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Measurement and modelingofparticulate matter (PM_{10})Concentration from on-road vehicles in Metro Cebu, Philippines

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ABSTRACT

The increasing traffic volume in Metro Cebu cumulatively affect human health associated to particulate matter pollution. This paper presented real time data of traffic volume and PM_{10} concentrationand policy measures simulation using STELLA[TM]software. PM_{10}concentration from on-road vehicles were measured using Environmental Beta Attenuation Monitor (EBAM) inthree Metro Cebu cities, Lapu-Lapu City, Mandaue City and Cebu City. The vehicle fleet count was quantified using closed-circuit television (CCTV) records from the local city command centers. The 24-hour vehicle count and PM_{10}shows a strong correlation (r = 0.8586). Using Air Quality Index (AQI) breakpoints, Metro Cebu's PM_{10} is at good to fair level leaving no particular cautionary measures for the public though there are specific days where PM_{10} recorded a higher value. The four identified policy measures simulated using the System Dynamics Model(SDM) are purchase control, scrapping policy, traffic management, and vehicle emission mitigating measures. Hence, without policy implementation to decongest traffic in Metro Cebu, there will be an increasing demand of road expansion to accommodate traffic volume capacity.

Keywords—*system dynamics modeling; on-road vehicles; PM_{10}; EBAM; STELLA[TM]; Metro Cebu*

I. INTRODUCTION

Urban traffic congestion associated with vehicle fleet expansion, over the years is affecting human health and urban air quality remarkably [1-2]. The increasing global record of particulate matter pollution in correlation with the traffic congestion and vehicle fleet expansion affect the environment and the life therein. These occurrences emphasized that despite the global particulate matter monitoring effort, a large amount of real time PM_{10} measurement from on-road vehicles are tough to quantify. In the past decade much studies focused on monitoring PM_{10} concentrations, the consideration was then shifted to coarse (1.0-2.5 microns), fine (0.1-2.5 microns), and ultrafine (0.1 microns) particulate matter because of their gradual effects to human health. However, by monitoring itself will not solve the problem and the widespread efforts remain indistinct.

In the framework of air quality problems, particulate matter is a notable type of air pollution in particle forms. Particulate matter is abbreviated as PM. It is a mixture of solid particles and liquid droplets contaminating the air mainly from natural and anthropogenic sources. Several natural sources originate from volcanic eruptions, dust storms, forest and grassland fires, and hurricanes. Anthropogenic sources are from coal burning, oil combustion from vehicles, burning fossil fuels in power plants, deforestation and tobacco smoke. Particulate matter comes in a wide range of sizes depending on the diameter of the particles. Particulate Matter (PM_{10}) has an aerodynamic diameter of ten microns. This size of the particles is dependent on meteorological conditions such as temperature, relative humidity, wind direction, and wind speed. PM_{10} released to the atmosphere is predominantly from fuel combustion of on-road vehicles [3]. Particulate matter pollution from on-road motor vehicle sources is not a new problem but because of its unceasing public health and environmental effects, the efforts to improve real time air quality monitoring and strategy implementation are reasonable. Developing countries' population growth, urbanization, and increasing number of vehicles drive air pollution [4].

On the other hand, Metropolitan Cebu or Metro Cebu has experienced a haze alert last September 18, 2019. The Indonesia haze reached Metro Cebu according to the Department of Environment and Natural Resources (DENR) through the Environmental Management Bureau - Region 7(EMB-7). The haze was from the forest fire Indonesia and enhanced by the Southwest monsoon with the air quality advisory posted as "above safe levels". The observed Particulate Matter ($PM_{2.5}$) reached 56 $\mu g/m^3$ above the safe levels of 50 $\mu g/m^3$[5]. The haze is a conglomeration of natural and anthropogenic activities that resulted to an increase level of particulate matter. Metro Cebu is the primary urban settlement of the Central Visayas Region (Region VII) composed of seven cities; Cebu, Mandaue, Lapu-Lapu, Talisay, Naga, Carcar and Danao, and six (6) municipalities; San Fernando, Minglanilla, Cordova, Consolacion, Lilo-an, and Compostela [6]. Metro Cebu is a home of 2,849,213 people as of August 1,2015 [7].

Emission inventories for on-road vehicles require the number of vehicles, vehicle fleet, vehicle age, number of vehicles meeting the emission control strategies implemented, annual Vehicle Kilometer Travelled (VKT), vehicle speed, meteorological conditions, fuel characterization, and consumption information. These parameters for emission inventory are difficult to quantify for on-road vehicles. For baseline information, the total number of on-road vehicle fleet is the minimum requirement to start vehicle emission assessment. The system dynamics of on-road vehicles generally from the total number of vehicle fleet inflow and scrapping outflow. The interaction of vehicle inflow and outflow sustain balance in an ideal dynamic system. A vehicle fleet size will not grow exponentially for an indefinite period because it can reach to a maximum size limit caused by one of the deficiencies of one or more identified variables [8]. Local factors such as travel activity, traffic patterns, meteorological conditions, spatial and temporal combining its emission control programs have significant effects in the particulate matter dynamic system.

