Nature Environment and Pollution Technology
An International Quarterly Scientific Journal

p-ISSN: 0972-6268
e-ISSN: 2395-3454

Vol. 19 No. 1 pp. 93-101 2020

Original Research Paper Open Access

Real World Driving Dynamics Characterization and Identification of Emission Rate Magnifying Factors for Auto-rickshaw

Arti Choudhary*†, Pradeep Kumar, Manisha Gaur*, Vignesh Prabhu***, Anuradha Shukla* and Sharad Gokhale******

*Transport Planning and Environment Division, Central Road Research Institute, New Delhi, India
**Department of Physics, Institute of Science, Banaras Hindu University, Varanasi, India
***Centre for Study of Science, Technology & Policy, Bengaluru, India
****Department of Civil Engineering, Indian Institute of Technology, Guwahati, India
†Corresponding author: Arti Choudhary

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 07-05-2019
Accepted: 21-06-2019

Key Words:
Urban traffic flow
Traffic congestion
Vehicular emission
Speed-time factor

ABSTRACT

Most urgent transport related problems in India are traffic congestion and concomitant air pollutant emissions. During traffic flow, the common causes of congestion in urban centres are pedestrian interruption, unregulated traffic signals, unregulated bus stoppages and unauthorized roadside parking, which together, particularly during peak hours, create erratic traffic pattern causing higher emissions. In this study, we characterized auto-rickshaw driving dynamics by instantaneous measurements of speed and emission at different times of the day. Traffic speed is an important factor that is perceived by commuters. The speed variables and traffic volume are used as a base variable to examine the traffic flow patterns. The speed variables such as average speed (AS), velocity noise (VN, standard deviation of speed), and the coefficient of variation of speed (CV, the ratio of VN and AS) were examined with respect to traffic volume. The polynomial fit of CV shows three distinct zones of variations with increasing traffic volume, explaining the dynamics of traffic flow. Further, time, speed and mileage variable were investigated for the emission rate analysis in different traffic flow pattern. The analysis depicted that the combined factor of lower speed (speed ≤12 km/h) and higher time of travel in correspondence cause higher emission rate. Similarly, vehicle mileage of ≥52,000 km has significant impact on emission for pollutants CO, HC and NOx. The results provide real-time information on traffic flow characteristics and impacts of dynamic and age variables on emission rate in on-road driving condition, which may be useful for the public and transport related agencies.

INTRODUCTION

Road traffic is one of the primary sources of air quality deterioration (Gulia et al. 2015). Due to increasing urbanization and economic development, number of trips per day are increasing (Guttikunda & Mohan 2014). Urban streets are characterized as intense roadside development and intense traffic density at access point of signalized intersection, no lane discipline that cause frequent interruption and congestion (Asaithambi et al. 2016, Choudhary & Gokhale 2019a). These conditions result in higher traffic conflicts. The speed of vehicles on urban streets is influenced by three main factors, street environment, interaction a.m. Ong vehicles, and traffic control (Mohapatra 2012). As a result, these factors affect quality of service (Grote et al. 2016). Traffic flow can be interrupted due to various conditions such as road work, peak hour traffic, accidents, and weather conditions. The pedestrians also create conflicts and lane obstructions created due to stopping or standing taxis, buses, trucks and parking vehicles generates disturbance in traffic-flow. These complex characteristics of urban roadway aid to the development of congestion, like interruption of traffic flow, especially during peak hours it is very significant, causing significant rise of emission (Chen et al. 2007, Choudhary & Gokhale 2019b). Traffic interruption and congestion is a regular phenomenon on urban roads, and it becomes critical at traffic intersections and junctions. It increases commuting time, fuel consumption and cause higher pollutant emissions. Vehicular emissions depend on vehicle speed, vehicle-km, age of vehicle, and emission rate (Pandian et al. 2009). The quantity of major air pollutants, such as NO_x, HC, CO and CO_2 drastically increases with reduction in motor vehicle speeds. For example, at a speed of 75 km/h, emission of CO is 6.4 g/veh-km, which increases by five times to 33 g/veh-km at a speed of 10 km/h (Singh 2012). Problem is aggravated due to high average age and poor maintenance of vehicles.

Auto-rickshaws (the three-wheeler vehicle) are important in the Indian traffic as they are used as an intermediate public transport. They fill a vital niche in developing cities between private vehicles ownership and fixed-route and large-capacity public transit systems (i.e. bus and metro) (Reynold et al. 2009). Auto-rickshaws are the popular mode of private transportation because of the low initial and low running cost (Singh 2006, Reddy & Balachandra 2012, Iyer 2003). Because of its small size it negotiates the smaller streets and weaves through the mixed traffic (Iyer 2003). Different types of auto–rickshaws are found on Indian roads, but the auto–rickshaws of capacity less than 4 persons including the driver, occupy roads are more in number and also have the largest market share, close to 80% (Iyer et al. 2013). Considerable share of auto-rickshaws in Indian traffic fleet and lack of adherence to lane marking (no-lane discipline) are unique and important features. Auto-rickshaw generally undergoes large wear and tear of the engines due to overloading, idling, and operating at less than ideal conditions, and lack of timely engine maintenance (Reynold et al. 2011). In real-word, auto-rickshaws consume 15% more fuel and emit 49% more HC and 16% more $P.M._{2.5}$ (Grieshop et al. 2012). The present study will analyse the real-world driving dynamics of auto-rickshaw and impacts of dynamic variables on exhaust emission rate.

