Research Article

Journal of Environmental Nanotechnology

Simulation Study on the Influence of the Traffic Conditions on Vehicle Performance and Emission

V. S. Baradhsundar and A. Srinivaas*

Department of Mechanical Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, TN, India
Received: 28.02.2024 Accepted: 29.04.2024 Published: 30.06.2024
*a_srinivaas@cb.amrita.edu

ABSTRACT

This study is to investigate on how the traffic condition affects the vehicle performance and emission through simulation. A real-world road network is chosen for the simulation which is Ghatkesar junction in Telangana, India. The tools used for simulation is the Simulation of Urban Mobility (SUMO) along with IPG Carmaker. Traffic conditions such as high traffic and low traffic are considered for the simulation. Components of emission for both the high and low traffic condition are obtained such as CO_2, CO, HC, PMx and NOx are assessed in the study. Also, speed of the vehicle and time taken for the trip are considered along with the traffic conditions to study the influence of the traffic on the vehicle performance. This work illustrates the pre-study of the Functional Mock-up Interface (FMI) for making simulation studies better with different software interacting dynamically and this work is a simplified and economic approach to the growing needs of the simulation-based studies.

Keywords: Emission; SUMO; IPG carmaker; High and low traffic.

1. INTRODUCTION

With the increase in population, vehicles on road are also increasing in India. As the number of the vehicles increases, the pollution produced by the vehicles tends to increase. Concentration of traffic and traffic congestion have become a critical aspect of travel. The congested traffic conditions lead to many social and health related problems. Air pollution causes extremely serious health risks. Poor air quality increases the risk of life-threatening conditions such as cancer and burdens the health with respiratory ailments like asthma and bronchitis.

Emission with traffic conditions is analyzed using SUMO software. Different traffic conditions such as high and low are used in the simulation. Real-world road and traffic data are used for simulation. The environment of simulation is recreated using IPG Carmaker, a vehicle dynamic simulation software to study the vehicle performance parameters such as, vehicle velocity, vehicle aerodynamic forces and resistance and the engine power, torque and rotation parameters (Ashok *et al.* 2018; Srinivaas and Thirumalini, 2019).

2. LITERATURE REVIEW

De Coensela *et al*. (2021) studied the Effects of traffic signal coordination on noise and air pollutant emissions. The work provides an insight into the traffic light coordination with emissions such as CO_2 NOx and PM10. A microscopic traffic simulation model was used and they concluded the introduction of the green wave could considerably lower the emissions of the considered air pollutants by 10% to at 40%. The green light split and the traffic intensity was found to have the largest influence on the reduction in emission. A considerable amount of reduction of emission occurs when traffic intensities are close to the capacities and the green light split is low. It was found that the cycle time has an influence only on travel times, but not on the emission. The introduction of a green wave resulted in an increase in the total emitted noise level, by up to 0.6 dB (A). Sound pressure levels were found to decrease by up to 1 dB (A) near the traffic signals, but they increased by up to 1.5 dB (A) between intersections. This research reported the influence of traffic signal coordination on noise pollution and airborne emissions.

Meneguzzer *et al.* (2017) studied the comparison of exhaust emissions at intersections with traffic signal versus roundabout control using an instrumented vehicle. They compared the emission levels of the vehicle in an intersection and the emission level at the same place where the intersection is replaced by a roundabout. They mainly concentrated on CO_2, CO and NOx emissions.

The study observed a lower CO_2 emission in almost all testing conditions and posed an argument for replacing the traffic signal with the roundabout. For CO emissions, the results were mixed and the differences between the two were statistically non-significant in most of the cases. The NOx emissions were always lesser for the signalized intersection, but for roundabout it was high, and the difference was noticeable. Generally, emissions are highest for the acceleration driving mode and the only exception is CO and it is lowest for the idle mode. This research adds to the understanding of how traffic signal control and roundabouts affect vehicle emissions.

Li *et al.* (2017) also studied about signal control effects on vehicular traffic emissions through a sequence of traffic lights. In their work, emissions studies were carried out in a single-lane roadway with sequence of traffic signal lights. A signal state function was used to create the traffic light states. The signalized intersections traffic behavior was studied by the Car-following model. The vehicle behavior was grouped into three: stop mode, free-running mode, and car following mode. The simulations were carried out to analyze the effect of the three signal control parameters such as cycle, split and offset time. Different traffic patterns were also analyzed by changing signal control parameters. This paper proved that the vehicle's emissions depend highly on signal control parameters. Finally, the paper suggests that signal control parameters can alter the emission of vehicles on the road. The impact of traffic signal control parameters on vehicle emissions has been explored in this research.

In 2017, (Muhammad *et al.* studied urban traffic simulation using SUMO. They accurately simulated the traffic conditions in software SUMO. The simulation was done for two intersections at Surabaya, Indonesia. They used sensors to measure the number of the vehicles passing the intersection. To control the traffic condition, the authors inter-linked Matlab with SUMO using TranCI. These simulation results confirmed that the SUMO software is capable of analyzing these types of simulations accurately. The study evaluated the effectiveness of the SUMO software in replicating real-world traffic scenarios at urban intersections.

3. EXPERIMENTAL METHODOLOGY

The simulation with SUMO is carried out in 4 steps

3.1 Data collection

3.2 Road Network

3.3 Upload Road network to SUMO and

3.4 Simulation

3.1 Data Collection

This investigation involves the requirement of actual traffic data and a data from junction on an Indian road is considered. The project considers two scenarios which are 1) At a high traffic condition and 2) At a low traffic condition. The data used by Meruga Siva Parvathi and Basavaraj Akki, who carried out a project on classified traffic volume study at Ghatkesar junction (Meruga and Basavaraj, 2017) is considered for this study. They carried out the experiment in such a way that they counted the number of vehicles passing through Ghatkesar junction in the interval of 15 minutes and tabulated it. They have done this for different time schedule and different days. Then, they analyzed the vehicle volume conditions. From their experiment, it is found that the high condition of the Ghatkesar junction is 234 vehicles per 15 minutes and the low condition is 112 vehicles per 15 minutes. This data from the study is used for defining high and low traffic condition.