The study is conducted to establish baseline data of Metro Cebu's real time PM_{10} concentration and traffic volume measurement from its chartered cities. The measured PM_{10} concentration and real time traffic volume can be a useful data in evaluating local and national air quality standard, vehicle emission, mitigating measures, and future policies. Policy implementations were argued due to lack of reliable data that authenticates the policies. While it is also evident that PM_{10} concentration from on-road vehicles can affect human health and the environment by means of unrestricted, uncontrolled, and unquantified measures. The study findings can be maximized in mitigating Metro Cebu's particulate matter pollution from on-road vehicle fleet. The study output can be used as a reference for environmental and transportation agencies for policy implementation. The study presented helpful scenarios for local government to support new technologies for sustainable environmental impact in the coming years in Metro Cebu. It specifies number of useful scenarios through forecasting and analyzing the system dynamics of real time traffic volume.

II. Field Measurementsand Social Survey

A. Study Site Description

The study sites are situated in the three chartered cities of Metro Cebu, Philippines. Metropolitan or Metro Cebu is in the Cebu province of the Central Visayas Region, composed of seven (7) cities and six (6) municipalities. The seven cities are Cebu, Mandaue, Lapu-Lapu, Talisay, Naga, Carcar and Danao. The six (6) municipalities are composed of San Fernando, Minglanilla, Cordova, Consolacion, Lilo-an, and Compostela (Fig. 1). Metro Cebu has a total population of 2,849,213 as of August 1,2015 [7]. The Philippine Statistics Authority (PSA) is the implementing agency for primary data collection and conducting censuses particularly population sector.

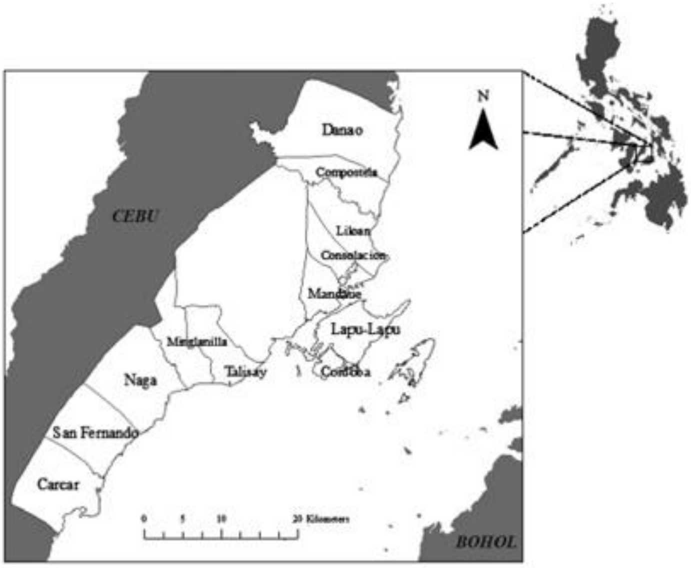


Fig. 1. Location map of Metro Cebu, Philippines.

B. Sampling Sites for PM_{10}

The three (3) sampling sites were positioned in major junctions and driving routes with moderate to high traffic volume daily. Fig. 2 indicates the location of the sampling sites where PM_{10} concentration sampling and vehicle fleet counting were conducted. Sampling site 1 is located at Lapu-lapu City's one of its major junctions where traffic bottle neck usually occurs from and to the Osmeña bridge. Sampling site 2 in is located near the N. Bacalso national road connecting from Cebu City to the South area of Cebu and few crossroads of the nearby barangays. Sampling site 3 is located on one of the jammed junctions in Mandaue City, A. Soriano Street where vehicles like trucks, trailers, SUVs, and personal cars mostly travel.

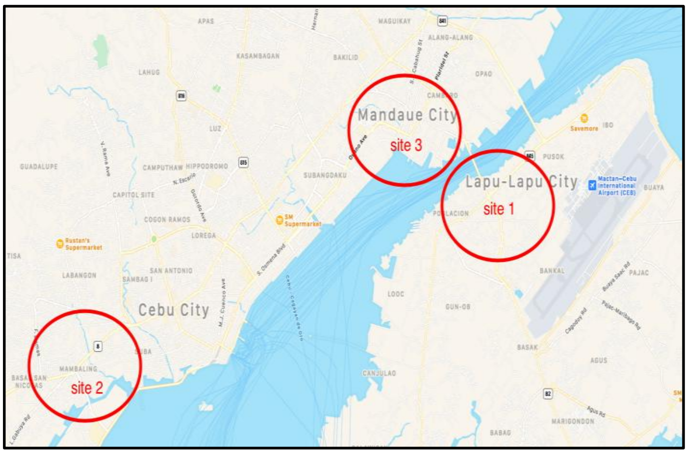


Fig. 2. Location of the sampling sites.

The 24-hour measurement cycle for PM_{10} from 12AM to 11PM in the three sampling sites were taken by using an EBAM. At the same sampling period, a 24-hour vehicle fleet counting for sampling site 3 in Mandaue City was observed to fully examine the traffic volume daily. Furthermore, a total of 2 hours vehicle fleet counting for sampling site 1 in Lapu-lapu City was captured to get an hourly snapshot count; one hour counting from 6AM to 7AM and 5PM to 6PM. The chosen time of hourly snapshot vehicle fleet counting which is six to seven in the morning and five to six in the evening, were in reference to the study of traffic patterns. As reported by Ganveer and Tiwari [9] in their study, several vehicular accidents recorded in a day are mainly happened during six in the morning to six in the evening. Vehicular accidents slow down traffic flows. This study is limited to CCTV vehicle fleet counting. There were no vehicular accidents happened during the vehicle counting period in the specified sampling sites, and no other related factors related to vehicular accidents were observed.

