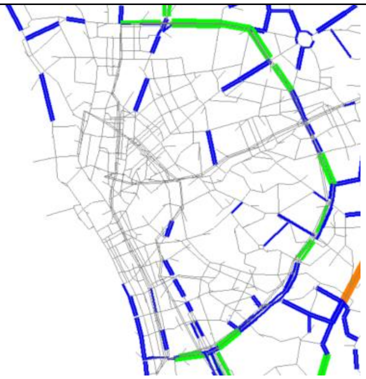
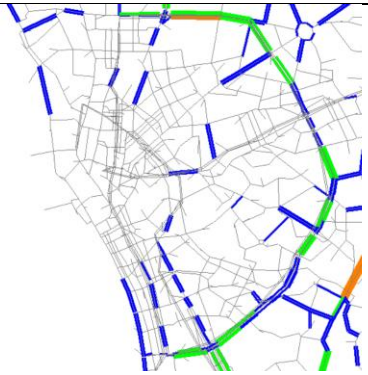
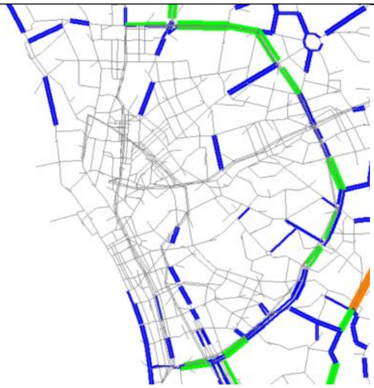
Scenario	**2019**	**2020**	**2025**
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 200 kg 🟩 200 kg – 400 kg 🟧 400 kg – 600 kg 🟨 600 kg – 800 kg 🟥 >800 kg		

TABLE 36 PM emissions of existing and alternative scenarios of regional network

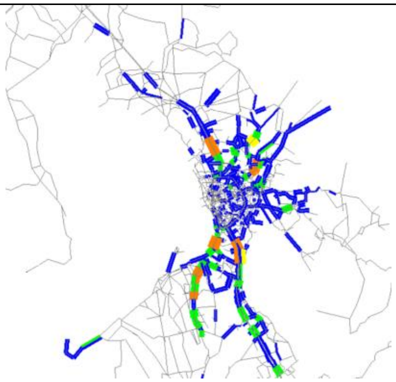
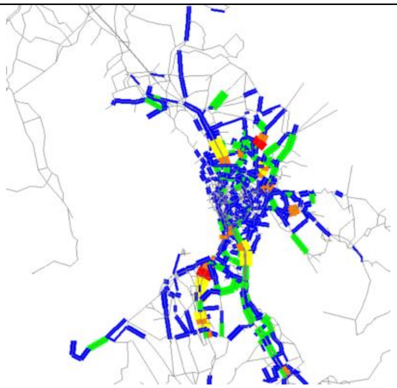
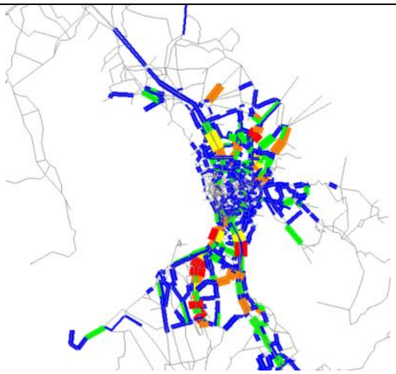
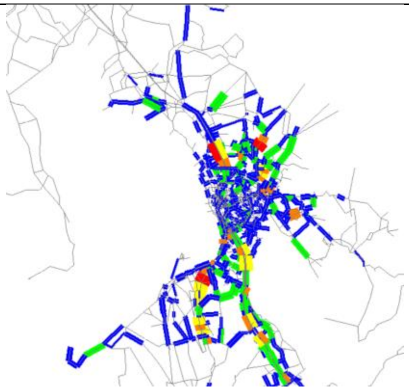
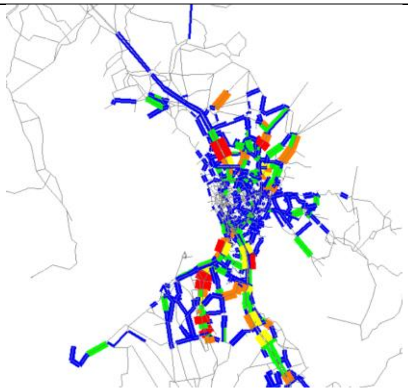
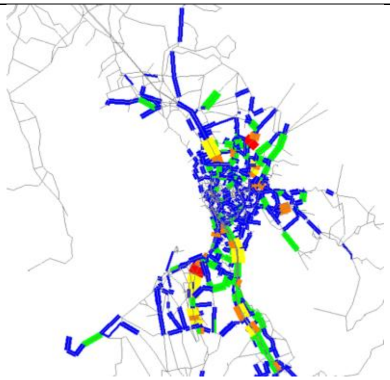
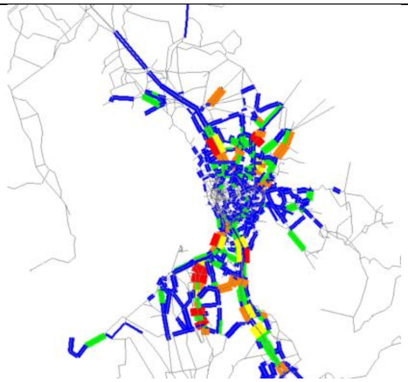
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 200 kg 🟩 200 kg – 400 kg 🟧 400 kg – 600 kg 🟨 600 kg – 800 kg 🟥 >800 kg		

TABLE 37 PM emissions of existing and alternative scenarios of EDSA

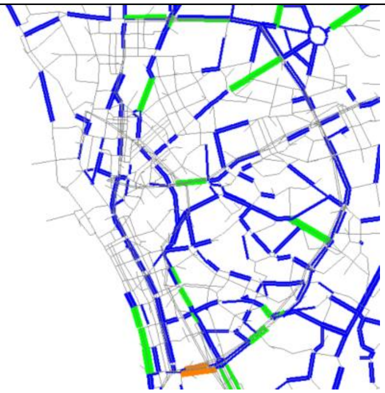
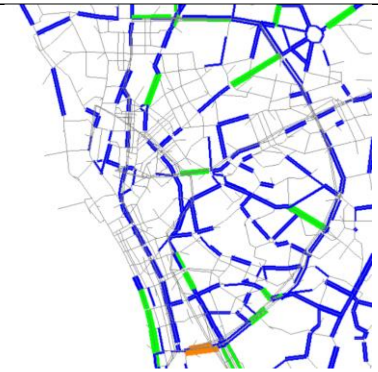
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 200 kg 🟩 200 kg – 400 kg 🟧 400 kg – 600 kg 🟨 600 kg – 800 kg 🟥 >800 kg		

