An Approach to Tackle Urban Congestion and Vehicle Emission by Manipulating Transport Operations and Vehicle Mix

Sudeshna Mitra and P. Krishna Pravallika

Abstract Emission from motorized vehicles is a major source of air pollution in urban areas. However, it varies significantly with vehicle technology, type of fuel used, operating conditions, vehicle mix, etc. Understanding the relationship amongst congestion levels in terms of Level of Service (LOS) policies, emission levels and traffic compositions is important for effective policy development for pollution reduction. This study adopted an integrated optimization model to understand this complex relationship with the help of suitable performance indices considering total emissions, fuel consumption, vehicle delays as well as capacity utilization of an intersection in Kolkata, India. SYNCHRO, a transportation operational analysis program is used to develop all the possible LOS thresholds. Twelve different traffic compositions are considered by modifying the share of vehicle categories. Emission inventories are generated using MOBILE, SYNCHRO and CRRI methods of emission calculation. To validate the emission inventories developed from these models, concentrations of the two major pollutants, Suspended Particulate Matter (SPM) and Oxides of Nitrogen (NO_x) are collected from the intersection site using High Volume Air Sampler. Estimation of emission for base case by MOBILE yielded closest results with that of actual emissions estimated by the High Volume Air Sampler at the site. While comparing the performance indices, for the Kolkata intersection, LOS B is found to be the most effective operating point for combined emissions, fuel consumption and traffic congestion (delay at the intersection) point of view. There is also evidence that reduction in emission is associated with decreased share of motorcycles.

Keywords Urban congestion · Vehicle emission · Operating condition · Vehicle mix · Emission at urban intersections

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1 Introduction and Background

Road transportation consumes a major share of the total energy used by the transport sector. In developing countries motorized vehicles primarily use fossil fuel, thereby significantly contributing towards air pollution. The principal pollutants from the transport sector responsible for adverse health effects include lead, various types of particulate matter, oxides of nitrogen (NO_x), volatile organic compounds (VOCs), carbon monoxide, ammonia and sulphur dioxide. However, the proportion of these various pollutants depend on a number of factors, including vehicle technology, quality of fuel as well as the driving conditions. When countries go through an economic growth, there will always be a growth in vehicular traffic. Recently in India, similar trend is seen and the growth of vehicular traffic on roads has been far greater than the growth of the highways; as a result the main arteries in small and major cities are facing capacity saturation leading to increased delay, congestion and air pollution. As mentioned by Ramachandra and Swetmala (2009) the transport sector in India consumed about 16.9 % (36.5 million tonnes of oil equivalent) of total 217 million tones of energy in 2005–2006. Major share of this energy demand is satisfied by sources such as coal and fossil fuel (diesel and petroleum) resulting in vehicular emission and air pollution. According to TEDDY, India (2006) road transport; rail and air transport are responsible for 80, 13 and 6 % of total emissions respectively. In addition, vehicular emissions account for about 60 % of the greenhouse gas (GHG) from various activities in India (Patankar 1991).

It is a fact that between year 1951 and 2002 the vehicle population in India grew at a compound annual growth rate (CAGR) of close to 11 % compared to CAGR of 4.3 % in total road length. Composition of vehicle population in India in the year 2004, the latest year for which the data is available, reveals preponderance of motorized two-wheelers (M2W) with a share of more than 71 % in total vehicle population, followed by cars with 13 % and other vehicles (a heterogeneous category which includes 3 wheelers, trailers, tractors etc.) with 9.4 %. As the M2W vehicles are used intensively due to affordability as well as ease in manoeuvrability in congested and narrow roads, the problem of local air pollution is increasing rapidly due to their highly polluting two-stroke engines.