3.2 Road Network

For establishing the road network, Open Street Map (OSM), a free editable map is used. From OSM, the Ghatkesar junction location is mapped using the coordinate points (Fig. 1). After locating the area that is to be studied, transportation map is chosen and is exported. For the convenient use of the map in SUMO and IPG Carmaker, OSM format is used.

The map can be edited using NetEdit software in the SUMO environment for faster simulation results.

3.3 Creating a Simulation Environment in SUMO

SUMO is a python-based software; so, we can use code in command prompt for creating simulation environment. The first thing that we want to do is convert the downloaded map which is in OSM format to SUMO network format.

The next step for simulation environment creation is adding trip and route to the network using built-in Python scripts randomtrips.py. The following code is used.

python PATH\randomTrips.py -n <input file name> -r <output file name> -e 50 –l

While using the Python script random trips, it allocates traffic condition with the vehicle ids and the route followed by the vehicle. It generates both the route file and trip file. Two conditions for simulations, one high condition with 234 vehicles in 15 minutes and one is the low condition which is 112 vehicles per 15 minutes are considered. A simplified representation of the actual road network used to simulate traffic conditions in urban intersections is shown in Fig.2. Route files for both high and low condition are generated independently since the routes are allocated using the random trip Python code, one vehicle is chosen and the route of that vehicle made for the study is same for both the conditions. This vehicle is considered as the test vehicle.