EXPERIMENTAL DESIGN

A highly trafficked stretch of an urban traffic corridor in Guwahati was selected for the study. This road segment represents typical urban traffic-flow with high traffic volume, mix vehicles, no-lane discipline, frequent interruption and congestion due to interaction with pedestrians and vehicles. The test-run was of 4 km long, double lane, of 16 m wide each. The road segment does not have traffic lights and both the lanes are heavily trafficked, particularly, during peak hours. Field work was carried out to collect traffic volume data, tail-pipe instantaneous emission data of the test vehicles (auto-rickshaws) along with the driving profile. The traffic volume count was done with a video camera recording. It was done for a full week, each day twelve hours from 7 a.m. to 7 p.m. The videotapes were analysed manually for a 100 m stretch on the road. Such method has also been followed by Robertson (1994). The traffic count data were analysed to determine traffic-flow patterns and traffic composition. The videotapes analysis revealed that traffic volume, commercial activity, and roadside parking on the both lanes were similar. The traffic composition was classified into four categories- two-wheelers (scooters, motorbikes and moped; 2W), three-wheelers (auto-rickshaws; 3W), four-wheelers (cars, jeeps and medium-utility vehicles; PC-MUV), and light-heavy commercial vehicles (bus, minibus and small trucks; LHCV). The speeds were estimated for each category vehicle for 5 min travel time.

The real-world measurements of instantaneous speed, acceleration, and deceleration and tail-pipe emissions of auto-rickshaws were measured with an auto-gas analyser and a V-Box. Different mileage test vehicles were selected, each test vehicle was run at three different times of the day to capture the real characteristics of the range of speed and acceleration, deceleration of urban traffic. During each time, test-run was repeated to produce at least two sets of data and each run lasting for 25 to 45 min depending upon the traffic on the road. Tests were carried out during 7:00-8:30 a.m., which is an off-peak time, during 10:30-11:30 a.m., which covers the morning peak time and 4:30-5:30 p.m., which covers the evening peak time. These time periods are described as off-peak hours (OPH), morning peak hours (MPH) and evening peak hours (EPH) respectively. Thus, collected data were analysed for the traffic composition, traffic flow pattern analysis, correlation of speed, time of travel and mileage with the emission. The detailed methodology of data analysis is described by Choudhary & Gokhale (2016).

RESULTS AND DISCUSSION

Traffic-Flow and Traffic Composition

The traffic-flow on working days exhibits a typical trend with two peaks, around noontime and in the evening. The lowest traffic was observed during 7-8 a.m. and higher traffic during 10 a.m.-12 noon and 4-7 p.m., however, the traffic composition changed every hour, especially the proportion of two-wheelers and three-wheelers. Fig. 1 shows the hourly variation of traffic-flow of different category vehicles on working days, averaged from Monday to Friday. Table 1 shows the descriptive statistics of hourly traffic volume and traffic speed for working days. The positive value of kurtosis coefficient of hourly traffic volume indicates that data distribution has heavier tails and a sharper peak than the normal distribution and the negative value of skewness of traffic volume suggest that distribution is toward left, whereas traffic speed data is slightly skewed toward right. It has been observed that about 87% of the total traffic was comprised of two and four-wheelers (2W+PC–MUV) followed by 9 to 10% of three-wheelers (3W) and mere 3 to 4% of buses (LHCV). During the OPH, PC-MUV and 2W shared 52% and 28%, respectively, while during the PH, it was observed to be 34%, and 53%, respectively (Figs. 2d, e, f).

Table 1: Descriptive statistics for hourly traffic composition and traffic fleet speed.

Descriptive Parameters	Working days	
	Hourly traffic volume (veh/h)	Hourly traffic speeds (km/h)
Mean	7676.0	33.5
Std. error	621.4	3.2
Median	8245.0	32.2
Std. deviation	2152.4	11.1
Sample variance	4632925.8	123.9
Kurtosis	2.4	0.4
Skewness	-1.8	0.9
Minimum	2591.0	19.7
Maximum	9368.0	57.5
Count	12	12