While there are many ways to reduce road transport related air pollution, the common measures in practice are fuel quality improvement, use of alternative fuels, improvement in vehicle technology, traffic management and control strategies as well as travel demand management through innovative policies. In his study Badami (2004) took an approach of ‘‘value-focused thinking’’ for policy-making related to this complex problem of congestion and vehicle emission with specific reference to motorized two-wheelers. He chose this particular vehicle type since they play an important role in transport air pollution but also provide affordable mobility to millions of Indians with few other attractive options. Using a multi-objective framework, he concluded that primarily three different approaches such as catalytic conversion, vehicle engine technologies, and fuel and oil quality improvements would likely satisfy objectives related to M2W vehicle emissions.

There is also substantial research available on the impacts of transportation improvements on traffic flow and demand. However, most of the literature does not evaluate these impacts on emissions. Studies focusing on the effect of traffic operational characteristics on vehicular emission are limited. In a paper by Cobian et al. (2009) a travel demand forecasting model was developed for Grover Beach, California (CA). The outputs from planning model such as the demand in terms of number of trips by modes were analyzed in emission models to determine the relationship between the target LOS thresholds and emissions produced. The network was modeled for both roadway link LOS and intersection LOS conditions. For roadway links, the overall lowest amounts of emissions were released at the LOS B threshold and the greatest incremental decrease in emissions occurred between LOS D and C. At intersections, the lowest emissions point was LOS A and the largest incremental decrease occurred between LOS D and C. When considering the feasibility of implementation of LOS thresholds, LOS C was determined to be the most effective operating point for emissions. Pandian et al. (2009) did a comprehensive review of existing literature to examine traffic and vehicle related factors influencing vehicular emissions near intersections. They pointed out the fact that most studies found vehicular exhaust emissions near traffic intersections were largely dependent on fleet speed, deceleration speed, queue time in idle mode with a red signal time, acceleration speed, queue length, traffic-flow rate and ambient conditions. However, they concluded that traffic flow, vehicle and road characteristics have profound effect on vehicular emissions at urban intersections. For example, they concluded that cars contribute more to CO emissions whereas heavy-duty vehicle emits more PM, while two-wheelers contribute to HC and NOx emission. This is an important finding since it has strong influence on total emission and would vary with vehicle mix. Most studies have also concluded that older and vehicles with more mileage are associated with increased vehicular emissions. Vehicle emission also varies by a vehicle make and engine capacity; and generally speaking CO emissions reduce with higher engine capacity. Fuel use is influenced by vehicle size and weight, which also influence higher CO2 emissions. The emission of other pollutants typically, but not always, increases by size and weight (Kim 2007). Finally, vehicle load often increases the fuel consumption and produces more emissions for a given vehicle on an individual basis or for groups of vehicles on an average basis.

Two other studies by Gokhale and Khare (2004) and Gokhale and Pandian (2007) focused on the relationship of traffic flow and emission at urban intersections. They used simple semi-empirical box models for traffic intersection based on routinely available traffic flow information and meteorological data. With these they predicted an hourly average CO concentration. However, a major limitation of the work is consideration of traffic flow-density relationship at intersections rather than delay, which is more appropriate for such locations. This is due to the fact that at intersections, idle emission due to delay should be of interest and vehicle speed is not an important factor in deciding emission at intersections. Sturm et al. (1997) and Husch (1998) suggested use of SYNCHRO, a macroscopic traffic simulation model for compiling emission inventories after suitable adjustments for type of emission. These studies used advance emission models that account for start-up emissions, roadway types etc. by using advanced MOBILE6 model. These models have the capability to account separately for startup emissions and running emissions and are better to be used for more realistic estimation. While absolute value of emission using such models may vary based on location of study due to fuel quality, results from these models provide strong basis at least for comparison purpose across various scenarios.