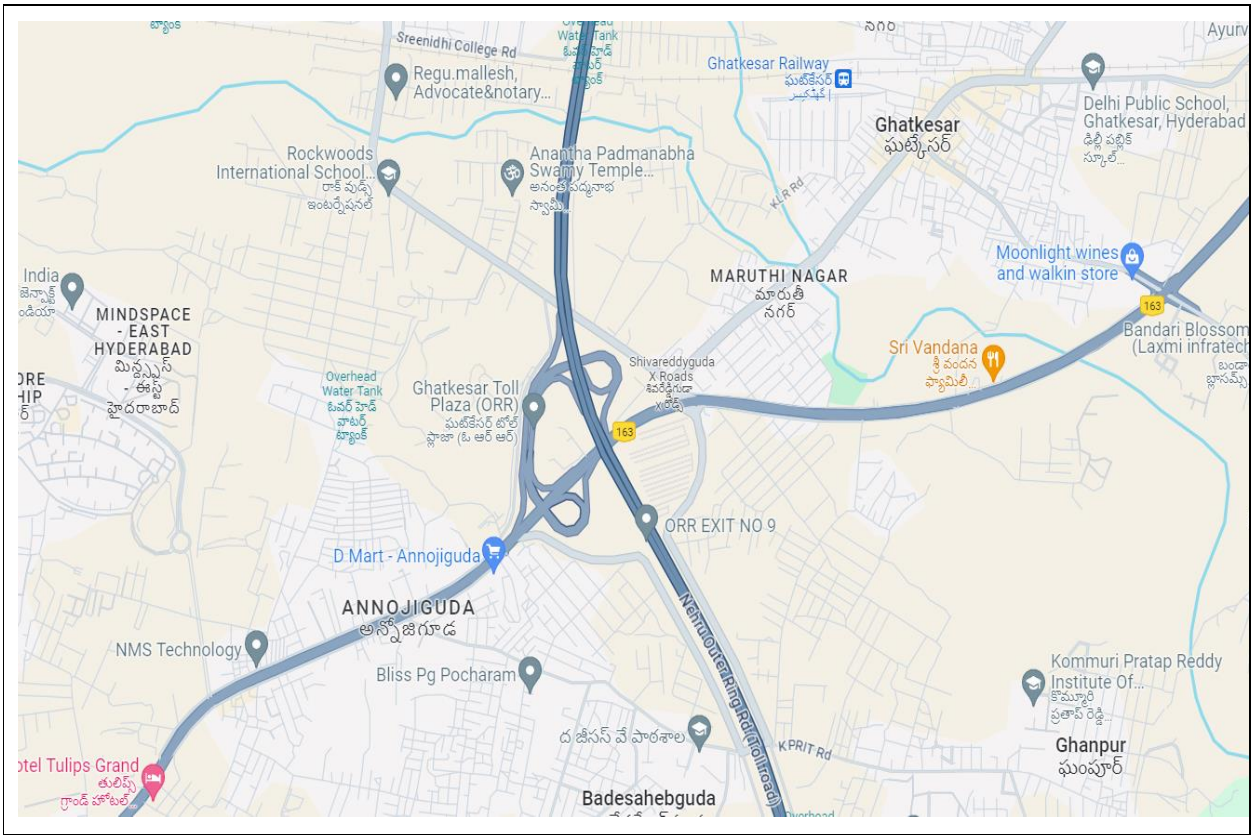

Fig. 1: Image of Ghatkesar junction

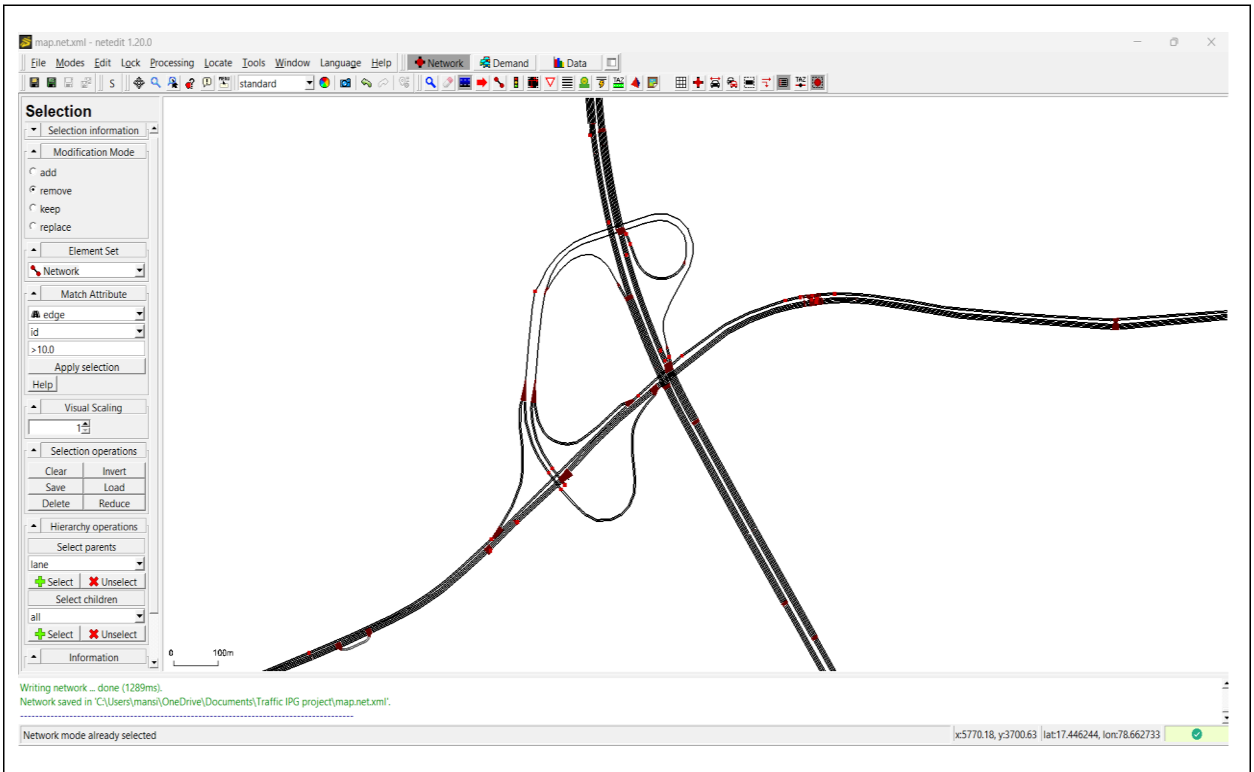

Fig. 2: Road network in SUMO

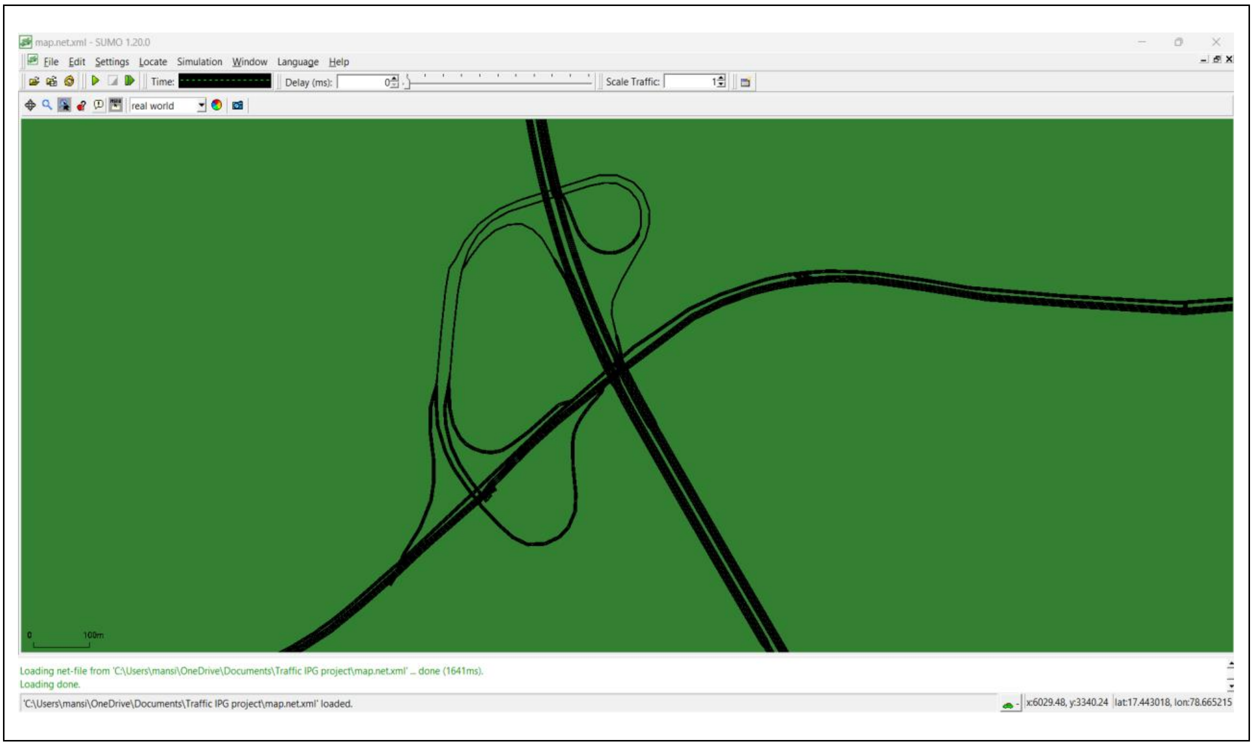

Fig. 3: SUMO GUI with Road Network

3.4 Running Simulation and Result Generation

For visualizing the traffic scenario and operation, the configuration file is also operated. Python code is used for the emission output.

The code facilitates recording of emission details such as CO_2, CO, NOx, PMx, speed, noise, fuel usage of all vehicle in the simulations as an XML file. Output for high and low traffic conditions are generated independently. Vehicle id of every vehicle is also provided in the file. The details of the vehicle which is of interest is identified and operated in the same route in both traffic conditions, the vehicle which is running in the same route in both conditions. The results are sorted and analysed. Fig.3 provides an overview of the road network.