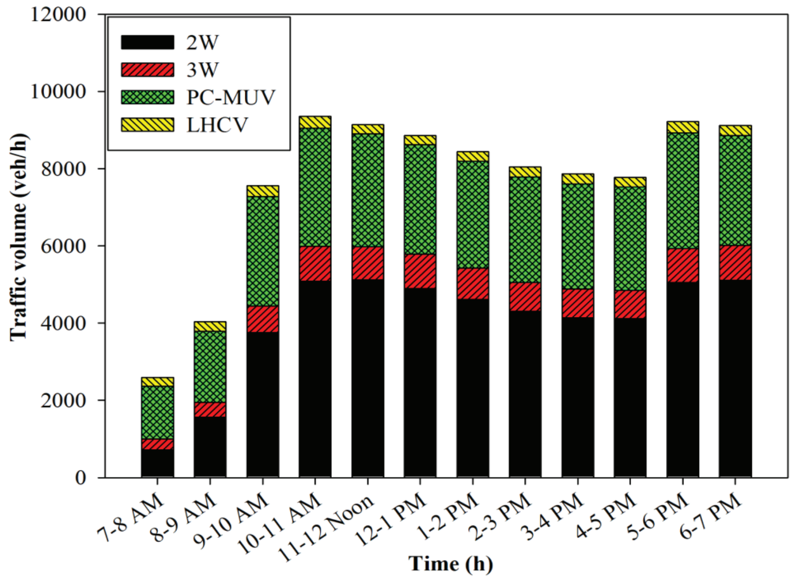

Fig. 1: The hourly variation of the proportion of traffic composition for working days (average of Monday to Friday).

Traffic-Flow vs Speed

Traffic speed and volume are two important characteristics, which directly affect the traffic-flow on roads (Anjaneyulu & Nagaraj 2009). Therefore, the time variation of speed due to traffic volume has been used to describe and define the traffic–flow patterns. The videotapes were analysed for traffic volume (veh/5 min) and traffic speed (km/h) analysis were done for defining the various traffic-flow patterns. Three descriptive statistics were used to represent the relationship, viz.-average speed (AS) in km/h; velocity noise (VN) a standard deviation of speed in km/h and the coefficient of variation of speed (CV), the ratio of VN and AS. Fig. 3-I (a, b, c) shows the relationships of-AS, VN and CV with traffic volume (veh/5 min) in which the minimum volume suggests the free-flow condition and higher volume suggests the density near roadway capacity. As the traffic volume increased, the AS decreased and VN and CV increased, which after reaching the volume of about 400, dropped continuously indicating the higher level of vehicle to vehicle interactions, which further increases.

As traffic volume increases, the interaction between the vehicles increases, i.e. the speed of a vehicle is affected by the vehicles plying together with it, which results in the increase of variation in the speed, as has been observed from the sharp rise in CV and VN. Further, increase in volume forces a vehicle to reduce its speed. In this condition, fluctuation

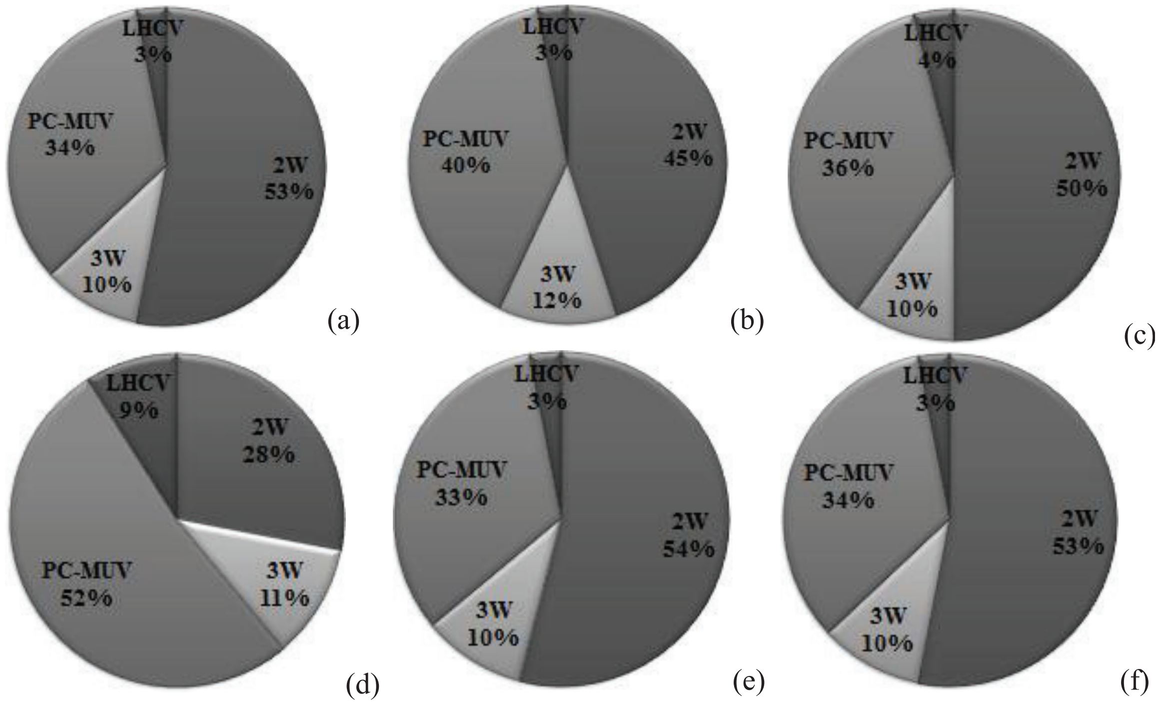

Fig. 2: The vehicle composition for (a) working days, (b) non-working days (c) a whole week, (d) morning off-peak 7-8 a.m., (e) morning peak, 10 a.m. to 12 noon, and (f) evening peak, 4-6 p.m.

in average speed is less, which decreases the standard deviation and decreases the ratio of VN/AS. Thus, these three characteristics (AS, VN and CV) together with traffic volume describe the three different traffic-flow conditions.