Based on the literature review it is evident that there are some studies that focus on estimation of vehicular emissions based on traffic flow rate and speed data. There is also some evidence that vehicle type is given importance in estimation and finding ways to reduce emission. However, there is a few, if not any, studies that focused on intersection level traffic operational characteristics, vehicle composition and their implications on emission to form suitable operating policies. For example, it is possible that certain vehicle mix at certain operating condition will result in lowest emission. Also, increase in certain vehicle types will increase emission to a higher rate than at certain operating conditions. With these in mind, it is considered important to understand the effects of LOS policies i.e. congestion levels, and vehicle mix on emission levels in order to take a step towards policy formation for reduction in emissions and delay at intersections—where pollution is generally very high due to idle emission. This study focuses on an approach by showing how urban traffic congestion and vehicle emission are interrelated and how the problem may be tackled by manipulating traffic operations and traffic composition in mixed traffic condition. The work is demonstrated with a case study from urban India. Comparisons are done by changing both traffic compositions as well as level of congestions to check if there exists a most effective traffic composition and operating condition that will lead to lowest emission. A performance indicator is also developed by considering the effect of congestion through the measure of level of service (LOS), pollutant emissions and fuel consumption for each traffic composition. The interrelation between major players of vehicle related air pollution provides insight about the complexity of the problem and helps us formulating effective policies to reduce air pollution from transport sector. In summary the objectives are:

- To establish a direct correlation with congestion level and emission i.e. to explore the relationship among (1) traffic composition, (2) LOS and (3) emission and
- To compare the impact on emission for various vehicle composition and congestion level (LOS) in mixed traffic.
- To determine the most effective operating policy in heterogeneous traffic.

2 Methodology

There are two broad ways by which emission inventories may be obtained from a road network or intersection. They are either by using empirical or semi-empirical models, or by analyzing air samples from the location of interest. In this study both methods are used. For data collection a signalized intersection in Kolkata, India was selected. At this location, traffic volume counts, signal timing and delay experienced by the vehicles are obtained for a week during peak and off-peak time. Using High Volume air Sampler (HVS), emission inventories are also collected at the site. These air samples are analyzed and utilized to compare with emission estimation from the empirical models. A total of three different empirical emission estimation models—MOBILE, SYNCHRO and CRRI are used for this purpose acknowledging their advantages and disadvantages. Results from these models are compared with the data obtained at the site, to identify the operating condition that matches closely to real data and has been considered as the base case. While it is anticipated that the estimates from these three models will vary significantly due to their underlying assumptions, the main purpose of this study is to capture the effect on vehicular emission due to modification in operating conditions and vehicle mix. As a result the incremental change rather than the absolute values are of importance for this study. With this in mind, all the above mentioned emission software are used, even though the first two were developed in the USA. CRRI method was developed by Central Road Research Institute of India and by far is the only available emission estimation model for India. The steps followed in this study are given below.

2.1 Traffic Data Collection

The first step of the study was to perform traffic volume count at intersections. For this purpose counts are taken for three different time periods viz. morning peak hour, evening peak hour and off peak hour. Vehicles are classified in five broad categories such as cars, HV/Trucks and buses, Auto Rickshaw (AR) (motorized three-wheelers), Motorcycles (MC) and Bicycles (BC)/Cycle Rickshaws (CR). In addition to the turning movement data, information about current signal phase, cycle time, startup loss and queue lengths are also measured at the site. A summary of the vehicle mix at this intersection is shown in Fig. 1. The codes 1, 2, 3, 4 and 5 are represented by Cars, HV/trucks, MC, BC and AR respectively.

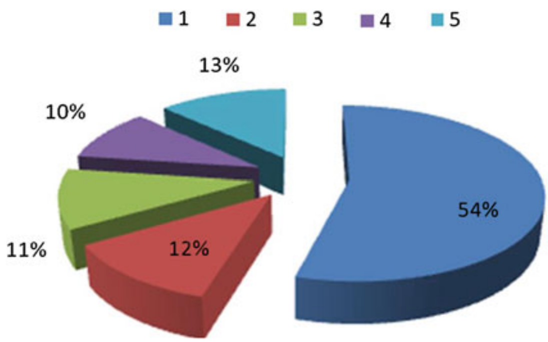

Fig. 1 Observed vehicle mix at an Intersection, Kolkata. The codes 1, 2, 3, 4 and 5 represent Cars, HV/trucks, MC, BC and AR respectively