C. Measurement of On-road Vehicle Fleet

This study focused on field measurement for real time vehicle fleet counting conducted in Lapu-lapu City and Mandaue City instead of using registered vehicles record in the Land Transportation Office (LTO), since some vehicles aren't running in the same roads and at the same time where they were registered. This study also involved Closed-Circuit Television (CCTV) records because CCTV captures real time data, all types of vehicles, and can be stored and reviewed for further validation. The real time CCTV videos were extracted from the Closed-Circuit Television (CCTV) monitoring from Lapu-lapu City and Mandaue City command centers. The CCTV copies were retrieved from the command centers with proper permission and coordination of the purpose stated in this study.

The 24-hour vehicle fleet counting took place at sampling site 3 located in Mandaue City Sports and Complex, UN Avenue, Mandaue City. The two-hour daily snapshot vehicle fleet counting for sampling site 1 is at the major junction of Basak-Marigondon Rd. and M.L Quezon National Highway, Lapu-lapu City near Menzi Complex Corner. Sampling site 1 hourly vehicle fleet count in the morning (6:00 AM - 7:00 AM), and an hour vehicle count in the evening (5:00 PM - 6:00 PM). For sampling site 2 located in Cebu City command center, real time vehicle fleet count was not available for the sampling dates due to CCTV system breakdown.

This study grouped on-road vehicle fleet into diesel fueled and gas fueled vehicles. According to the LTO region 7 record in 2015, the two widely used motor vehicles are gasoline and diesel fueled. The study quantified vehicle type through manual description by listing down in the vehicle counting sheet the number of motor vehicles as seen on CCTV. The approach used to guide the quantification of the on-road vehicle count follows that of USEIA [10]. The diesel fueled vehicle fleet in this study predetermined grouped into SUV, bus, truck, and trailer. The gas fueled vehicle fleet was also clustered into car, jeepney, and motorcycle or tricycle. It was distinctly evaluated by USEIA [11] that most consumers of gasoline fuels are cars, light trucks, and motorcycles.

Travel activities served as vehicle inflows and vehicle outflows. Vehicle inflow is from Lapu-lapu City to Mandaue City to Cebu City routes. Vehicle outflow is from Cebu City to Mandaue City to Lapu-lapu City. The consistency of the traffic flow was not dependent on the driving routes. The inflow from Lapu-lapu City (site 1) not necessarily goes through the same inflow in Mandaue City (site 3). And not all inflows in Mandaue City were also coming from Lapu-lapu City. On-road real time vehicle counting varies every time on different places, local factors, and conditions. This study considered the real time vehicle count on the same date of the PM_{10} sampling to observe its correlation. For sampling site 1, vehicle inflow from Lapu-lapu City to Mandaue City (Fig.3a), while vehicle outflow from Mandaue City to Lapu-lapu City. All vehicle inflow and outflow passed through Osmeña bridge as the bottle neck of the traffic linkage from Lapu-lapu City and Mandaue City. For sampling site 3, Mandaue City vehicle inflows were from A. Soriano Street of Mandaue City to Cebu City, while vehicle outflows were from Cebu City to A. Soriano Street main highway that goes through the Northern part of Cebu province, Lapu-lapu City, or local barangays within the area (Fig.3b). Vehicles that travel to sampling site 1 in Lapu-lapu City were consistently considered as outflow of the vehicle traffic count.

(a) (b)

Fig. 3. Actual CCTV vehicle inflow and outflow travel activity at (a) Osmeña bridge front at Lapu-lapu City and (b) A. Soriano street near Mandaue City sports and complex, Mandaue City

D. Social Survey

This study adapted the Slovin's random sampling technique formula to estimate the appropriate sampling size in Metro Cebu. Slovin's formula used in related study found in article DOI: 10.21474/IJAR01/6935 [12]. The Slovin's formula,

$$n = \frac{N}{(1 + Ne^2)} \quad (1)$$

where, n= no. of samples; N= total population; e= margin of error

Substituting the total population (N) of 2,849,213 and margin of error (e) 10% , the sample size needed is 100. One hundred individuals were the minimum sample size to estimate the true population proportion with the margin of error (10%) and confidence level of 95%.