1. Traffic-flow condition 1: Shows slow increase in CV and VN at lower traffic volume and higher traffic speed.
2. Traffic-flow condition 2: Shows sharp increase in CV and VN with increasing traffic volume and decreasing traffic speed.
3. Traffic-flow condition 3: As traffic volume approaches to near roadway capacity CV and VN decrease sharply that forces vehicles to crawl.

The Fig. 3-II shows the best polynomial fits to the AS, VN and CV, which distinguish the traffic-flow patterns. The R^2 values were 0.95, 0.96, and 0.97 for AS vs traffic volume, AN vs traffic volume and CV vs traffic volume, respectively. The adjusted R^2 values were 0.94, 0.95 and 0.96 for AS vs traffic volume, AN vs traffic volume and CV vs traffic volume, respectively. The three distinct zones have been identified from the CV and traffic volume relationship by taking tangents at the points of inflection, which resulted into two break points classifying into three distinct levels of traffic-flow (Anjaneyulu & Nagaraj 2009). It has been observed that the speed characteristics show distinct zones with the increasing traffic volume. The best polynomial fits of AS, VN and CV with traffic volume show three distinct zones marked as Level 1, 2 and 3 based on speed gradient. The Level-1 represents the free-flow condition in which initially the traffic volume is less, the vehicular speed is more and the variation of speed (CV) is low indicating the least vehicle to vehicle interaction. As the traffic volume increases the CV sharply increases. This represents Level-2 in which a higher fluctuation in speed occurs due to phase transition from free-flow to random stop-and-go. The frequent stop-and-go causes higher deviation from mean speed and, therefore, a higher CV is observed. The Level-2 represents the interrupted traffic-flow condition. After this, vehicle to vehicle interaction increases and traffic volume approaches to roadway capacity, which forces the vehicles to crawl, leading to the decrease of CV. This represented the congested-flow condition, Level-3.

Travel Time and Speed vs Emission

The vehicular exhaust is influenced by many operating variables of which particularly important in urban driving are, speed, period and number of sharp acceleration and deceleration, number and time of the stop-and-go pattern (Faiz et al. 1996). The air to fuel ratio also changes with mode of operation, for example, whether it is cruising,

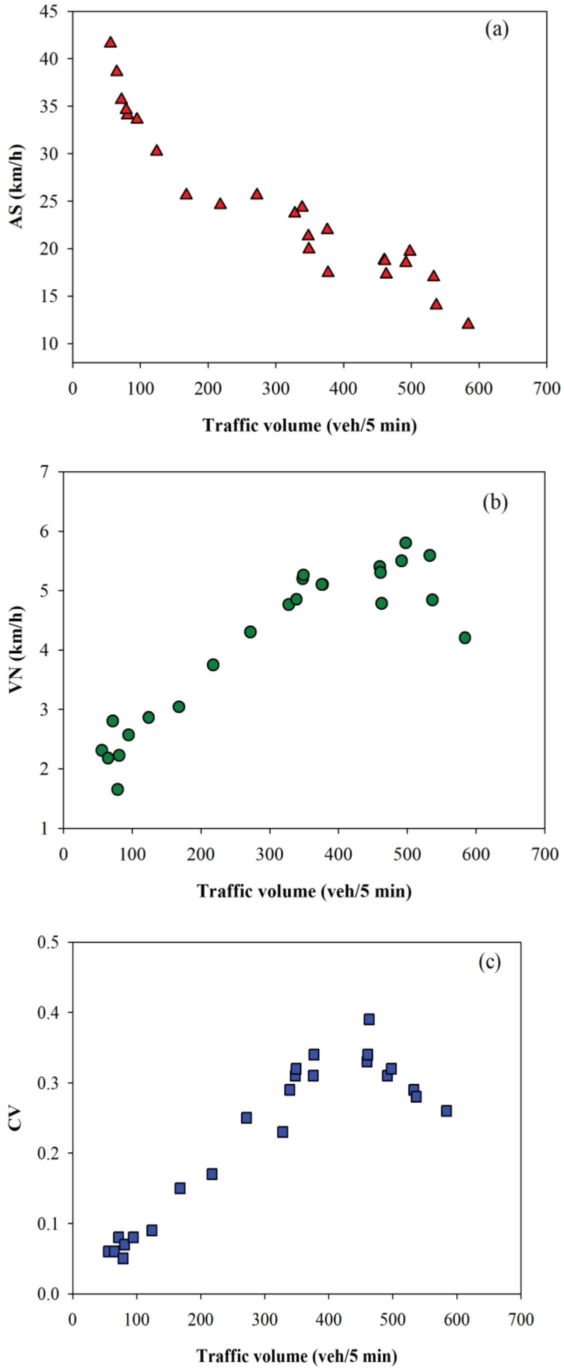

Fig. 3-I: Relationship of traffic volume and speed for the test runs.