2.2 Emission Measurement with High Volume Air Sampler

High Volume Air Sampler (HVS) is used to find out the concentration levels of Particulate Matter (PM), Oxides of Nitrogen (NO_x) and Sulphur dioxide (SO_2) at the intersection site. Volumetric filtration using a microfiber filter is used to measure PM. Laboratory analysis is carried out by Gravimetric method of weighing the mass of the particles (PM) deposited on the microfiber filter. For measurement of NO_x and SO_2, volumetric sampling of air through a collecting medium at a known flow rate for a specified time was used. Colorimetric method using spectrophotometer was used in the laboratory to analyze these air samples taken at the intersection in Kolkata.

2.3 Dispersion Model

A simple box model is developed based on the study of Gokhale and Pandian (2007) to estimate the dispersions at the intersection. It is assumed that the emissions disperse uniformly in the box, therefore constant throughout the box. The box height refers to the plume height (Z) which is assumed to be 5 m. The dispersion of pollutants emitted with in the box depends upon the meteorological parameters such as wind speed (u, m/s) and direction (θ degrees). The emissions (Q) at the traffic intersection are calculated from the concentration values (C) using the following equation suggested by Dirks et al. (2003).

$$C = \frac{Q}{Z * U * \boldsymbol{Sin\theta}} \quad (1)$$

Vehicle wake factor and background concentration values which are part of the original equation are omitted as the data for these values are not available.

2.4 Emission Calculation by MOBILE

The US Environmental Protection Agency (US EPA) developed Mobile Source Emission Factor Model (MOBILE) a computer program that estimates emission factors for gasoline and diesel fueled highway motor vehicles. The MOBILE emission model was developed based on laboratory dynamometer driving tests for vehicles. The two different versions of MOBILE, MOBILE5 and MOBILE6 differ significantly in their input requirements and the output structures. In this study MOBILE5b is used for estimating running and idle emission factors for pollutants such as CO, NO_x, VOC and HC. PM emissions factors (idle and running) are estimated using MOBILE6.

2.5 Emission Calculation by SYNCHRO

SYNCHRO is transportation operational analysis software for modeling and optimization of traffic signal timings. It implements the Intersection Capacity Utilization (ICU) 2003 method for determining intersection capacity. This method compares the current demand to the intersections ultimate capacity. SYNCHRO also estimates emissions based on fuel consumption, which utilizes various vehicle and fleet characteristics such as cruise speed, total signal delay, vehicle miles travelled and total stops per vehicle etc. Based on inputs on traffic volume, signal timing details, optimal signal timing can be obtained. From this analysis it is also possible to obtain average delay, number of stops, fuel consumption, as well as estimates of CO, NO_x and VOC emissions. The analysis from SYNCHRO provides information on v/c ratio, delay, intersection capacity utilization, intersection LOS and ICU LOS. The SYNCHRO emissions model based on fuel consumption is as follows:

$$F = TT * k_1 - TD * k_2 + ST * k_3 \tag{2}$$

where

$k_1 = 0.075283 - 0.0015892 * S + 0.000015066 * S^2$
$k_2 = 0.7329$
$k_3 = 0.0000061411 * S^2$

and

F fuel consumed in gallons
S cruise speed in mph
TT vehicle miles traveled
TD total signal delay in hours
ST total stops in vehicles per hour

With the fuel consumption known, the emissions produced are determined using the following formulas:

CO F * 69.9 g/gal = Carbon Monoxide Emissions (grams)
NO_x F * 13.6 g/gal = Nitrogen Oxides Emissions (grams)
VOC F * 16.2 g/gal = Volatile Oxygen Compounds Emissions (grams)
F Fuel Consumption (gallon)

2.6 Emission Calculation by CRRI Method

The CRRI method (Ravinder et al. 2010)which is proposed for a road network for the prediction of emissions from automobiles is as follows:

$$E_i = \sum_i (Veh_j * D_j) * e_{ij} \tag{3}$$

where,

E_i is total emission of pollutant i (g/day),
Veh_j is the number of vehicles of type j,
D_j is distance traveled by vehicle type j,
e_i, j, km is the emission factor for pollutant i for vehicle type j (g/km)

CPCB 2000 emission factors are used in this method.