III. System Dynamics Modeling

This study used STELLA™ software to develop and simplify complex systems such as the dynamic of real time on-road scenarios. The System Dynamics Model (SDM) framework of this study has three essential sectors namely, population and health, vehicle fleet and traffic, and PM_{10} concentration (Fig. 4). Each sector contributes to one another. The framework was specifically designed for on-road vehicles and PM_{10} concentration system dynamic modeling. One major feedback cycle started from population growth inflow to a population stock. The *population* was subject to an increase or decrease of its quantity by the population growth and mortality. These individuals in the population stock were the same individuals who has the probability and capacity to purchase a vehicle. The purchase rate was initially set to 3% of the total population of 3,000,000 (whole number estimate for Metro Cebu from the previous 2015 census of 2,849,213). *Purchase* served as inflow to the vehicle fleet conveyor. The *vehicle fleet* conveyor has a sub-model that identifies the maturity stages of the total vehicle fleet. The current value of the conveyor is set to 30,000 vehicles in reference to ADT values plus the incoming purchases. These vehicle quantity goes through maturity stages through its external input of the Vehicle Kilometer Travelled (VKT). The total vehicle fleet was subject to scrap after five - year maturity stages. Total vehicle fleet contributes to the on-road traffic volume inflow conveyor. The *traffic volume* conveyor was initially set to 18,000 based from actual vehicle count in Mandaue City. Mandaue City has an average of 18,000 average daily traffic. As vehicles gets in the conveyor, it remained for a certain period due to some traffic delays before exiting. Traffic delays was already considered in the vehicle transit time. The outflow of the traffic volume contributes to the traffic congestion then to the vehicle emission conveyor. *Vehicle emission* conveyor increase or decrease gradually because of the quantity fed by the traffic volume. Primary pollutants were mixed or interacted with other pollutant due to meteorological condition factors and other anthropogenic activities in the surrounding area, it was fed into the secondary pollutant inflow then to the PM_{10} conveyor. PM_{10}as a conveyor helped processed the short-term and long-term effects added to the atmosphere and health effects to the population. Health effects not just mainly coming from PM_{10} exposure but even during traffic congestion where traffic stress already felt, as per social survey 23% get stressed and another 23% get frustrated and stressed at the same time. Stress is not directly related to PM_{10}. However, traffic stress can affect human health. Human health was affected by particulate matter pollution. Human health converter served as an external input to the increase or decrease of the population growth.

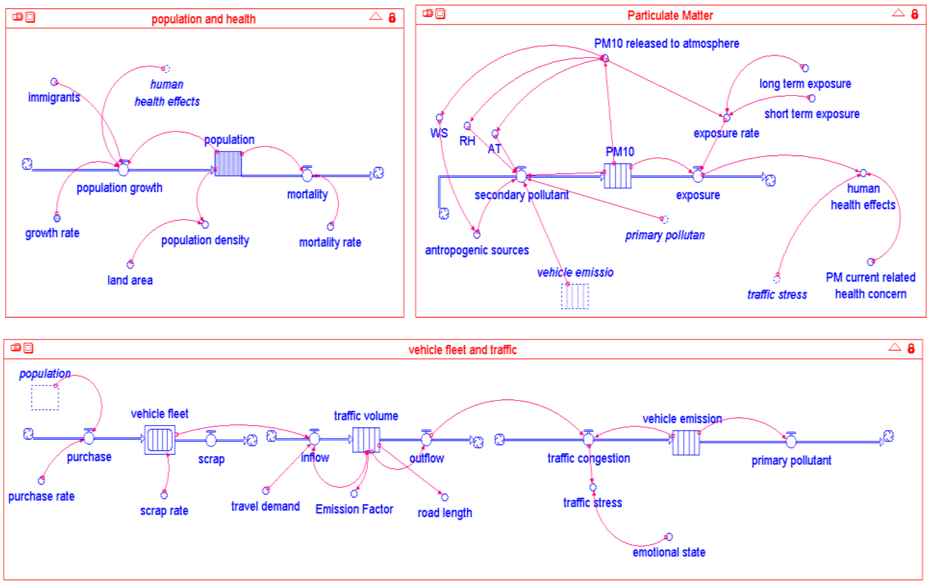


Fig. 4. System Dynamic Model (SDM) framework using STELLA™ software for real time on-road vehicle fleet and PM_{10} concentration modeling.

The PM_{10} concentration conveyor was initially conditioned to 150μg/m^3 in reference from the National Ambient Air Quality Guideline Values (NAAQGV) of PM_{10} concentration. The 150μg/m^3 considered moderately polluted where health impact is felt like breathing discomfort for individuals with respiratory related concern. At this concentration level, the public is not yet likely to be affected. An increase of 1μg/m^3 is already considered a poor air quality. The SDM also simulated scenarios for 120μg/m^3 annual averaging time.

A defined course of action in the model was interpolated to distinguish difference from initial conditions. Policy measures introduced in the model determines present and future decisions with its acceptable procedures and realistic values. The purchase control influenced the purchase rate of vehicles, scrapping policy to the number of vehicle fleet, traffic management to organize the average traffic volume, and mitigating measures to be implemented to minimize vehicle emission. An addition of 50% implementation of the four policy measures such as purchase control, scrapping policy, traffic management, and mitigating measures converters resulted to a decreasing behavior of the variables (Fig. 5).