The simulation for IPG Carmaker is carried out using the following steps

3.4.1 Vehicle and Road Creation

3.4.2 Driver Attributes or Parameters

3.4.3 Traffic Scenario Creation

3.4.4 Simulation and Plotting Results

3.4.1 Vehicle and Road Creation

To maintain similarity, the vehicle parameters are tuned in the IPG Carmaker with the parameters of the SUMO vehicle data sets (Table 1).

Table 1. The parameters of the IPG Carmaker and SUMO applications

Vehicle Type	Passenger class
Length / Width of the vehicle	5 m / 1.8 m
Min Gap between vehicle and traffic object	2.5 m
Simulation input Speed of the vehicle	70 km/hr
Max speed possible	200 km/hr
Acceleration	2.6 m/s^2
Deceleration	4.5 m/s^2
SUMO emission class	"PC_G_EU4" (Euro 4 Equivalence)
SUMO Lane change model	'LC2013' – (Default in IPG Carmaker)
SUMO Car follow model	'Krauss' – (Default in IPG Carmaker)

3.4.2 Driver Attributes or Parameters

The driver attributes are of key importance since modes such as sports, urban or our user setting can be implemented which directly control the mauver attributes of the vehicle. Here, we created a course sufficient to complete the simulation for the taken path of road, to include a practical driving condition on Indian roads. The start and the traffic object overtaking and sharp turns in the road are controlled with reduced speed for safe manoeuvring.

3.4.3 Traffic Scenario Creation

The road set up using the OSM for the SUMO platform is integrated for the same path and same parameters. To have the high and low traffic condition, the number of vehicles in the SUMO environment is same as the high traffic for vehicle count of 50 and low traffic at vehicle count of 21 including the various vehicle class such as commercial container, bus, car, motorcycle and slow-moving objects like animal crossing and bicycle are also added to create simulation of actual Indian road in the Traffic Scenario editor. Several setups are made and the appropriate one matching the random traffic creation in the SUMO platform is matched to have a similar environment to run the simulation.

3.4.4 Simulation and Plotting Results

A complete synchronisation auto check is carried out on the model check and errors are eliminated to finalize the parameters of the Car Dynamic properties such as road, driver, manoeuvre input and traffic scenario editor inputs.

The required output is plotted using the IPG Control setup for both the high and low traffic conditions and several parameters of the car performance are logged, and the most significant parameters are engine power, torque, rotation and the vehicle aerodynamic side force, torque and relative velocity and the speed of vehicle.

4. RESULT AND DISCUSSION

4.1 CO_2 Emission

When we compare the cumulative emission of CO_2, it is found that the amount of emission is high in the low traffic condition (Fig. 4).

The cumulative emission at high traffic condition is found to be 92815.02mg/s; for low traffic condition it is found to be around 1057880.03 mg/s. The difference in CO_2 is because of the amount of fuel usage. For low traffic condition, the speed of the vehicle is high compared to the high traffic conditions. For increasing the speed, more fuel is used. When more fuel is burned, more CO_2 will be emitted from the vehicle (Srihari *et al.* 2018).

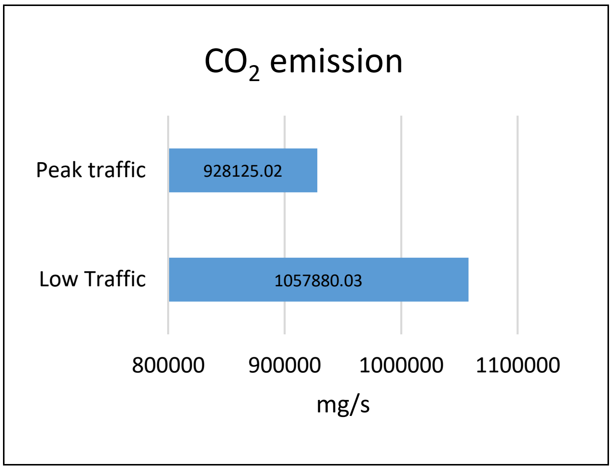

Fig. 4: CO_2 emission graph

4.2 CO Emission

The comparison of cumulative emission of CO is shown in Fig.5. There is a good difference in CO emission in high and low traffic conditions. It is found that at high traffic conditions, the CO emission is very high.

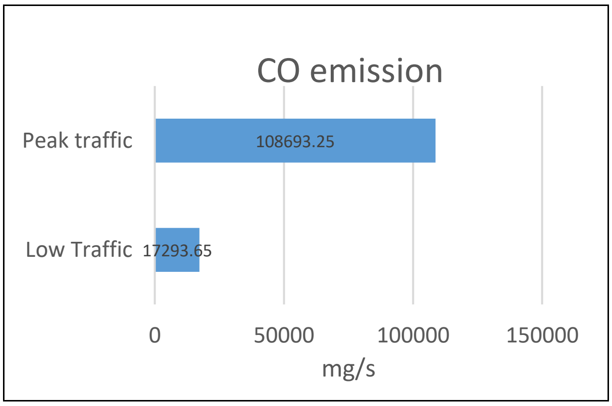

Fig. 5: CO emission graph

At high traffic conditions, cumulative emission of CO is found to be 108693.25 mg/s and at low traffic condition, it is found to be 17293.65mg/s. The difference is due to the fact that at high traffic condition, the chances of complete oxidation of fuel is less, the incomplete burning of fuel may lead to CO emission (Srihari *et al.* 2018).

4.3 HC Emission

When comparing (Fig.6) cumulative emission of HC, it is found that at low traffic condition the amount of HC emission is low compared to the high traffic condition.