2.7 Traffic Composition and LOS Variation

Since one of the aims of this work is to correlate emission with LOS and traffic composition, the starting point was the base case. It is improved by adding capacity and deteriorated by reducing capacity to get all the possible LOS cases. Once the LOS variation is taken into account and the corresponding variation in emissions is noted, the next task is to check for variation with various vehicle-mixes. Again the starting point for that was the base case vehicle mix and after that various hypothetical vehicle mixes as shown in Table 1. A total of twelve different traffic compositions with varying percentages of three major vehicle categories such as cars, motorcycles and heavy vehicles are considered. After that emission estimation was done for each of these traffic conditions at various LOS to find the combined effect of congestion and vehicle mix.

Table 1 Traffic composition cases

Case	% of Cars	% of MC	% of HV/T
1	10	10	80
2	20	20	60
3	30	30	40
4	40	40	20
5	80	10	10
6	60	20	20
7	40	30	30
8	20	40	40
9	10	80	10
10	20	60	20
11	30	40	30
12	40	20	40

2.8 Integrated Optimization Model

The next step in this study was the development of an Integrated Optimization Model (IOM), similar to Li et al. (2004) where a total of four Performance Indices (PI) have been developed. The functions for optimization are aimed at improving traffic quality by improving the level of congestion, which is measured by LOS and to reduce emissions, fuel consumption and vehicle delays. With the help of PI functions the effect of traffic composition on the emissions and traffic congestion are investigated and demonstrated. Since delay at a signalized intersection is the measure of LOS, it is used as the index of traffic quality whereas the amount of fuel consumption and exhaust emission of vehicles at an intersection are measures of emission and used for calculating the indices. Emissions are either considered as total emissions; or PM and NO_x are considered as two separate indices. Although this was done so that measured NO_x and PM may be used for PI computation, PI_2 and PI_3 should be given priority over the PI_1 and PI_4 since they consider total emission as opposed to emissions from two pollutants only. It is also important to point out that in calculating the indices normalization is very important due to the difference in unit. This is done by taking ratios of each of the parameters compared to the base value rather than the absolute value of the parameter. Different weights are assigned to these ratios to show the significance of a particular factor over the other. The sum of these ratios adds up to 10, i.e. the upper limit of the indices is 10 and this corresponds to the PI value for base case. PIs for other LOS as well as traffic composition may be compared with the base case, which is highly congested and operating presently at the worst LOS. The following are the four PI functions defined in the IOM:

$$PI_1 = \left(\alpha \times \frac{D}{D_I}\right) + \left(\beta \times \frac{CU}{CU_I}\right) + \left(\gamma \times \frac{F}{F_I}\right) + \left(\delta \times \frac{NO_x}{NO_{xI}}\right) + \left(\varepsilon \times \frac{PM}{PM_I}\right) \quad (4)$$

$$PI_2 = \left(\alpha \times \frac{D}{D_I}\right) + \left(\beta \times \frac{CU}{CU_I}\right) + \left(\gamma \times \frac{F}{F_I}\right) + \left(\zeta \times \frac{TE}{TE_I}\right) \quad (5)$$

$$PI_3 = \left(\eta \times \frac{D}{D_I}\right) + \left(\theta \times \frac{TE}{TE_I}\right) \quad (6)$$

$$PI_4 = \left(\iota \times \frac{D}{D_I}\right) + \left(\kappa \times \frac{NO_x}{NO_{xI}}\right) + \left(\lambda \times \frac{PM}{PM_I}\right) \quad (7)$$

where,

D	Intersection signal delay
CU	Intersection Capacity Utilization
F	Fuel consumption
$NO_x = NO_x$	emissions
PM	PM emissions
TE	Total emissions (NO_x, PM, CO, HC and VOC)

α, β, γ, δ, ε, ζ, η, θ, ι, κ and λ are the corresponding weights of the indices having values 3, 1, 2, 2, 2, 4, 5, 5, 4, 3 and 3 respectively.