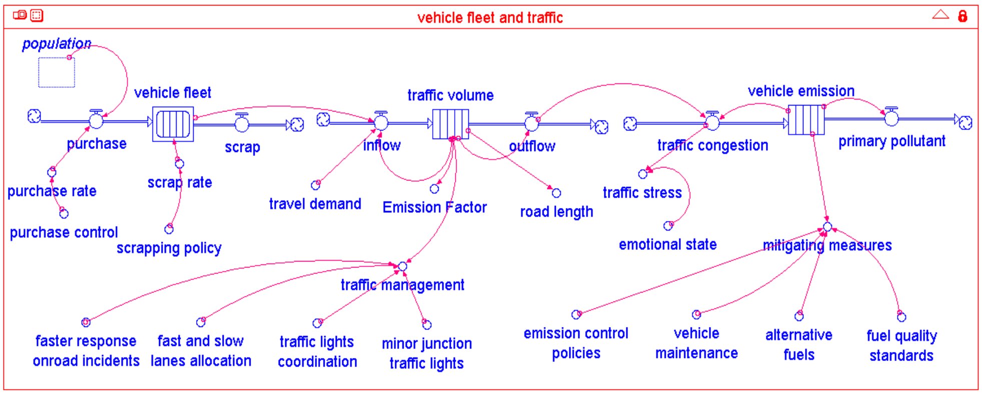
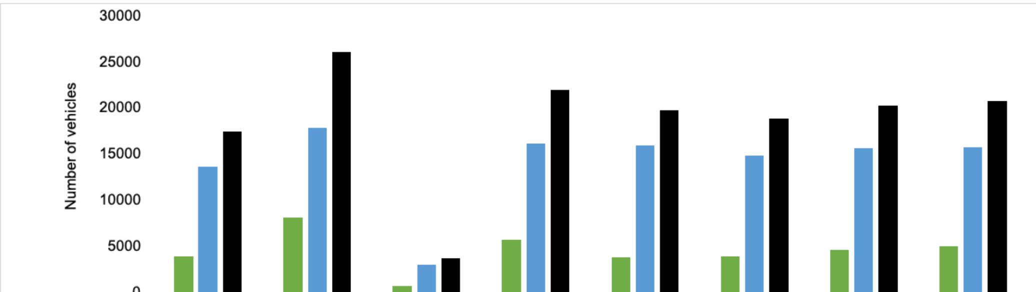


Fig. 5. SDM framework with the four interpolated policy measures; purchase control, scrapping policy, traffic management, and mitigating measures.

IV. Results and Discussion

A. Daily Traffic Volume

After thorough observation and vehicle fleet counting, Fig. 6 presents the total 24-hour counting cycle from November 8 to 15, 2019. The vehicle fleet count was classified by vehicle fuel type; diesel fueled fleet and gas fueled fleet. For the total duration of the vehicle counting period, the highest total vehicle fleet was observed on November 9, 2019 on Saturday for 26,104 number of vehicles running on road. The total vehicle fleet recorded on Saturday was 26,104 number of vehicles, a close record to the estimated Average Daily Traffic (ADT) of 30,000. For the sampling period, Mandaue City has an average of 18,000 on-road motor vehicles daily for the specific major junction in Mandaue City Sports and Complex, UN Avenue, Mandaue City. The lowest number of on-road vehicle fleet was recorded on November 10,2019 on Sunday at 3,740. The total vehicle fleet was 149,100 for the vehicle counting duration. Diesel fueled accounts 36,044 and gas fueled 113,056 number of vehicles. Gas fueled vehicle fleet consistently showed higher count from November 8 to 15, 2019. Either gas or diesel fueled vehicle fleet, it appeared to have higher count on Saturday and lowest count on Sunday.

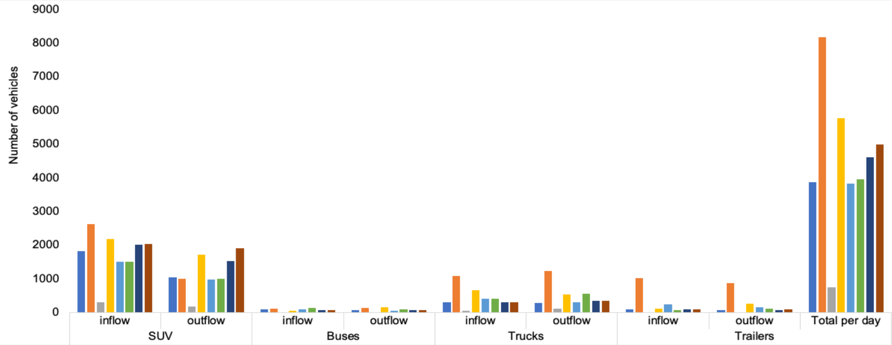


	Friday 8-Nov	Saturday 9-Nov	Sunday 10-Nov	Monday 11-Nov	Tuesday 12-Nov	Wednesday 13-Nov	Thursday 14-Nov	Friday 15-Nov
Diesel fueled fleet	3885	8193	755	5784	3832	3962	4629	5004
Gas fueled fleet	13641	17911	2985	16217	15965	14894	15684	15759
Total vehicle fleet	17526	26104	3740	22001	19797	18856	20313	20763

Fig. 6. A 24-hour comparison for diesel and gas fueled vehicle fleet in Mandaue City Sports and Complex, UN Avenue, Mandaue City from November 8 to 15, 2019