TABLE 38 CO emissions of existing and alternative scenarios of regional network

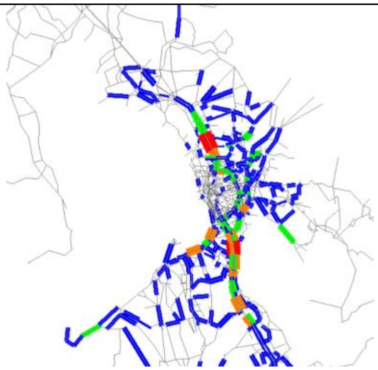
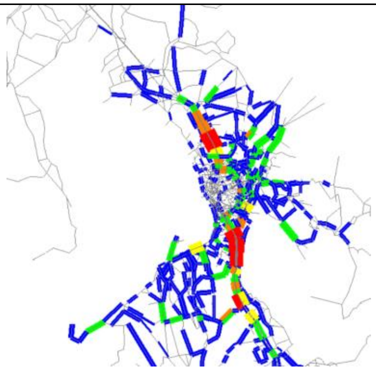
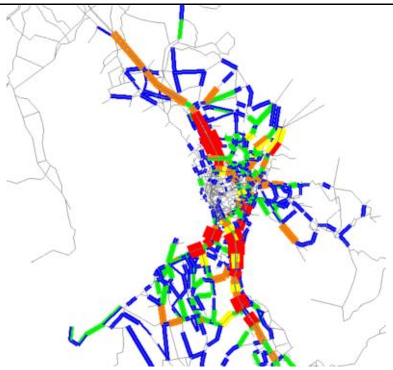
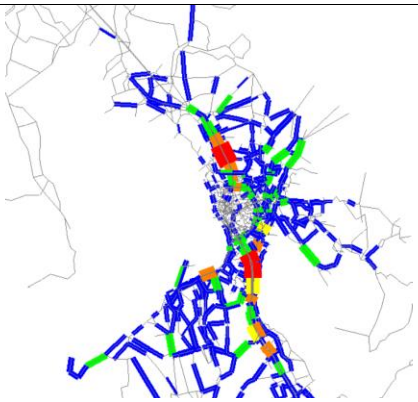
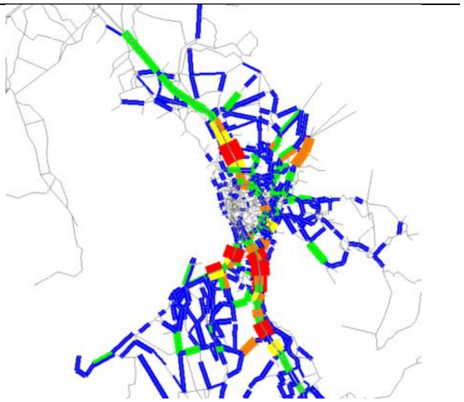
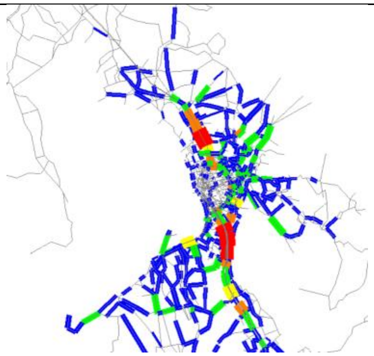
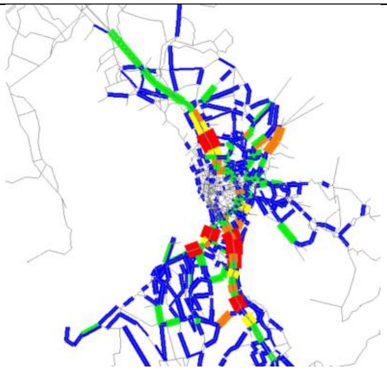
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 2,000 kg 🟩 2,000 kg – 4,000 kg 🟧 4,000 kg – 6,000 kg 🟨 6,000 kg – 8,000 kg 🟥 >8,000 kg		

TABLE 39 CO emissions of existing and alternative scenarios of EDSA

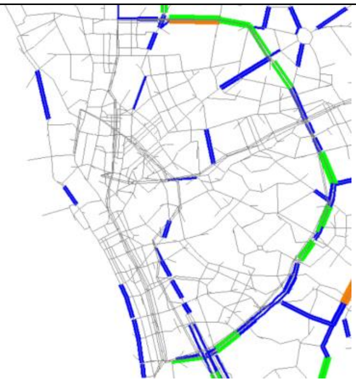
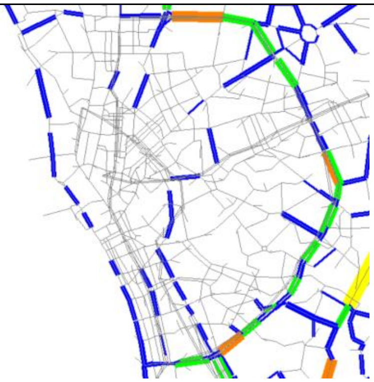
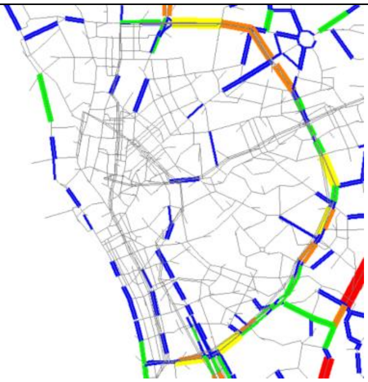
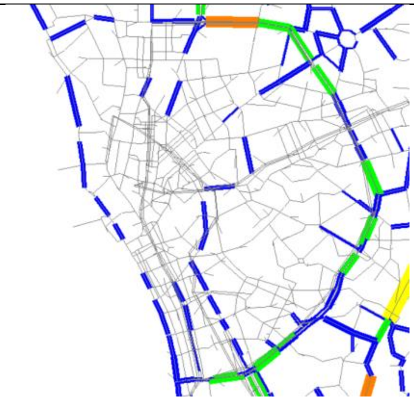
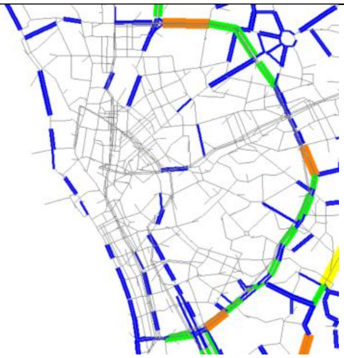
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 2,000 kg 🟩 2,000 kg – 4,000 kg 🟧 4,000 kg – 6,000 kg 🟨 6,000 kg – 8,000 kg 🟥 >8,000 kg		