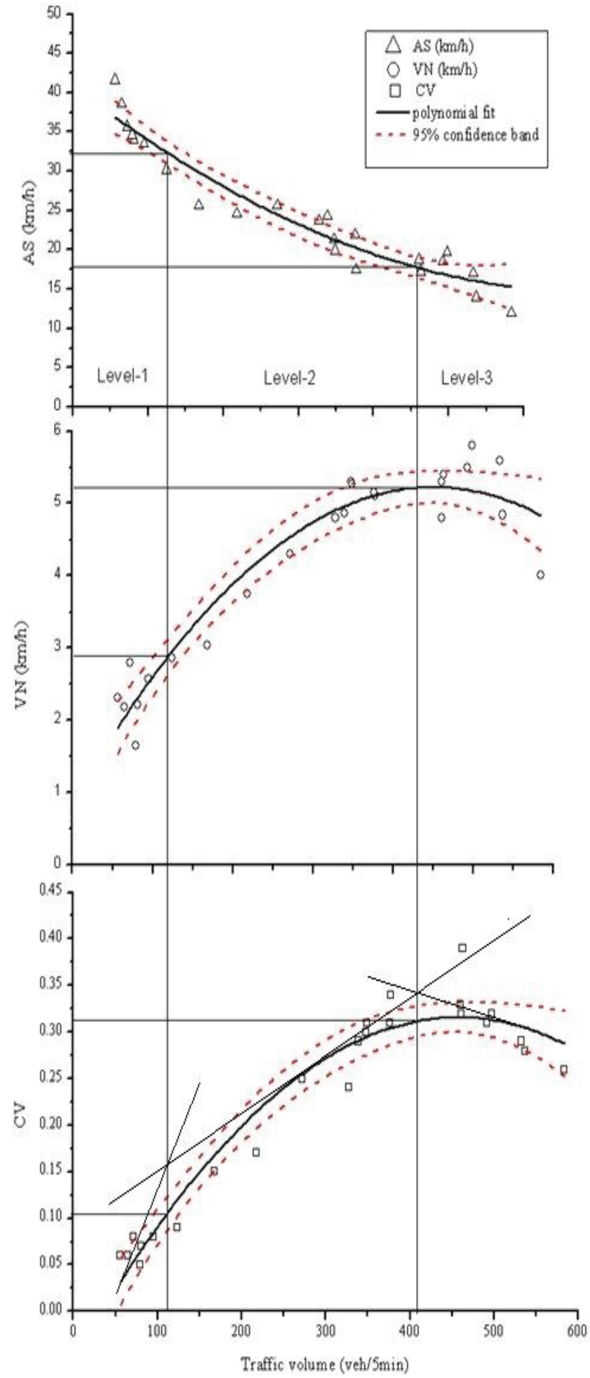

Fig. 3-II: Different levels of traffic-flow patterns observed in the test runs.

accelerating, decelerating or idling (Joumard 1999, Marsden 2001). In this study, travel time during PH was increased more than twice the travel time of OPH due to reduction in operating speed. The operating speed directly affects the vehicular exhaust emissions. Therefore, the relationship of exhaust emissions in different traffic-flow conditions corresponding to the travel time spent in those conditions for the span of 60s has been analysed for a period of 10 minutes of the test-runs. Fig. 4 shows the correlation of travel time and corresponding emission for 10 consecutive minutes of test-run for auto-rickshaw in different traffic-flow patterns respectively. The one stacked bar represents the span of 60s/

minute, so total 10 stacked bar, each representing one minute, were analysed (Fig. 4). The stacked bar colours indicating the different traffic flow patterns and the height of stacked bar depicting time spent in each traffic flow patterns. To study the correlation of operating speed and corresponding travel time, the vehicle speed categorized into 0 – 2 ± 2, 3 – 15 ± 3, 16 – 30 ± 3 and above 31 ± 3 km/h corresponding to idle–flow, congested flow (CF), interrupted flow (IF) and free-flow (FF), respectively. It was found that during the test-run auto-rickshaws travelled for over 80% of the time in the speed range 10-30 km/h.

Fig. 4 also depicting the emission rate of CO, HC, NO_x and CO_2 corresponding to different traffic-flow patterns and time spent in particular traffic-flow. It has been observed that the magnitude of emission rate in auto-rickshaw is higher due to longer time of travel and lower operating speed for the pollutants CO and HC. The emission rate of NO_x significantly increased for speed of > 30 km/h but did not show any effect for time of travel. The magnitude of CO_2 emission rate was found higher for IF condition as compared to the combination of higher travel time and lower speed.