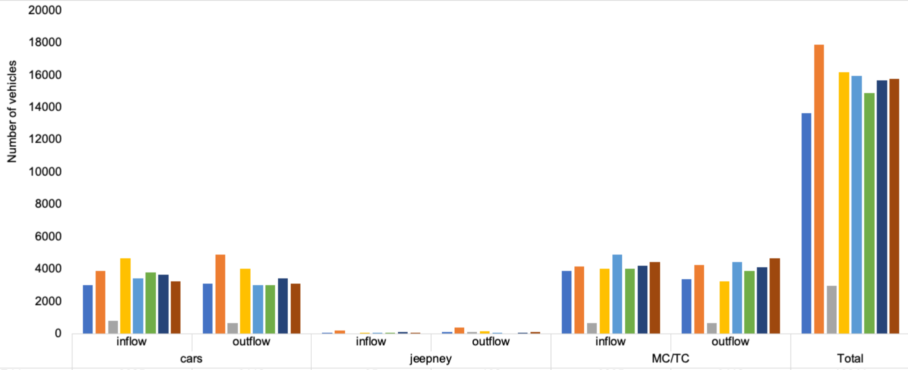
Gas fueled vehicle fleet has the higher total number of vehicles compared to diesel fueled fleet. The strong number of the gas fueled vehicle fleet was from motorcycles and tricycles or MC/TC. MC/TC total inflow for eight days was 30, 372 and 28,812 for outflow, a total of 59,184 running on road for the duration. This account the highest among the vehicle fleet category. The SUV's was the second highest vehicle fleet count with the inflow of 14,077 and outflow of 9,453, total of 23,530. The lowest count for gas fueled vehicle category were from jeepneys with the inflow of 794 and outflow of 1,115, total of 1,909. Bus contributes the lowest count for the diesel vehicle category that accounts the inflow of 721 and 702 outflow, total of 1,423.

The breakdown of the vehicle counts per day and per fuel used is presented in Fig. 7and 8. SUV appeared the highest trend count for diesel fueled and MC/TC displayed the highest trend count for gas fueled vehicle fleet. SUV highest trend recorded was on November 9 and 15, 2019 for 2,642 (inflow) and 1,923 (outflow) respectively. MC/TC has 4,895 (inflow) on November 12 and 4,695 (outflow) on November 15, 2019.



	SUV inflow	SUV outflow	Buses inflow	Buses outflow	Trucks inflow	Trucks outflow	Trailers inflow	Trailers outflow	Total per day
8-Nov Friday	1825	1045	102	93	325	301	112	82	3885
9-Nov Saturday	2642	1008	127	152	1095	1242	1032	895	8193
10-Nov Sunday	315	196	18	15	65	122	18	6	755
11-Nov Monday	2189	1727	66	176	680	550	132	264	5784
12-Nov Tuesday	1525	995	95	56	425	310	258	168	3832
13-Nov Wednesday	1520	1014	145	95	425	560	88	115	3962
14-Nov Thursday	2016	1545	92	88	325	363	113	87	4629
15-Nov Friday	2045	1923	76	87	320	352	94	107	5004

Fig. 7. A real time diesel fueled vehicle fleet count from November 8 to 15, 2019 in Mandaue City Sports and Complex, UN Avenue, Mandaue City



	cars inflow	cars outflow	jeepney inflow	jeepney outflow	MC/TC inflow	MC/TC outflow	Total
8-Nov Friday	3025	3112	95	102	3895	3412	13641
9-Nov Saturday	3918	4920	230	405	4152	4286	17911
10-Nov Sunday	807	666	25	107	695	685	2985
11-Nov Monday	4690	4015	66	175	4015	3256	16217
12-Nov Tuesday	3425	3025	85	76	4895	4459	15965
13-Nov Wednesday	3825	3012	75	43	4045	3894	14894
14-Nov Thursday	3672	3455	120	89	4223	4125	15684
15-Nov Friday	3274	3122	98	118	4452	4695	15759

Fig. 8. A real time gasoline fueled vehicle fleet count from November 8 to 15, 2019 in Mandaue CitySports and Complex, UN Avenue, Mandaue City

B. PM10 and Human Health

The PM_{10} concentration averaging time ($\mu g/m^3$, 24-hr) measured in the three sampling areas of the chartered cities in Metro Cebu showed from good and fair AQI breakpoints with no cautionary statements for the public (Table 1).

Table 1. PM_{10} Averaging Time (µg/m^3, 24hr) for Lapu-lapu City, Cebu City, and Mandaue City from the selected duration of September 18 to November 30, 2019.

PM_{10} concentration averaging time (µg/m^3, 24hr)														
Date (2019)	18-Sep	19-Sep	20-Sep	21-Sep	22-Sep	23-Sep	24-Sep	25-Sep	26-Sep	27-Sep	28-Sep	29-Sep	30-Sep	1-Oct
Lapu-lapu City	69	64	49	61	68	82	61	58	56	57	65	49	53	57
Date (2019)	17-Oct	18-Oct	19-Oct	20-Oct	21-Oct	22-Oct	23-Oct	24-Oct	25-Oct	26-Oct	27-Oct	28-Oct	29-Oct	30-Oct
Cebu City	46	49	47	47	40	34	36	39	31	31	23	29	38	37
Date (2019)	1-Nov	2-Nov	3-Nov	4-Nov	5-Nov	6-Nov	7-Nov	8-Nov	9-Nov	10-Nov	11-Nov	12-Nov	13-Nov	14-Nov
Mandaue City	50	40	24	43	48	45	47	77	112	50	94	100	84	95
	15-Nov	16-Nov	17-Nov	18-Nov	19-Nov	20-Nov	21-Nov	22-Nov	23-Nov	24-Nov	25-Nov	26-Nov	27-Nov	28-Nov
	70	73	53	84	93	99	96	89	49	50	49	74	86	76
	29-Nov	30-Nov												
	57	52												