TABLE 40 SOx emissions of existing and alternative scenarios of regional network

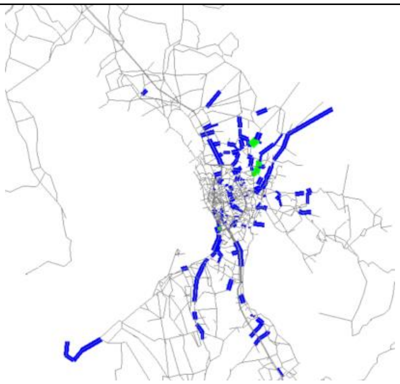
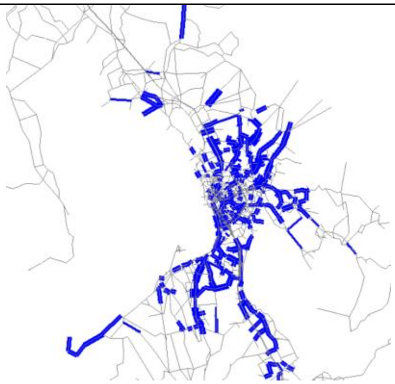
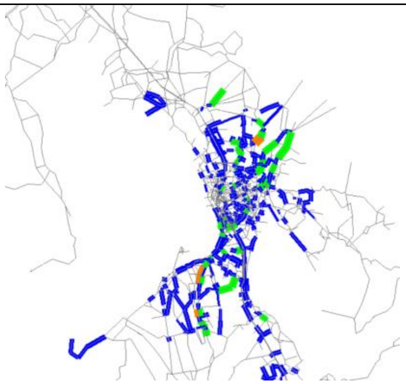
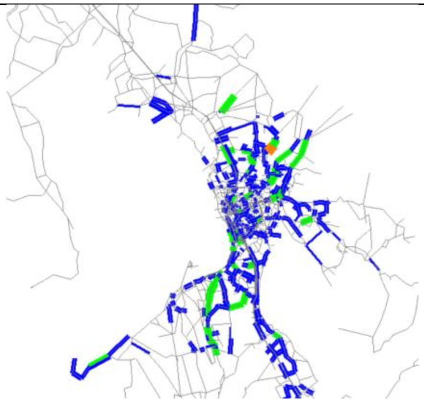
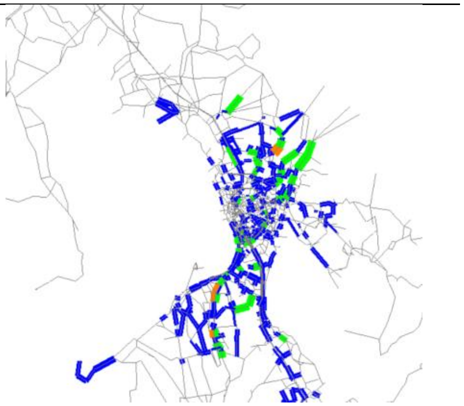
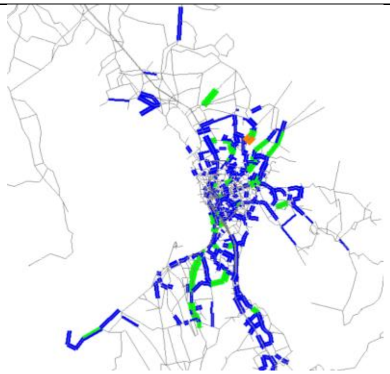
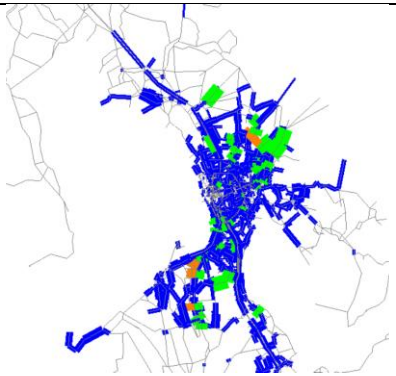
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 20 kg 🟩 20 kg – 40 kg 🟧 40 kg – 60 kg 🟨 60 kg – 80 kg 🟥 >80 kg		

TABLE 41 SOx emissions of existing and alternative scenarios of EDSA

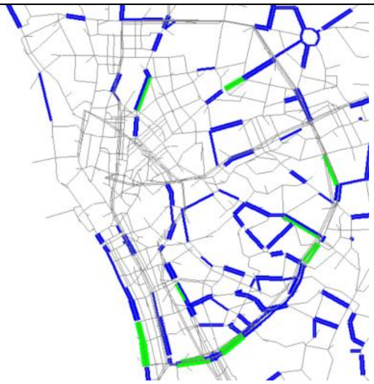
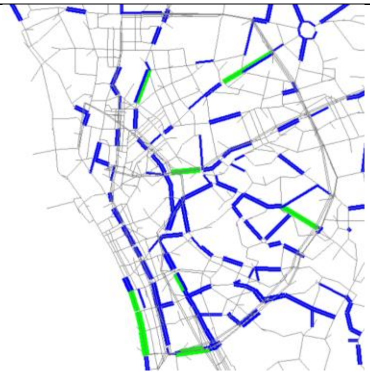
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 20 kg 🟩 20 kg – 40 kg 🟧 40 kg – 60 kg 🟨 60 kg – 80 kg 🟥 >80 kg		