Combined Effect of Speed-Time on Emission Rate

To determine the combined effect of travel time and associated speed on exhaust emission, a speed-time spent factor, which is a multiplication of average speed of particular speed interval and the time spent of that traffic flow, was used. Details of speed-time spent factor are tabulated in Table 2. The Fig. 5 shows the relationship of pollutants emission rate with the speed-time spent factor for auto-rickshaw. It was observed that CO, HC and CO_2 emission increase as the speed-time factor increases. It indicates that the speed at which vehicles run and the time they spend directly affects the emission rate. However, the emission of NO_x shows opposite trends; has higher emission for combination of higher speed and lesser time spent and similarly very low emission was observed for combination of lower speed and higher time spent.

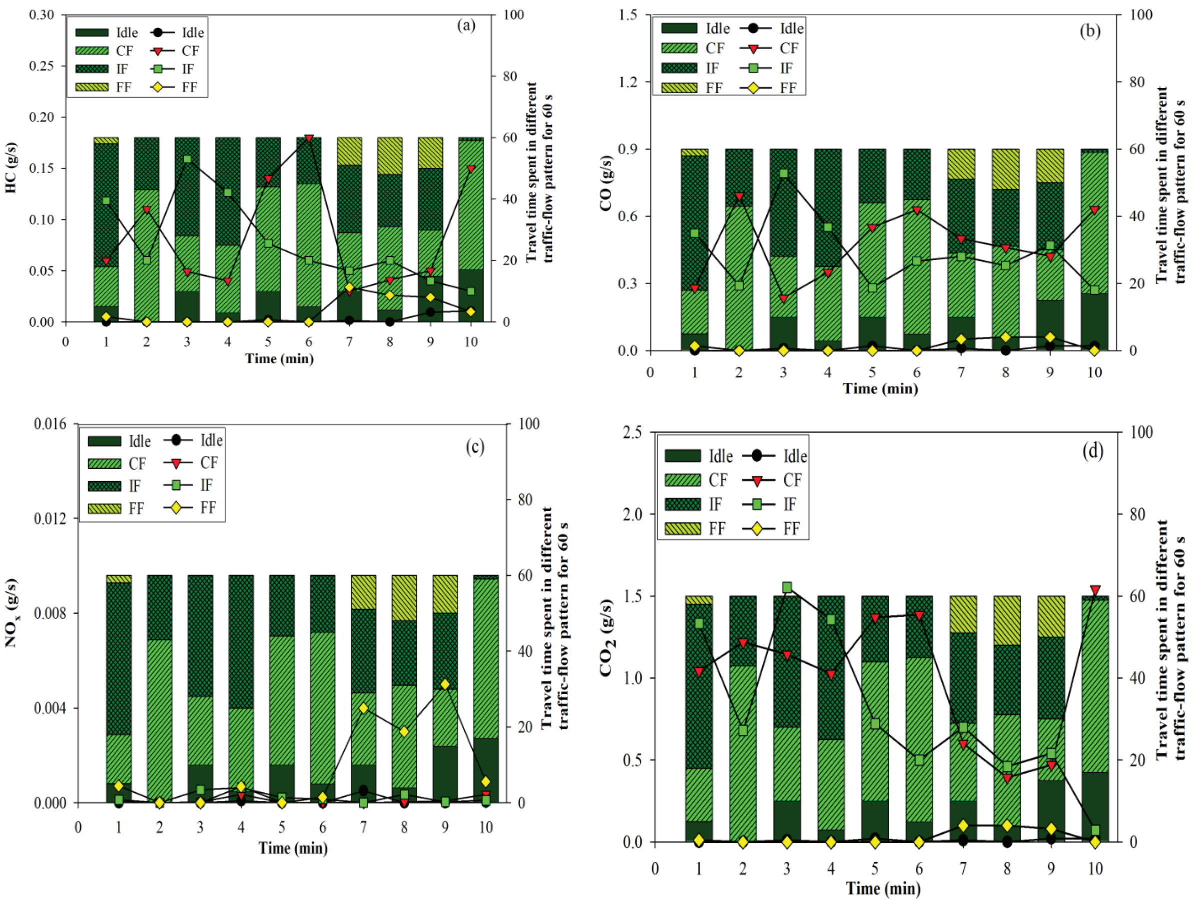

Fig. 4: The variation of pollutants emission in different traffic-flow pattern corresponding to time spent in each traffic-flow pattern during pH in auto-rickshaw.

Table 2: Speed-time factor analysis.