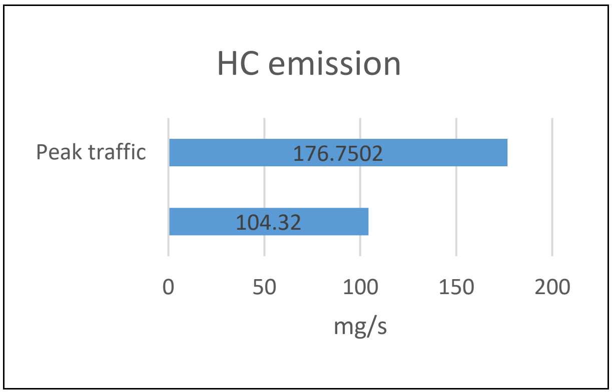

Fig. 6: HC emission graph

At high traffic condition, it is found that the cumulative HC emission is around 176.7502 mg/s. In low traffic condition, it is around 104.32 mg/s. The reason behind these results will be the incomplete burning of fuels due to the quick change in acceleration of the vehicle varying the throttle of the engine more often than the condition at the low traffic.

4.4 NO_x Emission

In the comparative study of cumulative emission of NOx, (Fig.7), it is found that NOx emission is high at low traffic condition. In the high traffic condition, the NOx emission is found low.

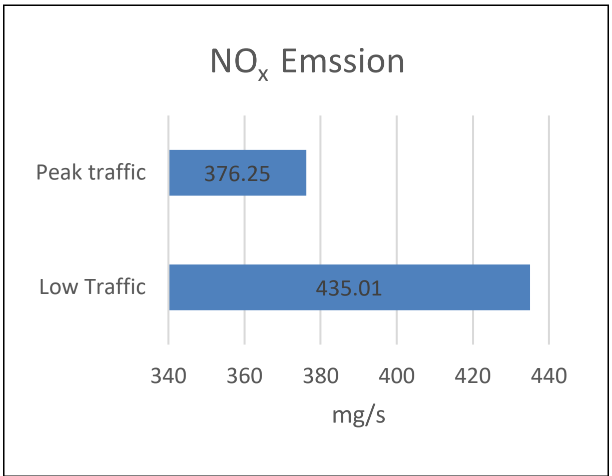

Fig.7: NO_x emission graph

At high traffic condition, the value of cumulative NOx emission is found to be 376.25 mg/s and that at low traffic condition is found to be 435.01 mg/s. At low traffic, fuel burnt is not utilized for mobilising the vehicle hence the excess heat available inside the cylinder leads to high temperature in the cylinder for the consecutive engine cycle operations and leads to higher NOx emission in the low traffic conditions compared to the high traffic conditions (Senthil and Thirumalini, 2022).

4.5 PMx Emission

In the case of particulate matter, it is found that at low traffic condition, the particulate matter emission is low compared to high traffic condition.

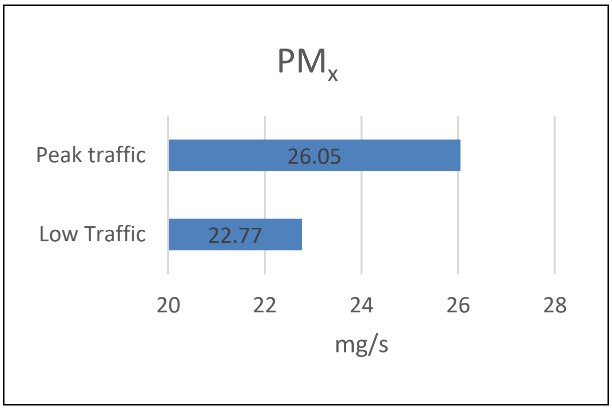

Fig. 8: PM_x Emission graph

From Fig.8, it can be found that the value of cumulative PMx emission at high traffic condition is 26.05 mg/s and that at low traffic conditions 22.77 mg/s. Though the difference is not high, there is a reasonable difference between them.

4.6 Engine – Power, Torque and Rotation

The engine parameters of the vehicle dynamics simulation software environment are recorded and discussed here.

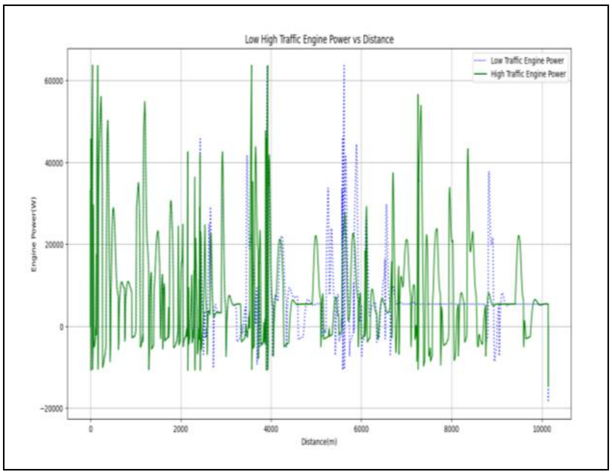

Fig. 9: Engine Power of Low and High traffic Vehicle dynamics simulation environment

From Fig.9, it is evident that the high traffic simulation produces high power in the engine due the consumption of fuel with various gear shifting and driving manoeuvre to tackle the high traffic. The simulation is created such a way that the vehicle of interest overtakes other traffic objects and the traffic object vehicle overtakes the vehicle of interest to recreate the daily manoeuvre in our road environment.

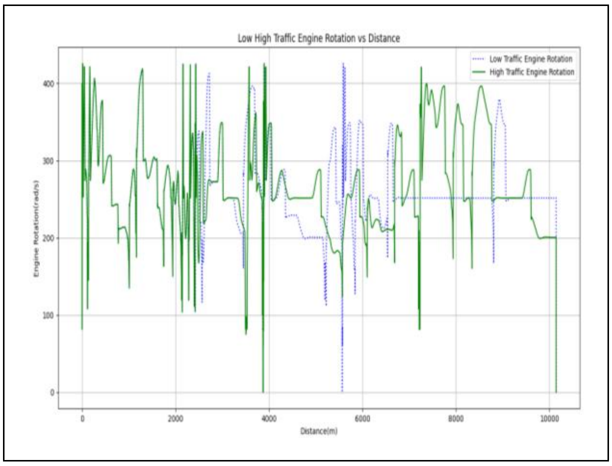

Fig. 10: Engine Rotation of Low and High traffic Vehicle dynamics simulation environment