TABLE 42 HC emissions of existing and alternative scenarios of regional network

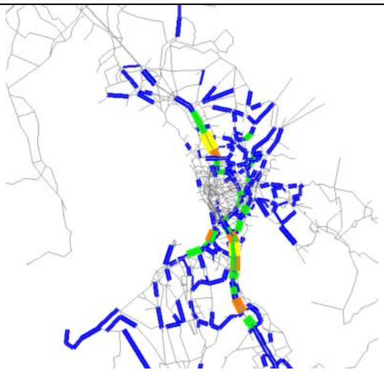
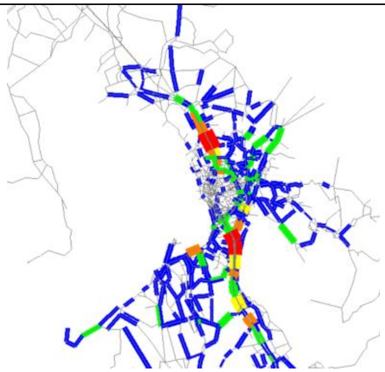
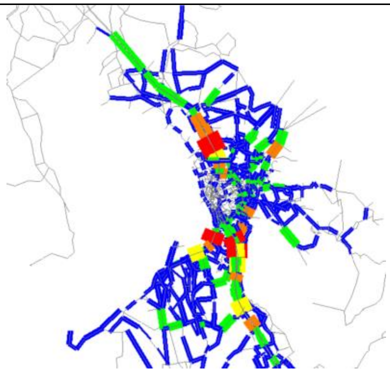
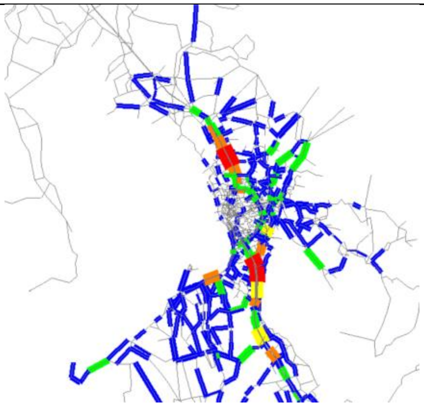
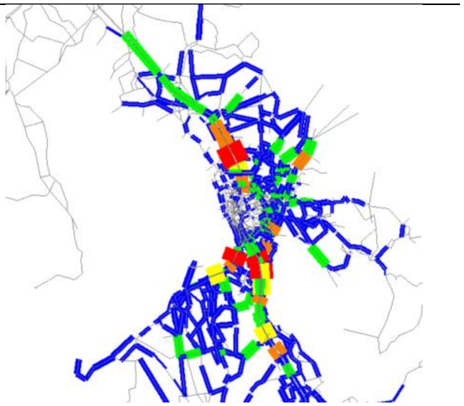
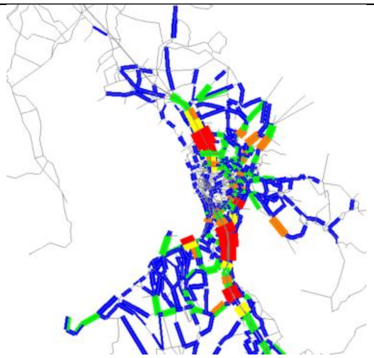
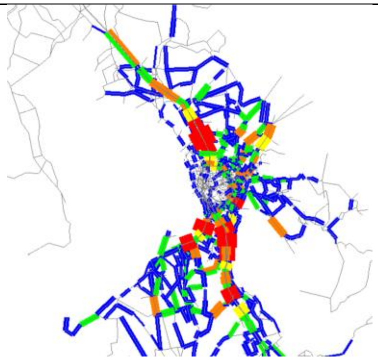
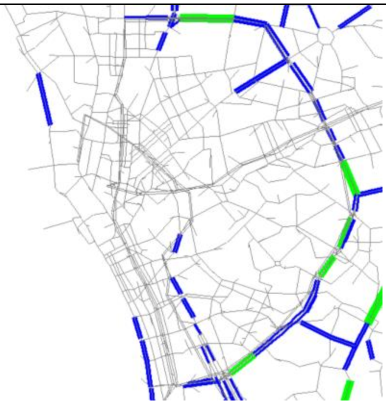
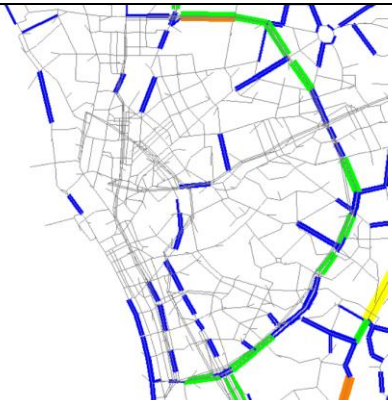
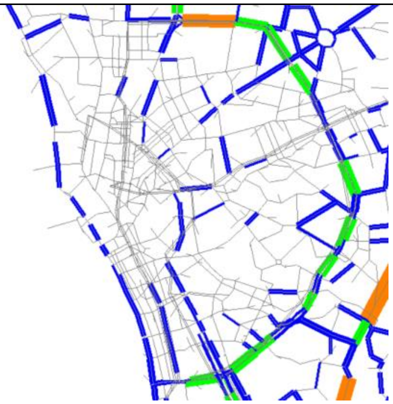
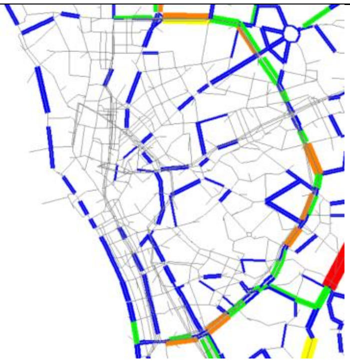
Scenario	2019	2020	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 300 kg 🟩 300 kg – 600 kg 🟧 600 kg – 900 kg 🟨 900 kg – 1,200 kg 🟥 >1,200 kg		

TABLE 43 HC emissions of existing and alternative scenarios of EDSA

Scenario	**2019**	**2020**	2025
Scenario 1			
Scenario 2			
Scenario 3	**Legend:** 🟦 0 – 300 kg 🟩 300 kg – 600 kg 🟧 600 kg – 900 kg 🟨 900 kg – 1,200 kg 🟥 >1,200 kg		

4.2 Segment-Specific Analysis

The previous section focused on the impacts of implementing the bus rerouting scheme from a region-wide standpoint by considering the entire network as the analysis area. However, there is a downside in the analysis since localized traffic and environmental impacts are not specified.

For the segment-specific analysis, the road network was divided into five segments: NLEX, Paso de Blas, SLEX, and San Pedro National Highway as show in Figure 36.

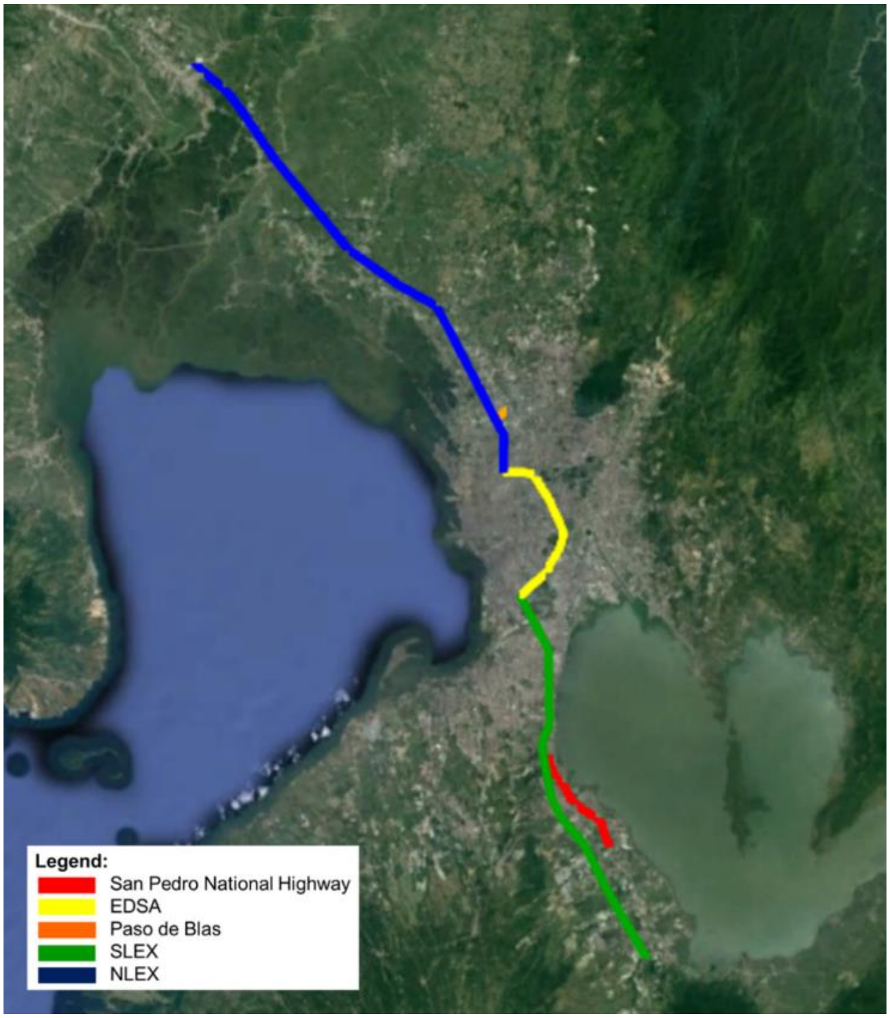


FIGURE 36 Road segments in the study area.