Legend:

Good	Fair	Unhealthy for sensitive groups	Very Unhealthy	Acutely Unhealthy	Emergency

C. 24-hour PM10 and On-road Vehicle Fleet Correlation

This study used the Pearson Product-Moment Correlation Coefficient (PPMCC) (Level 3 Advanced Subsidiary GCE, 2014). Pearson r correlation used to measure the degree of relationship between the two linear variables. A 24-hour vehicle counting cycle was conducted in at Mandaue City Sports and Complex, UN Avenue, Mandaue City from November 8 (Friday) to November 15 (Friday), 2019. The average PM_{10} concentration data set in correlation to the vehicle count was equated at the same date of the vehicle sampling duration. Fig. 9shows a strong positive relationship of the total vehicle fleet and PM_{10} concentration at a correlation coefficient of r = 0.8587. As the number of PM_{10} concentration increases, the total vehicle fleet also increases. The extreme value causing the positive relationship was coming from the data set on November 10, 2019, Sunday, when the total vehicle fleet count and PM_{10} concentration were notably lower compared to some other days of the sampling duration.

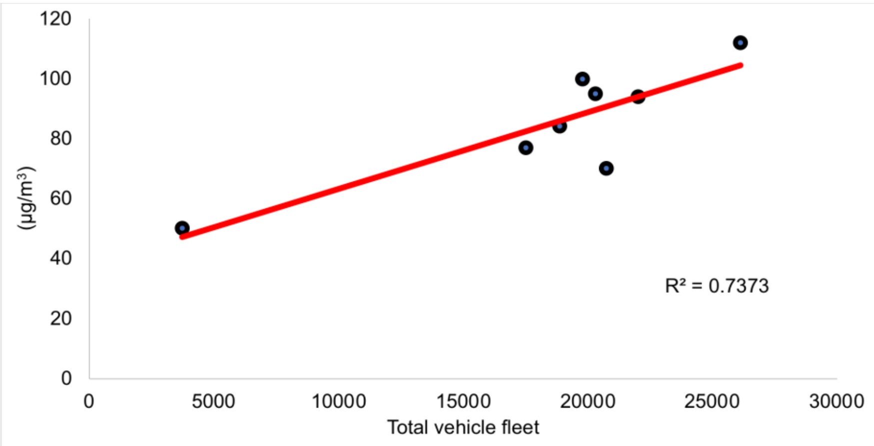


Fig. 9. The 24-hour PM_{10} concentration and total vehicle fleetcorrelation

D. SDM Simulation Results

The initial conditions were set as follows; PM_{10} at 150μg/m^3, population of 3,000,000, and purchase rate of 3%. The 3% of the total population is equal to 90,000 estimated individuals who purchased vehicles. Vehicle fleet initial conditions in the vehicle fleet sub-model was estimated Average Daily Traffic (ADT) of 30,000 vehicles. In the sub-model, it is consistently distributed to 5 cohorts which resulted to 150,000 vehicles for the first simulation period. Traffic volume initial condition is at estimated 18,000 daily average based from the real time traffic volume in Mandaue City. Scrapped vehicles on the first simulation resulted to 30,000 on its first year and on the following 5 years. Starting on the fifth year, the 90,000 purchased vehicles on the first simulation run will be scrapped. The model is conditioned to every five years scrapping of vehicles. Human health effects simulated result value came from traffic stress, Particulate Matter (PM) health related concern, and direct exposure from PM_{10} concentration. The value of human health effects resulted to 5% or 150,000 (3,000,000 * .05) individuals particularly residing within the radius in Metro Cebu. The SDM simulated statistical results for Metro Cebu's population, vehicle purchase, and vehicle fleet for ten years projection is shown in Fig. 10. The three variables point out an increasing direct variation from the start of the simulation. Largely, the number of vehicles in the vehicle fleet are from the growing population who has the capacity to purchase a vehicle.

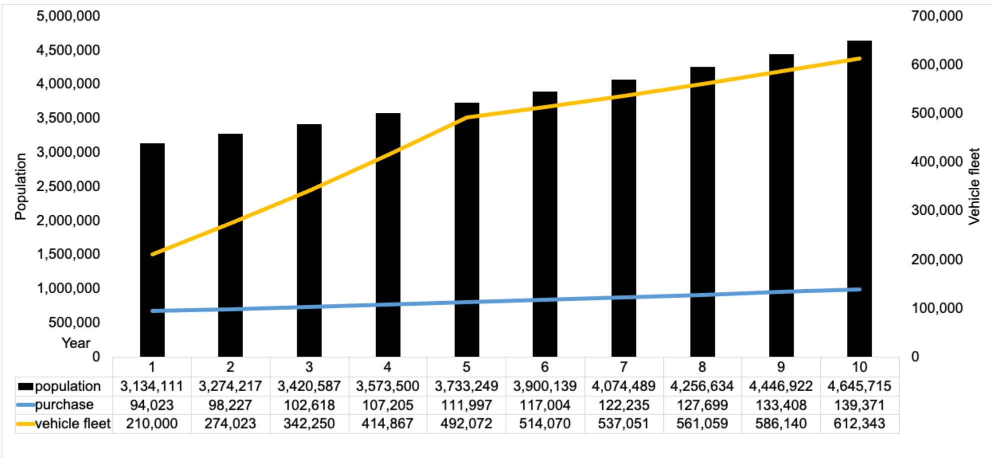


Fig. 10. SDM simulated results for Metro Cebu's population, vehicle purchase, and vehicle fleet for ten (10) years projection.