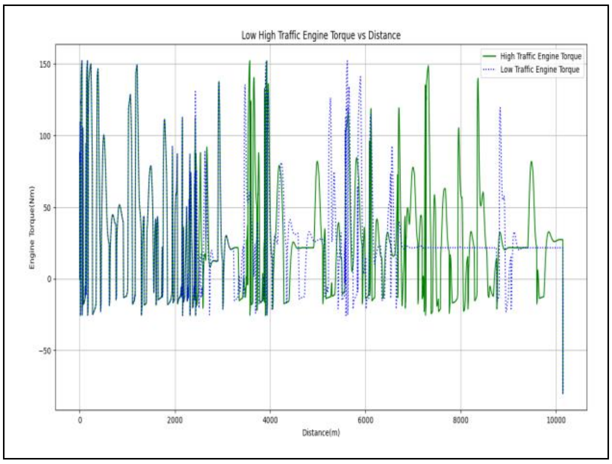

Fig. 11: Engine Torque of Low and High traffic Vehicle dynamics simulation environment

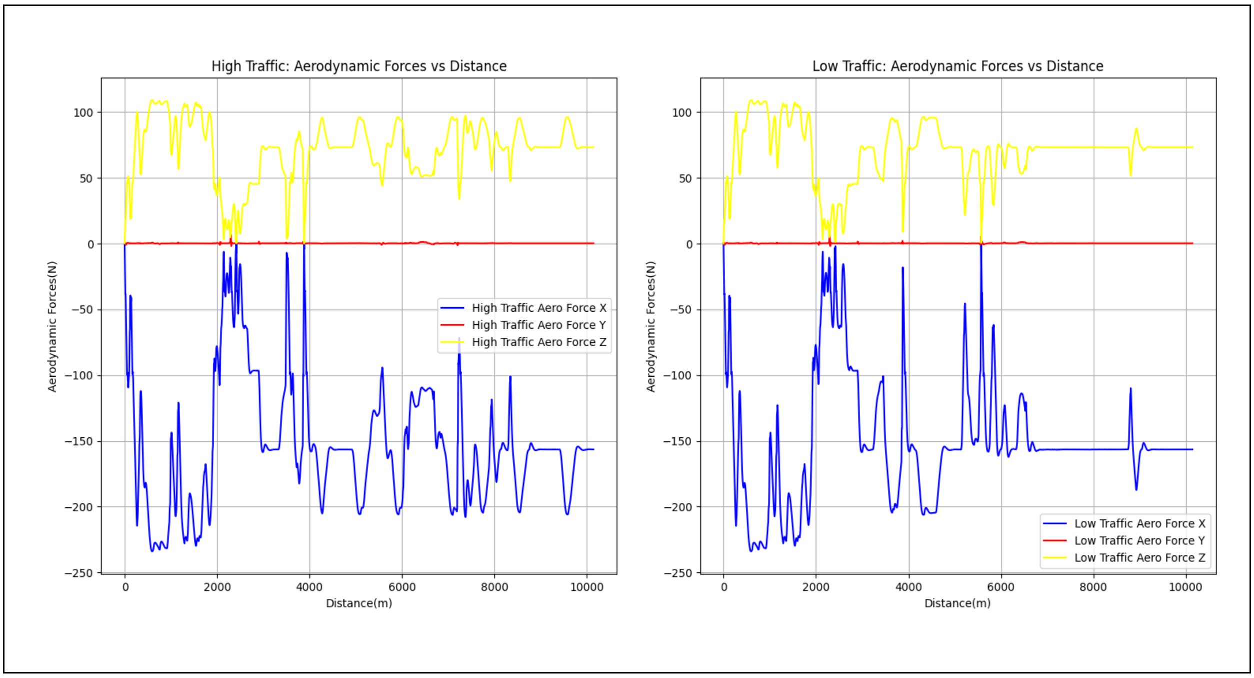

Fig. 12: Aerodynamic Force of Low and High traffic Vehicle dynamics simulation environment

From Fig. 10, we can see that the low traffic condition simulation makes higher engine rotation which indicates the energy generated is not utilized as the energy requirement for the vehicle driving.

Fig. 11 shows the average torque of a vehicle in low and high traffic conditions. The torque is higher in low traffic conditions, and it decreases as the traffic density increases. This is because the vehicle must accelerate and decelerate more frequently in high traffic conditions, which requires less torque. The graph also shows that the torque is higher at lower speeds. This is because the engine must work harder to overcome the inertia of the vehicle at lower speeds. The vehicle is likely to be more fuel-efficient at higher speeds in low traffic conditions, because the engine will be operating at a higher torque and lower speed.

4.7 Aerodynamic - Side Force, Torque and Relative velocity

The aerodynamic parameters of the vehicle dynamics simulation software environment are recorded and discussed here.