A simple logic is followed to determine the most effective operating condition that may be implemented for maximum benefit. This is explained as follows:

- If LOS A resulted in the lowest PI values, it was disregarded because for the most part implementing a LOS A policy threshold is not feasible since it requires an unrealistic capacity of infrastructure to be built.
- The point at which the lowest PI is obtained is compared with the point where the greatest incremental decrease in PI occurred. Two scenarios could occur:
- If the points matched, then it is considered as the most effective LOS threshold and would be the targeted operating condition for a particular traffic composition.
- If the points did not match, then the point with greatest incremental decrease in PI is considered the most feasible option and the corresponding LOS would be suggested for a particular traffic composition.
- Once the best operating condition is obtained then the traffic composition needs to be modified to check the effect of different mix of vehicles on emission, fuel consumption and traffic congestion.

3 Results and Discussion

The emission inventories developed using MOBILE, CRRI and SYNCHRO methods are compared to that of HVS method. MOBILE yielded the closest estimate of emissions compared to others. Even then emission estimation from MOBILE resulted in 20 % overestimation and that from CRRI method is

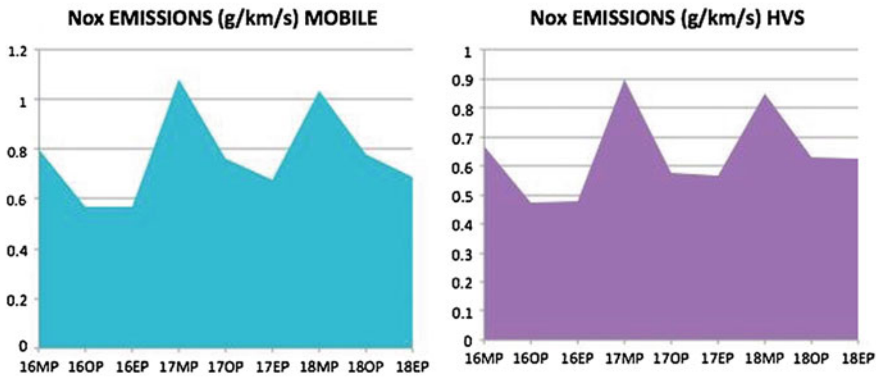

Fig. 2 Comparison of NOx emission from MOBILE and HVS

overestimating more than half of the HVS estimates. On the other hand SYNCHRO underestimated emission compared to HVS. Hence, for modeling purpose MOBILE is used. Figures 2 and 3 show comparison of outputs from MOBILE and HVS. Here it is worth mentioning that HVS provides concentration rather than direct emission. Concentration near road intersection may vary both due to emissions and meteorological characteristics. As identified by Dirks et al. (2003), it is possible to predict the effect on concentration as a result of a 10 % increase in traffic flow for a particular wind speed at a particular time of day. It is also true as identified that the emission rate is not only affected by the increase in the vehicular population but also by constantly changing traffic flow patterns and vehicles' driving modes. In addition, the nature of the vehicular flows also affects the rate and nature of the dispersion of pollutants in the vicinity of the road, influencing the pollutant concentration (Gokhale and Pandian 2007). Hence, it is quite complex to simulate the exact effect even using existing commercial models. As a result, a higher value of error is accepted with the primary objective of comparison of results across various scenarios.

The current or the base operating condition at the Kolkata intersection indicated a LOS of F, during peak hour with cycle failure. The average delay per vehicle was more than 2 min and there were oversaturated queue in all of the approaches except one. To improve this operating condition, hypothetical changes are made in terms of adding more capacities and optimizing the signal timing. After that all of the four performance index values are computed and shown in Table 2 for the existing traffic composition. LOS threshold selection by comparing the incremental changes is also shown in Table 2.