Speed range (km/h)	Speed (m/s)	Frequency	Factor (V*frequency)	HC (g/s)	CO (g/s)	NO_x (g/s)	CO_2 (g/s)
0-5	0.72	69	49.68	0.004	0.052	0.020	0.599
5-10	2.14	60	128.40	0.009	0.121	0.013	1.601
10-15	3.50	83	290.50	0.008	0.149	9.00e-3	1.698
15-20	4.82	81	390.42	0.010	0.192	7.20e-3	2.422
20-25	6.24	84	524.16	0.014	0.158	1.21e-3	2.256
25-30	7.51	49	367.99	0.012	0.174	9.21e-4	3.273
30-35	9.03	36	325.08	0.010	0.171	1.92e-4	3.000
35-40	10.35	27	279.45	0.012	0.147	5.00e-4	2.536

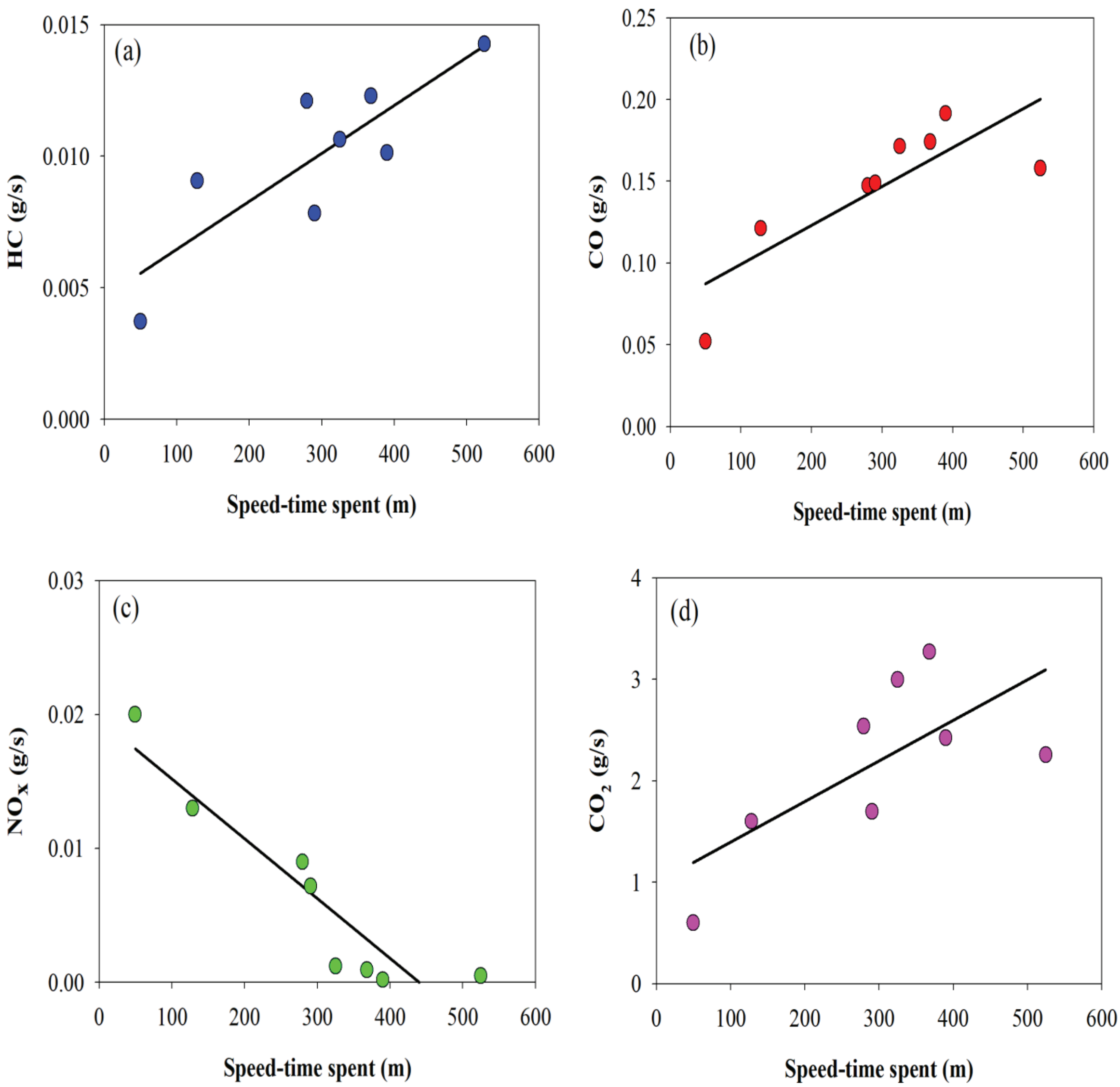

Fig. 5: The relationship of speed-time spent with the emission of pollutants (a) HC, (b) CO, (c) NO_x and (d) CO_2.

Table 3: The Tukey-Kramer emission-mileage matrix.

Test Vehicles		Test vehicle mileage		
		9,200 km	52,000 km	142,000 km
Test vehicle mileage	9,200 km	-	CO, HC	CO, HC, NO_x
	52,000 km		-	CO, HC, CO_2, NO_x
	142,000 km			-

Table 4: Summary of mean emission values ANOVA analysis.