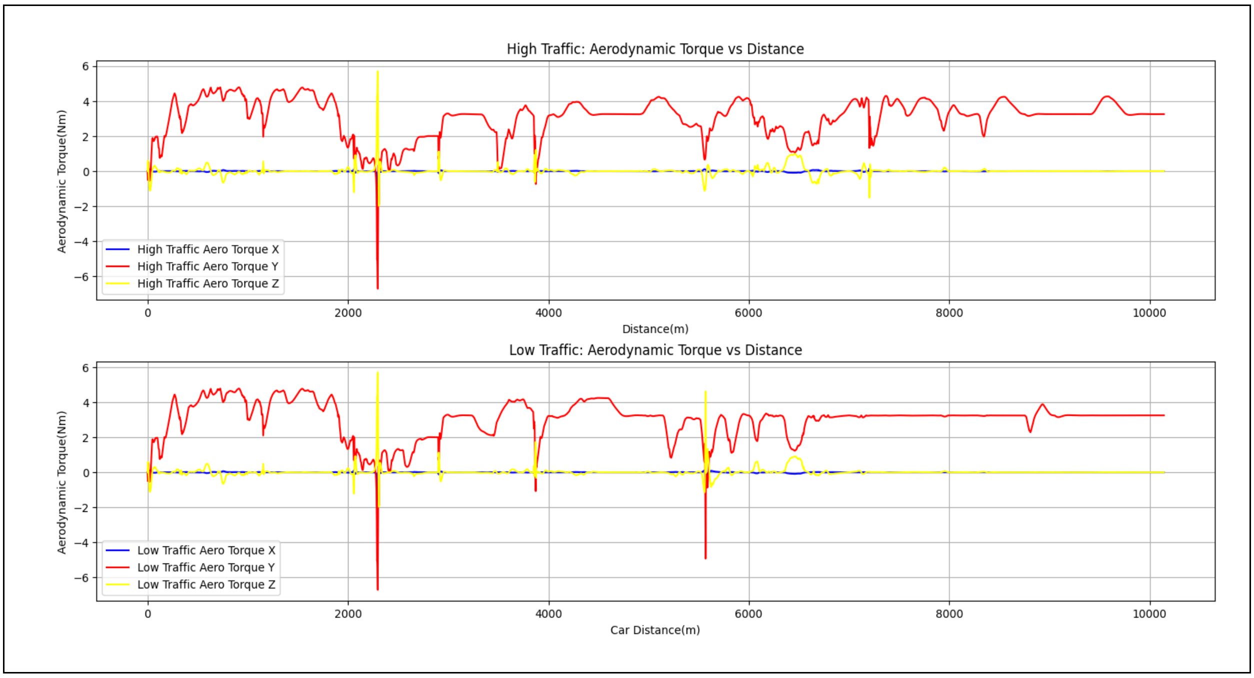

Fig. 13: Aerodynamic Torque of Low and High traffic Vehicle dynamics simulation environment

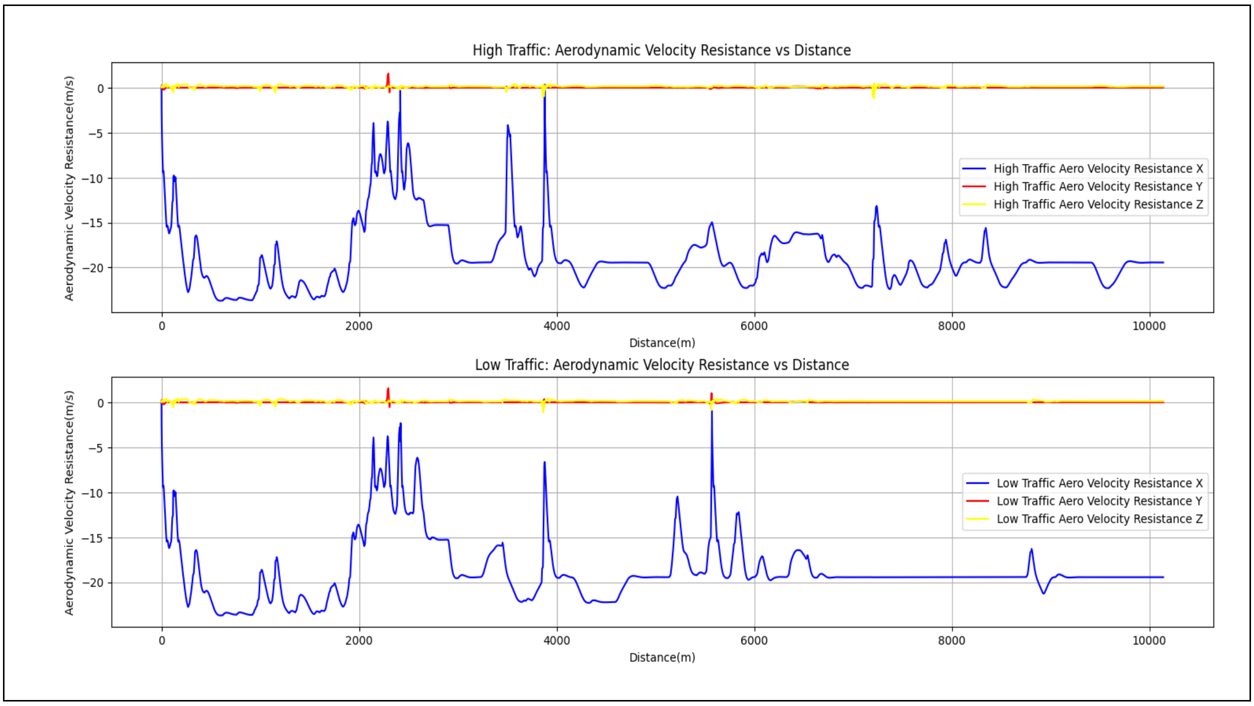

Fig. 14: Aerodynamics velocity resistance Low and High traffic Vehicle dynamics simulation environment

Fig. 12 shows that the aerodynamic force increases with distance in both low and high traffic conditions. However, the aerodynamic force is higher in high traffic conditions than in low traffic conditions. This is because the vehicles in high traffic conditions are closer together, creating more drag. The graph also shows that the aerodynamic force is higher at lower speeds. This is because the air has more time to interact with the vehicle at lower speeds, which creates more drag.

Fig.13 shows the difference between high and low traffic distance in terms of aerodynamic force. The high traffic distance has a higher aerodynamic force than the low traffic disc. This is because the high traffic disc is closer to the other discs, which creates more drag. The aerodynamic force also increases with speed for both high and low traffic distance. Vehicles in high traffic conditions will experience more aerodynamic drag than vehicles in low traffic conditions. This leads to reduced fuel efficiency and performance. The graph shows that vehicles traveling at higher speeds will experience more aerodynamic drag than vehicles traveling at lower speeds.

Fig. 14 shows that the aerodynamics velocity resistance is low at low traffic conditions than the high traffic conditions. Vehicles are farther apart in low traffic conditions, which reduces the aerodynamic drag. Aerodynamic drag is the force that opposes the forward motion of a vehicle. It is caused by the resistance of the air as the vehicle moves through it. In high traffic conditions, vehicles are closer together, which increases the aerodynamic drag. This is because the vehicles in front of and behind a vehicle create turbulence in the air, which makes it more difficult for the vehicle to move forward.