Tables 28 and 29 show that the travel speeds within Mertro Manila are significantly lower compared to the surrounding streets. Since NLEX and SLEX are expressways, they have a higher average speed of 50kph while EDSA, Paso de Blas, and San Pedro National Highway have an average speed of around 25kph. Travel speeds along these sections did not improve with the alternative scenarios.

It can also be observed from Tables 30 and 31 that road sections in and around Metro Manila are almost at capacity. Further, Paso de Blas has already reached capacity and significantly got worse with the introduction of the bus policy. This is due to the road's limited capacity with only one lane available for each direction. The location of the interchange with NLEX also affected the traffic condition negatively since it connects the east and west sections of Valenzuela city with vehicles having no other alternative but to access this section.

San Pedro National Highway also had worse conditions with the implementation of the policy. The national highway is a major road linking the province of Laguna with Metro Manila. By extending the bus routes along this area, private vehicles such as cars are forced to find cheaper alternative routes such as shifting to use SLEX.

Consistent with results of the region-wide analysis of the network, the segment travel distances and travel times show that scenario 2 had the highest values for both years 2020 and 2025 for all segments. Meanwhile, considering the vehicle emissions as shown in Figures 39 to 44, it can be observed that SLEX had the highest contribution for CO2, PM, CO, and HC emissions, while NLEX had the highest emissions for NOx, and EDSA for SOx. It is important to note that emissions are also affected by distance as shown in the formula used for the emissions estimation. In this case, longer sections such as both expressways have a larger contribution compared to shorter sections such as Paso de Blas and San Pedro Highway.

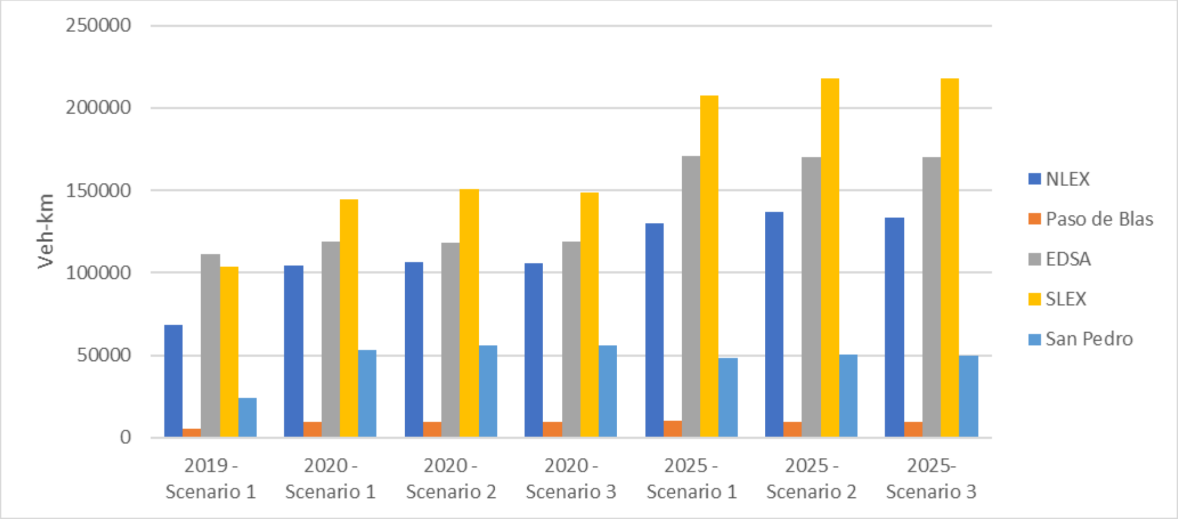


FIGURE 37 Total kilometers travelled for all scenarios.

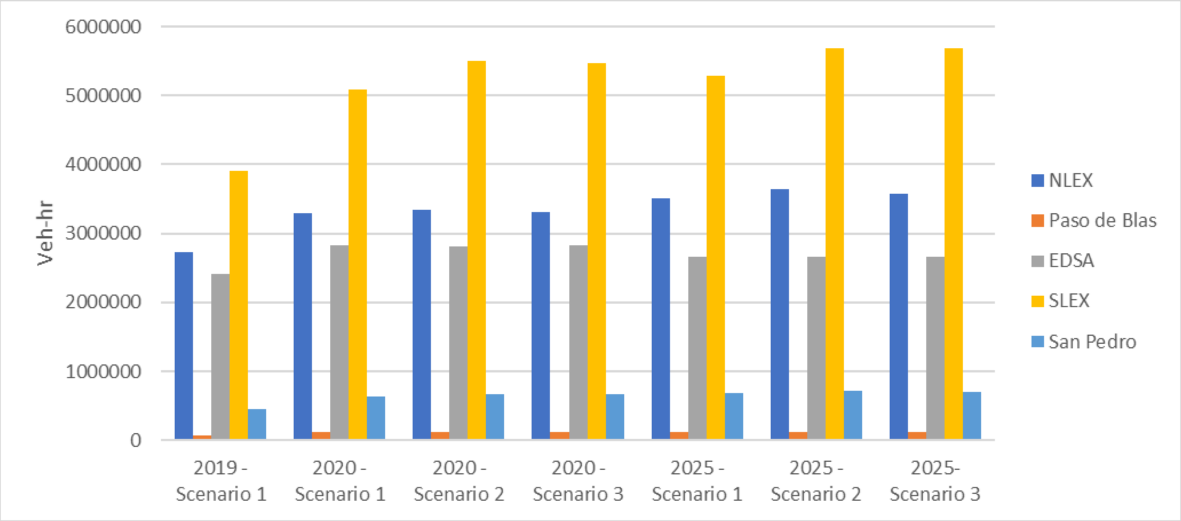


FIGURE 38 Total hours travelled for all scenarios.

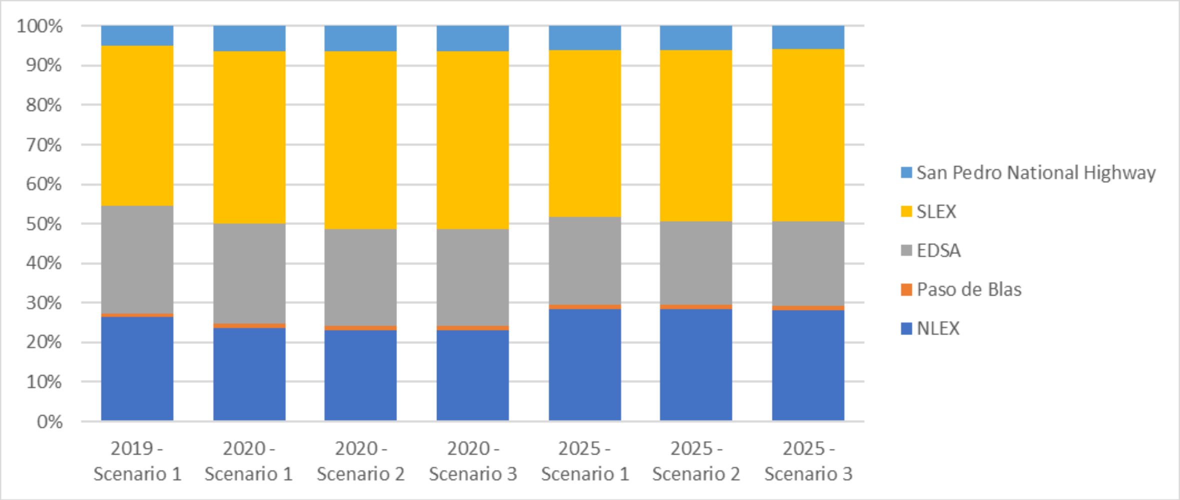


FIGURE 39 Emission distribution for CO2.