Although the lowest PI values occurred at LOS A, the largest incremental decrease in PI values (by PI_2 and PI_3) occurred between LOS C and B. Considering the feasibility and implementation of LOS thresholds, LOS B is determined to be the most effective operating point when a combined effect of emissions, fuel consumption and traffic operational parameters are considered.

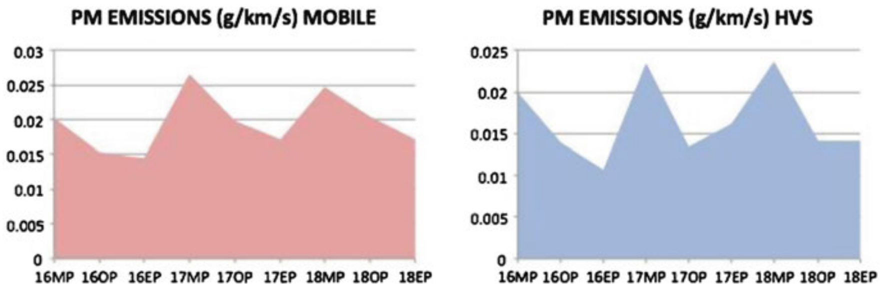

Fig. 3 Comparison of PM emission from MOBILE and HVS

Table 2 LOS threshold selection

ICU LOS	PI function values				Incremental decrease in PI values				LOS Threshold
	PI_1	PI_2	PI_3	PI_4	PI_1	PI_2	PI_3	PI_4	
A	4.195	2.797	2.312	4.675	0.431	0.521	0.508	0.353	A
B	4.626	3.318	2.82	5.028	1.626	2.038	2.273	1.576	B
C	6.252	5.356	5.093	6.604	0.675	0.849	0.941	0.65	C
D	6.927	6.205	6.034	7.254	0.037	0	-0.189	-0.13	D
E	6.964	6.205	5.845	7.124	0.709	0.892	0.989	0.683	E
F	7.673	7.097	6.834	7.807	0.808	1.01	1.111	0.771	F
G	8.481	8.107	7.945	8.578	1.519	1.893	2.055	1.422	G
H	10	10	10	10					

Once the PIs are obtained for all of these traffic compositions, they are plotted against a varying traffic composition for a various LOS thresholds.

Since, LOS B yielded best operating scenario it is discussed here in detail. Comparing various traffic compositions for LOS B, and corresponding PI values from Fig. 4, it is clear that case #5, #6 and #4 resulted in the lowest PI values.

It is also observed that no matter what PI criteria is adopted these vehicle compositions results in lower PIs. If LOS is also considered with traffic composition, the general trend observed is an increasing PI with drop in LOS. The traffic compositions for the best cases are as shown in Table 3.

Based on the results the following observations are made:

- It is very surprising that very high percentage of cars—as much as 80 % resulted in the lowest PI. However, when compared with other vehicles it is observed to contribute lesser than heavy vehicles and even lesser than motor cycles.
- PI value of case 9 (10 % Car, 80 % MC and 10 % HV) is the worst case of traffic composition in most of the LOS plans, which shows that MC are worst and contribute the most when the combined effects of congestion, emission and fuel consumptions are taken into account.