4.8 Speed of Vehicle

The average speed of the vehicle at high traffic condition is found to be 15.39 km/hr. The average speed at low traffic condition is found to be 18.47 km/hr. The average speed at low traffic condition can be increased if we are using intelligent traffic signal system which will work according to traffic condition. Comparing the time of travel, there is a 32 sec time gain in time of travel in the SUMO based simulation environment (Fig. 15).

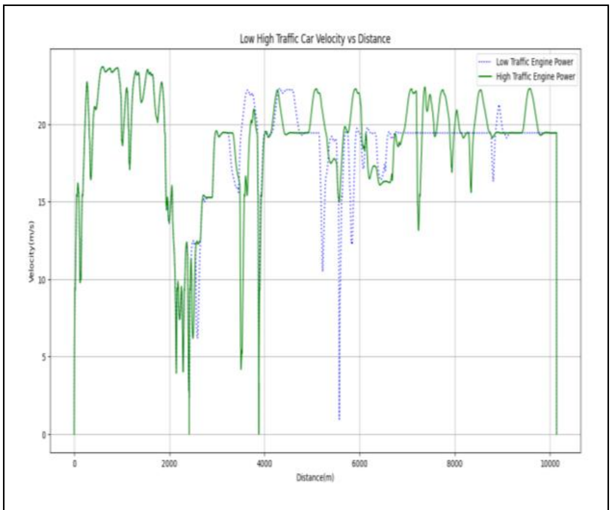

Fig. 15: Velocity of Low and High traffic Vehicle dynamics simulation environment

Low traffic simulation has taken lesser time for the destination and has higher velocity than the high traffic condition. This is due to the higher traffic condition leads to more maneuverer and lower speed to drive the course safe.

5. CONCLUSION

This study concentrated on how the traffic condition will affect air pollution. The results prove that even for a shorter distance and a small amount of time, there is a considerable change in the pollution values of CO, CO_2, HC and NOX. When the traffic is low, the speed of the vehicle is increased, and the time of travel also reduces. The CO_2 and NO_x emissions are found to be high in the low traffic conditions and all other emission parameters are found to be reduced with low traffic condition. In country like India, where the population of people and vehicle are high, it's easy to study the same in simulation environment rather than actual road condition monitoring and measuring the large geographic intensity of the country. So, doing simulation study will reduce the expenses and reduce the time of work.

As discussed in the results, when the traffic reduces the CO_2 emission is increasing. In big metropolitan cities, if we can maintain a particular speed of the vehicle which is not very high and not very low, the CO_2 and CO emission can be controlled. In this study, here we only have discussed the passenger cars. There are many possibilities of studying about other vehicles and road networks. There should be a speed at which all the emission parameters will be at an optimum level because we know that the speed has an important role in vehicle emission. An accurate model is possible with the development of the FMI to interact the well-established IPG Carmaker to be linked with the open source accepted SUMO software, which is the future scope of the present work.

REFERENCES

Ashok, K. S., Thirumalini, S., Mohankumar, P. Ram Sundar, R. and Aravind, C., Simulation Study on Variants of ABS, *IJET*, 7(3.6), 97 (2018). https://doi.org/10.14419/ijet.v7i3.6.14948

De Coensel, B. Can, A. Degraeuwe, B. De Vlieger, I. and Botteldooren, D., Effects of traffic signal coordination on noise and air pollutant emissions, *Environmental Modelling & Software*, 35, 74–83 (2012). https://doi.org/10.1016/j.envsoft.2012.02.009

Li, Y., Zhu, W. and Li, S., Signal control effects on vehicular traffic emissions through a sequence of traffic lights, *2017 Chinese Automation Congress (CAC), In: 2017 Chinese Automation Congress (CAC), IEEE Jinan*, 1930–1935 (2017). https://doi.org/10.1109/CAC.2017.8243085

Meneguzzer, C. Gastaldi, M. Rossi, R. Gecchele, G. and Prati, MV., Comparison of exhaust emissions at intersections under traffic signal versus roundabout control using an instrumented vehicle, *Transp. Res. Procedia*, 25 1597–1609 (2017). https://doi.org/10.1016/j.trpro.2017.05.204

Meruga, S. P. and Basavaraj, A., Classified Traffic Volume Study at Ghatekesar Junction, *J. Eng. Tech.*, 3(6), 420–435 (2017).

Muhammad, Z. Davindra, G. A. Endra, J. Member IEEE. and Herman, Y. S., Urban Traffic Simulation Using SUMO Open Source Tools, *Internetworking Indonesia journal*, 9(1), 83–88 (2017).

Senthil Kumar, D. and Thirumalini, S., Investigations on effect of split and retarded injection on the performance characteristics of engines with cashew nut shell biodiesel blends, *Int. J. Ambient Energy*, 43(1), 2251–2259 (2022). https://doi.org/10.1080/01430750.2020.1730961

Srihari, S. Sanjay Kumar, D. and S, T., Effect of inlet air temperature on SI engine fueled with diethyl ether-gasoline blends, *JMES*, 12(4), 4044–4055 (2018). https://doi.org/10.15282/jmes.12.4.2018.05.0351

Srinivaas, A. and Thirumalini, S., Modelling and Simulation of Skid Prediction in a Passenger Car, *ijrte*, 8(2S3), 854–859 (2019). https://doi.org/10.35940/ijrte.B1160.0782S319

APPENDIX

For creating the SUMO simulation configuration file, we type the codes in a note pad and saved it as a configuration file. The code used is

```xml
<configuration>
  <input>
        <net-file value="test.net.xml"/>
        <route-files value="test.rou.xml"/>
  </input>
  <time>
        <begin value="0"/>
        <end value="900"/>
  </time>
</configuration>
```