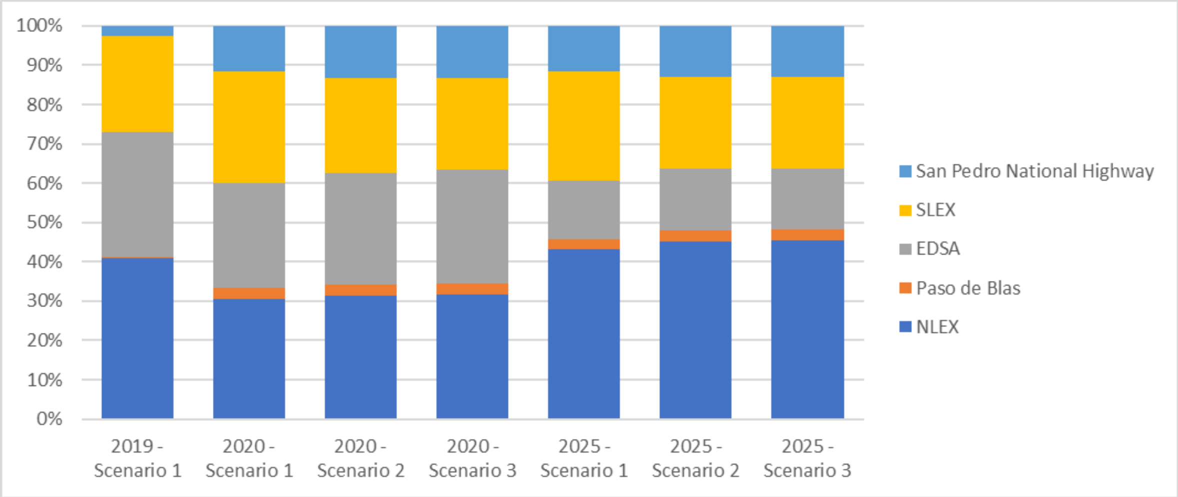


FIGURE 40 Emission distribution for NOx.

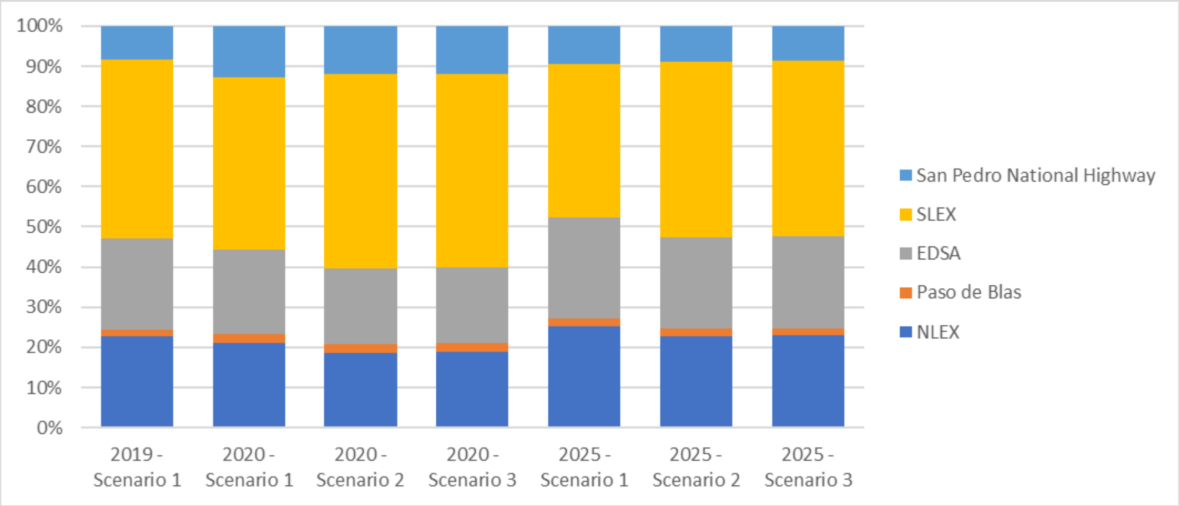


FIGURE 41 Emission distribution for PM.

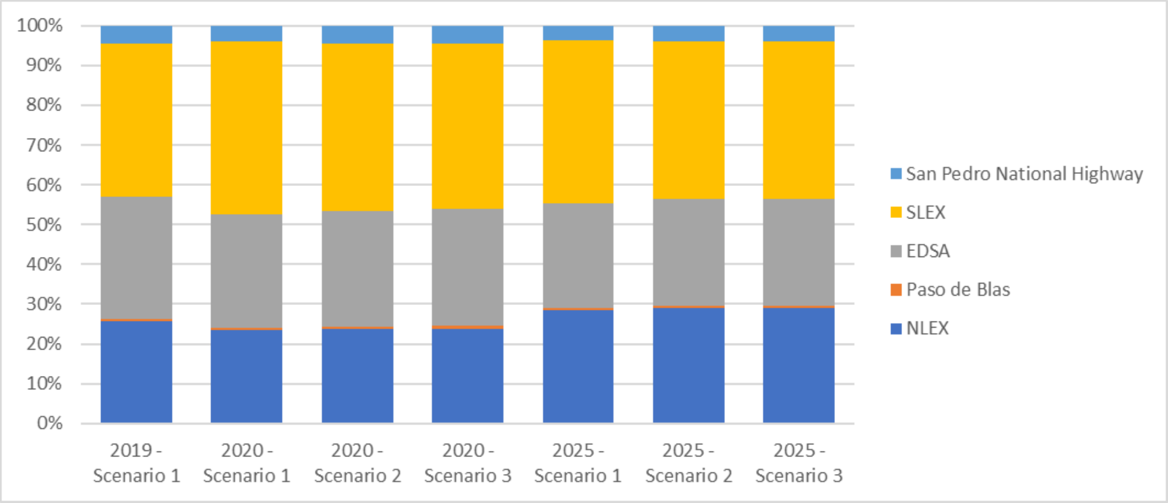


FIGURE 42 Emission distribution for CO.