Model simulation of PM_{10} concentration and traffic volume is displayed in Fig. 11. After ten years, from the initial condition values, the population reached 4,645,715. These 4,645,715 individuals residing in Metro Cebu, a maximum of 139,371 can purchase a vehicle which will be adequate for the total vehicle fleet of 612,343, traffic volume of 18,035, with a focusing health effects to the total population.

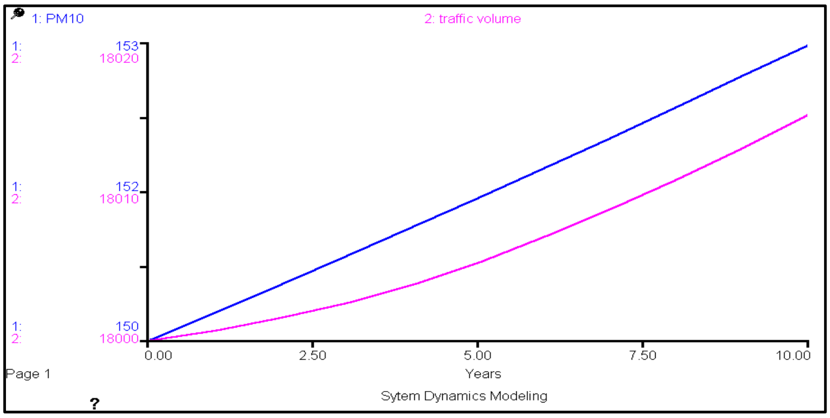


Fig. 11. Model simulation of PM_{10} concentration and traffic volume

E. SDM Scenario Analysis and Policy Implementations

The vehicle fleet in Metro Cebu grows exponentially over time without purchase control. The vehicle scrapping will not compensate the goal to sustain the average daily traffic because scrapping also means buying a new vehicle. Setting the purchase rate to 3% has restricted number of vehicle fleet to be purchased and eventually sustaining the on road average daily traffic volume. Scrap rate of 1% or higher every year will help lessen number of total vehicle fleet and traffic volume. The four identified policy measures interpolated in the SDM framework helped determine the effect of the implementation policy. The focusing effects of the policy measures namely purchase control, scrapping policy, traffic management, and mitigating measures converters gave the total predetermined simulation results. In the survey, eighteen percent (18%) of Metro Cebu's population will purchase a vehicle in the next five years. The SDM forecasted that after five years, Metro Cebu's population will reach, 3,733,249. The eighteen percent (18%) of 3,733,249 is 671,984, however, as the model simulated, the allowable total vehicle fleet is 492,072 to sustain on-road traffic volume. The real time vehicle fleet count recorded a total of 186,981 vehicles on-road for the counting duration in 2019, giving an average traffic volume of 18,000 daily. Thus, without proper mitigation and policy implementation to decongest traffic in Metro Cebu, there will be an increasing demand of road expansion to accommodate traffic volume capacity. The demand for space becomes greater than what is available leading to a more complex effects for transport and other sectors in Metro Cebu.

The SDM modeled direct health effects of PM_{10} concentration of annual average of 150µg/m^3 and 120µg/m^3 ranges from five to six percent of the total population in Metro Cebu depending on the level of exposure. At 120µg/m^3, 23% of the total population is estimated to be exposed of PM_{10} concentration giving a higher direct health effect of 6%. At 150µg/m^3, the total estimated population to be exposed is at 19% yielding 5% direct health effects.

V. CONCLUSION

The 24-hour measurement cycle between PM_{10} and total vehicle fleet observed in Mandaue City shows a strong correlation (r = 0.8587). The strong predictor of the high correlation was from the gas fueled vehicle fleet which dominantly comprises of motorcycles and diesel fueled vehicle fleet which is dominated by SUVs. The vehicle fleet temporal variations are observed to have high number of on-road vehicles from Mondays to Saturdays and low number on Sundays.

The PM_{10} concentrations obtained in the study were evaluated using the AQI breakpoints. The PM_{10} concentrations in the three sampling locations conducted in Lapu-lapu City, Cebu City, and Mandaue City detected as good to fair breakpoints level leaving no cautionary measures for the public. However, sudden spikes of PM_{10} concentrations were observed in specific days and time that exceed healthy breakpoints. Thus, a real time monitoring of PM_{10} concentration suitably necessary for Metro Cebu's continuous air pollution monitoring.

The SDM shows that vehicle fleet in Metro Cebu grows exponentially over time without purchase control. The sustainable purchase rate is at 3% or below yearly and a scrap rate of 1% or higher. The four identified policy measures such as purchase control, scrapping policy, traffic management, and vehicle emission mitigating measures converters interpolated in the SDM framework helped determine the effect of the implementation policy. As evaluated in the survey, eighteen percent (18%) of Metro Cebu's population will purchase a vehicle in the next five years. Hence, without policy implementation to decongest traffic in Metro Cebu, it may result to an increasing demand of road expansion to accommodate traffic volume capacity.

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