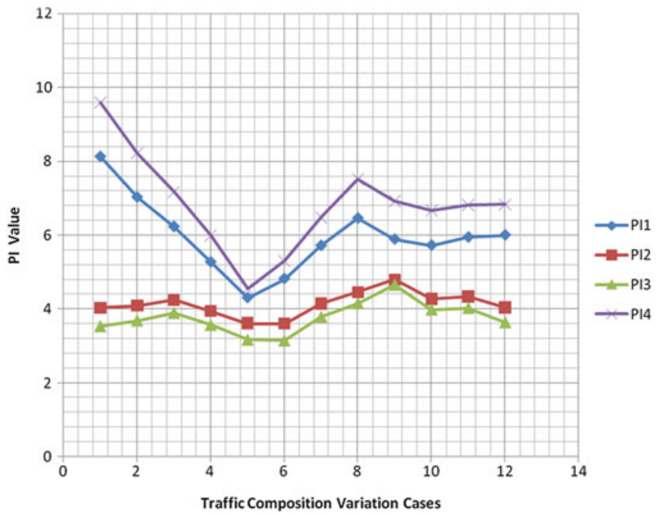

Fig. 4 Variation in performance index with traffic composition for LOS-B

Table 3 Best cases of traffic composition

Case	Car %	MC %	HV/T %
5	80	10	10
6	60	20	20
4	40	40	20

- It is also observed that case 9 is worse than the case 1 (10 % Car, 10 % MC and 80 % HV) where HV are the dominating share. This gives some indication that MC's are more polluting compared to even the HV.
- When cases 5 to 9—where composition of motor cycles gradually increase are closely observed, it is quite interesting to note with increase in MCs there is significant increase in total emissions. This again gives some hint that vehicle emissions greatly depend on MC traffic composition.
- When case 4 (40 % Car, 40 % MC and 20 % HV), case 7 (40 % Car, 30 % MC and 30 % HV) and case 12 (40 % Car, 20 % MC and 40 % HV) are compared, it shows that, with 10 % and 20 % shifts of traffic composition from MC to HV, the gain in PI is marginal. Comparisons across these three cases also indicate that keeping percentage of cars constant, small changes in MC and HV share will not result in significant gain in congestion, fuel consumption and emission. However, an important conclusion from this observation is that the total emissions can further be improved if the HV switch to alternative fuels like CNG—which is relatively easy for government to enforce.

4 Conclusions and Recommendations

In this study traffic volume and emission data are collected at a signalized intersection in Kolkata. The emission inventory obtained at the site is validated with that obtained from empirical models. Interrelationship among traffic composition, operational quality in terms of LOS and emission levels are explored. An integrated optimization is adopted to find the best operating condition. Based on the results following conclusions can be drawn:

- In mixed traffic condition, composition of traffic plays an important role for overall performance in terms of traffic operations, fuel consumption and emission.
- From the study of an urban intersection, it is observed that higher share of motorcycles are generally worse than higher share of heavy vehicles, not only from the point of view of pollution, but overall operations and fuel consumption.
- A gradual increase of motorcycle traffic in the traffic composition showed significant increase in total emissions.
- There was also some evidence that with 10 and 20 % shifts of traffic composition from MC to HV, there is no significant increase in total emissions. This indicates that even with increase in heavy vehicles increase in emission is not high.
- It is also observed that the highest share of the heavy vehicle is not as bad as the highest share of motor cycles from the view point of the performance index used in this study. Hence, it may be concluded that a higher share of heavy vehicle would be better from passenger transport point of view, and emissions from such vehicles can further be improved if HVs switch to alternative fuels.

The policy implications and the measures that may be suggested based on the results and observations are as follows:

1. Since MCs are one of the most polluting vehicle categories its usage has to be carefully assessed through better government policies. For example, in small cities where the share of MCs is generally very high, electric MCs may be encouraged through government incentives. Also, a government mandate to upgrade engine type from two-stroke to four-stroke would also help alleviate emissions from MCs.
2. HV, though contribute higher share of emission, it is found to be better than MCs. However, for further improvement, it will be better to convert the heavy vehicles mainly the trucks and public buses to alternative fuels like CNG. Innovative policies in terms of tax benefits may be an effective incentive to trucking companies who use alternative fuels over traditional fuels. This will be successful only through effective government intervention.
3. Last but not the least, it is clear from this study that a better public transport infrastructure will result in improved carrying capacity by reducing personal vehicle usage, reduction in congestion as well as overall emission.

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