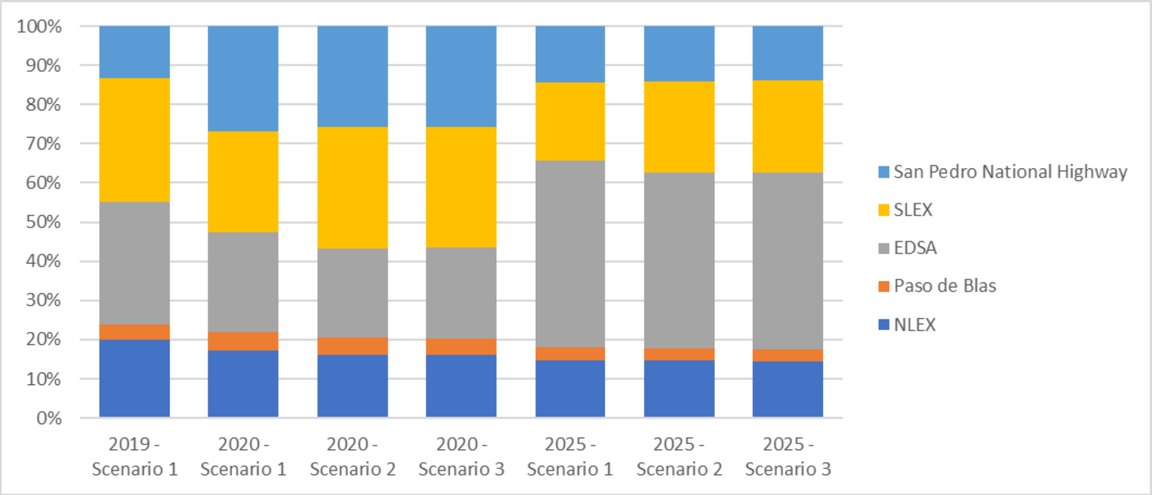


FIGURE 43 Emission distribution SOx.

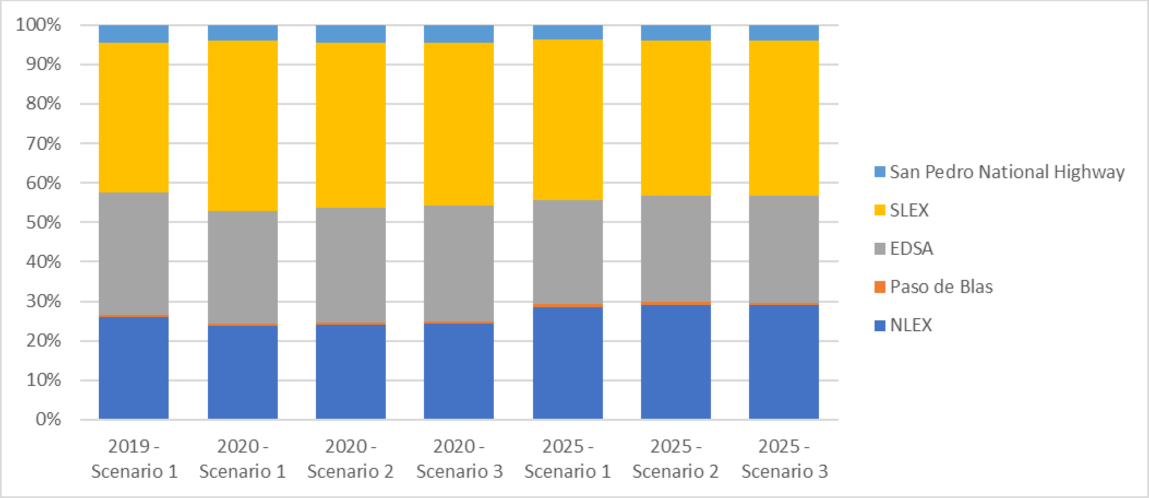


FIGURE 44 Emission distribution for HC.

Tables 44 to 48 present the percentage changes for the different road segments considered in the study. It can be observed that the effects of implementing the bus rerouting scheme have varying effects depending on the segment considered.

TABLE 44 Percentage changes with the implementation of alternative scenarios - NLEX

Scenarios	Veh-Hr	Veh-km	CO2	NOx	PM	CO	SOx	HC
2020 - Scenario 2	1.68%	2.41%	1.91%	-3.91%	10.05%	-1.02%	4.02%	-0.94%
2020 - Scenario 3	0.93%	1.42%	1.14%	-2.10%	5.78%	-0.52%	2.20%	-0.47%
2025 - Scenario 2	4.11%	5.38%	3.81%	-3.99%	15.91%	0.15%	6.19%	0.26%
2025- Scenario 3	2.13%	2.92%	1.98%	-2.11%	8.78%	-0.14%	3.61%	-0.07%

TABLE 45 Percentage changes with the implementation of alternative scenarios – Paso de Blas

Scenarios	Veh-Hr	Veh-km	CO2	NOx	PM	CO	SOx	HC
2020 - Scenario 2	-0.78%	-0.77%	-0.65%	0.69%	-1.37%	-0.23%	-0.77%	-0.45%
2020 - Scenario 3	0.12%	0.13%	0.18%	0.74%	-0.14%	0.47%	0.16%	0.36%
2025 - Scenario 2	-2.40%	-2.42%	-2.14%	1.38%	-4.26%	-0.25%	-2.50%	-0.75%
2025- Scenario 3	-2.29%	-2.31%	-2.04%	1.37%	-4.05%	-0.30%	-2.38%	-0.77%

TABLE 46 Percentage changes with the implementation of alternative scenarios – EDSA

Scenarios	Veh-Hr	Veh-km	CO2	NOx	PM	CO	SOx	HC
2020 - Scenario 2	-0.34%	-0.43%	-0.46%	-1.90%	-0.59%	-0.19%	-1.06%	-0.23%
2020 - Scenario 3	0.14%	0.06%	0.15%	0.61%	0.08%	0.01%	-0.25%	0.03%
2025 - Scenario 2	-0.34%	-0.30%	-0.35%	-3.51%	-0.32%	-0.02%	-0.34%	-0.03%

2025- Scenario 3	0.14%	-0.25%	-0.30%	-2.71%	-0.42%	0.06%	-0.33%	0.06%

TABLE 47 Percentage changes with the implementation of alternative scenarios – SLEX

Scenarios	Veh-Hr	Veh-km	CO2	NOx	PM	CO	SOx	HC
2020 - Scenario 2	8.32%	4.52%	7.69%	-19.56%	26.03%	-5.20%	31.02%	-5.02%
2020 - Scenario 3	7.53%	3.29%	6.86%	-21.07%	25.67%	-6.44%	30.75%	-6.26%
2025 - Scenario 2	7.48%	5.10%	6.82%	-23.15%	26.42%	-5.47%	24.33%	-5.18%
2025- Scenario 3	7.50%	5.12%	6.90%	-21.65%	26.16%	-5.34%	24.58%	-5.04%

TABLE 48 Percentage changes with the implementation of alternative scenarios – San Pedro National Highway

Scenarios	Veh-Hr	Veh-km	CO2	NOx	PM	CO	SOx	HC
2020 - Scenario 2	5.38%	5.36%	5.42%	5.10%	3.78%	9.67%	5.76%	9.42%
2020 - Scenario 3	4.94%	4.91%	5.06%	5.69%	2.99%	9.49%	5.31%	9.15%
2025 - Scenario 2	4.31%	4.06%	4.23%	3.26%	2.95%	7.41%	3.88%	7.31%
2025- Scenario 3	2.73%	2.29%	2.77%	4.04%	-0.01%	7.13%	1.98%	6.83%

Considering NLEX, total travel distance and total travel hours increased with both scenarios of the bus scheme for both years 2020 and 2025. This is because in the proposed scheme, provincial buses are allowed to continue until the SMART Connect Interchange before making a U-turn going back to Paso de Blas Interchange. The CO2, PM and SOx emissions increased but the NOx, CO, and HC emissions decreased. Scenario 3 provided a better alternative compared to Scenario 2 since it increased the NOx, CO, and HC at a relatively lower rate.

For Paso de Blas, there is a considerable reduction in total distance and hours travelled for both scenarios. Vehicle speeds along the segment has been reduced to 13kph at capacity. Thus, reducing the volume along this section. However, considering emissions, scenario 2 provided a better alternative in both years 2020 and 2025 since most of the vehicle emissions decreased aside from NOx.

The implementation of the bus ban benefited EDSA the most with scenario 2 reducing all emissions for both years 2020 and 2025. Scenario 3 only reduced emissions for SOx in 2020 and increased CO and SOx emissions for 2025. Further, with the provincial buses removed along EDSA, there was a reduction in the total travel distance as well as total travel times.

SLEX emissions increased significantly for PM and SOx emissions but significantly reduced NOX emissions for both alternative scenarios in years 2020 and 2025. Specifically, scenario 3 is a better alternative for year 2020 and scenario 2 for year 2025. The increase in emissions can be attributed to the increase in traffic volume caused by the shift of vehicles from San Pedro National Highway. Affected vehicles along the San Pedro Highway has deemed SLEX as a cheaper alternative with the increase in congestion brought about by the addition of the city buses in the area.

San Pedro National Highway fared the worst in both scenarios for years 2020 and 2025. Aside from longer travel times and distances, all emissions increased with the implementation of the bus policy. This also implies that with a longer route and additional passengers, buses are forced to stop more frequently along the road to accommodate these changes.

In terms of minimizing the total travel distance and travel time, the existing bus policy is still the best selection. Only Paso de Blas and EDSA had a reduced travel distance and travel time compared to other segments. The ban had increased travel distance by forcing the buses to use the national highways instead of the expressways in directly accessing the city. Further, a shift from the provincial to city buses would indicate that the passengers would have longer travel times since provincial passengers are only allowed to board and alight at selected stops whereas the city buses have more stops.

Although there are official stops provided along EDSA, there has been a lack of effective enforcement. Moreover, there are several stops without any sufficient entry/exit slopes required for the buses to park parallel to the kerbside for convenient passenger boarding and alighting. This eventually causes buses to over-hang in the road space outside the bus stop area leading to congestion (Almec Corporation, 2014).

As early as 1999, the MMUTIS Study has already highlighted the issue on the importance of the establishment of definite policies and development guidelines or terminals to sustain public transportation and to integrate transport nodes with each other and with urban development (ALMEC Corporation, 1999). Thus, prior to the implementation of the said policy the government must first ensure that this issue is addressed.

Moreover, with the provincial passengers using city buses for access, other problems may arise with passenger alighting. In this case, most provincial passengers carry a lot baggage when traveling. When provincial passengers alight, buses will take a longer time at stops to unload from baggage compartments leading to more congestion. Moreover, city buses are not designed to handle long distance journeys with limited luggage and overhead compartments which may greatly affect passenger comfort.

In terms of minimizing emissions, the bus ban policy provided varied effects depending on the pollutant considered. For the years 2020 and 2025, NLEX and SLEX reduced NOx, CO, and HC emissions. Whereas, scenario 2 was effective in reducing almost all pollutants for both years 2020 and 2025. But for San Pedro National Highway, all emissions increased with the existing condition being the most effective.

The segment-specific analysis indicates that there are winners and losers with the implementation of the bus policy. The general aim of the policy was to reduce congestion along EDSA which was attained as shown from the previous tables and figures. However, by doing so, minor roads close to the interim terminals had worsened traffic and environmental conditions.

5. CONCLUSION

The results from this study indicate that the proposed bus rerouting policy varies when it comes to reducing traffic and environmental impacts in both regional and segment-specific perspective. Looking at the region-wide analysis, the original bus rerouting scheme did not improve the traffic conditions for both years 2020 and 2025. In this case, buses were replaced by cars with the introduction of the policy. Moreover, in an environmental perspective, the total emissions had different effects depending on the emissions being considered such that CO2, PM, and SOx increased while NOx, CO, and HC decreased.

Meanwhile, traffic conditions along the specific road segments varied depending on the segment considered with NLEX, EDSA, and San Pedro National Highway worsening with the introduction of the policy, and Paso de Blas and SLEX improving.

The effect on the environmental emissions of the segment-specific analysis also had mixed results depending on the emission considered. Improved conditions were observed along EDSA with all emissions reduced, and along Paso de Blas with only NOx emissions increasing. While San Pedro had the worse effect with all the emissions increasing for both alternative scenarios.

The introduction of the bus policy did not improve traffic conditions along EDSA assumed by authorities but did improve environmental conditions by reducing CO, NOx, PM, and SOx emissions. In parallel, the implementation of the policy negatively affected road segments connecting to EDSA with NLEX and San Pedro Highway worsening. In this case, although the policy was effective in reducing travel times and distances along EDSA, it can be argued that the reduced values were displaced to its surrounding areas.

Moreover, the results are consistent with other studies stating the investment in public transportation in reducing travel times and distances leading to lower emissions. The implementation of the policy can be a success or a failure depending on the priority of the government. In this case, the improvement of the traffic conditions did not necessarily guarantee an improvement with environmental conditions and vice versa. Similarly, the results of the emissions varied with the pollutant being considered. Previous studies mentioned emission estimations focusing on PM, CO and NOx emissions. Thus, there is a need for the government to identify its priority when it comes to selecting the deciding factors.

Further, the differences between the scenarios were relatively small and some of the effects specifically on the segment-specific analysis have mixed effects that may need additional factors to be considered in the selection process. Moreover, as mentioned by Castro and delos Reyes in 2014, traffic and environmental impacts alone may not be enough in selecting the best alternative. A multi-criteria analysis can be a possible topic for future research. Additional criteria to be considered may include social and economic impacts, and difficulty in enforcement.

Lastly, it was found that the city buses are already at capacity even without the introduction of the bus rerouting scheme. In the proposed scheme, city buses are responsible for accommodating affected provincial routes but did not mention how the deployment of these buses will be affected. Moreover, in this study, the suggested number of studies were included but there is no guarantee that existing franchises are capable in supplying the required number of buses. The improvement of a public transport system can attract higher passenger volumes which may result in lower emissions. It is suggested that prior to the implementation of the said bus policy, the government must first address this issue.

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