Test vehicles	Mileage in km	CO (g/s)	HC (g/s)	NO_x (g/s)	CO_2 (g/s)
	9,200	0.12	0.0002	0.0006	9.50
	52,000	0.17	0.002	0.0005	5.18
	142,000	0.22	0.012	0.018	8.40

Mileage vs Emission

The vehicle mileage is another factor that determines the amount of emissions from a vehicle (Ntziachristos et al. 2000). The one-way ANOVA analysis was used to analyse the effect of mileage on exhaust emission. The completely randomised single-factor analysis of variance test (ANOVA) was applied to identify the statistically significant effects of vehicle mileage on emissions (Ntziachristos & Samaras 2000). Using this test, the average emission values of different mileage classes of test vehicles were compared to find any statistically significant differences between them (rejection of the null hypothesis of equal means). With the Tukey-Kramer emission mileage matrix (Barnes 1994), correlation of mileages with different mean values can be revealed. The double input matrix in Table 3 presents the results of this procedure. The cells of the matrix correspond to pair-wise comparison of different mileage classes of test vehicles found in the same row and column of the cell. This matrix has been built with 189 observations for auto-rickshaws. According to these results, it has been observed that for 52,000 km and above, mileage has significant impact on emission for pollutants CO, HC and NO_x. Summary of the mean emission values obtained from ANOVA for each mileage class is given in Table 4, which leads to the conclusion that there is a statistically significant correlation of CO, CO_2 and HC emissions with mileage.

CONCLUSIONS

Urban traffic-flow governed by many factors which mainly resulted from the poor traffic management, an unregulated roadside parking and a frequent pedestrian to vehicle interaction. These factors restrict the urban mobility and the most severe outcomes of the restricted urban mobility are increased pollutant emissions. The study identified three traffic-flow patterns classified as free-flow, interrupted-flow and congested-flow from the on-road traffic volume and traffic speed. The variable composition of vehicles on road governs the rate of exhaust emissions. The dynamic and age-related variables such as, time, speed and mileage were analysed for analytically categorized traffic-flow patterns. The analysis depicted that the combined factor of lower speed (speed ≤12 km/h) and higher time of travel cause higher emission rate, especially for pollutants HC and CO. NO_x emission is higher with increasing speed irrespective of time of travel. The magnitude of CO_2 emission rate mostly found higher for interrupted flow condition as compared to the combination of higher travel time and lower speed. Similarly, vehicle mileage of ≤52,000 km has significant impact on emission for pollutants CO, HC and NO_x.

The effective transport planning and environmental policies depends on the accurate assessment of vehicle exhaust emissions. Therefore, the finding of this study can be handy for the consideration in policy formulation and worthy for differentiation between measured and modelled results.

ACKNOWLEDGEMENTS

Arti Choudhary thankfully acknowledges the financial assistance provided by Science and Engineering Research Board (SERB), New Delhi, India, under the scheme of SERB National Post-Doctoral Fellowship (PDF/2017/001284).

REFERENCES

Anjaneyulu, M.V.L.R. and Nagaraj, B.N. 2009. Modelling congestion on urban roads using speed profile data. Journal of the Indian Roads Congress, 1: 65-74.

Asaithambi, G., Kanagaraj, V., Srinivasan, K. K. and Sivanandan, R. 2016. Study of traffic flow characteristics using different vehicle-following models under mixed traffic conditions. Transportation Letters, 1-12.

Barnes, J.W. 1994. Statistical Analysis for Engineers and Scientists: A

Computer-based Approach. McGraw-Hill, Inc.

Chen, C., Huang, C., Jing, Q., Wang, H., Pan, H., Li, L. and Schipper, L. 2007. On-road emission characteristics of heavy-duty diesel vehicles in Shanghai. Atmospheric Environment, 41(26): 5334-5344.

Choudhary, A. and Gokhale, S. 2016. Urban real-world driving traffic emissions during interruption and congestion. Transportation Research Part D: Transport and Environment, 43: 59-70.

Faiz, A., Weaver, C.S. and Walsh, M.P. 1996. Air Pollution from Motor Vehicles: Standards and Technologies for Controlling Emissions. World Bank Publications.

Choudhary, A. and Gokhale, S. 2019a. Evaluation of emission reduction benefits of traffic flow management and technology upgrade in a congested urban traffic corridor. Clean Technologies and Environmental Policy, 21(2): 257-273.

Choudhary, A. and Gokhale, S. 2019b. On-road measurements and modelling of vehicular emissions during traffic interruption and congestion events in an urban traffic corridor. Atmospheric Pollution Research, 10(2): 480-492.

Grieshop, A.P., Boland, D., Reynolds, C.C., Gouge, B., Apte, J.S., Rogak, S.N. and Kandlikar, M. 2012. Modeling air pollutant emissions from Indian auto-rickshaws: Model develop.m.ent and implications for fleet emission rate estimates. Atmospheric Environment, 50: 148-156.

Grote, M., Williams, I., Preston, J. and Kemp, S. 2016. Including congestion effects in urban road traffic CO_2 emissions modelling: do local government authorities have the right options? Transportation Research Part D: Transport and Environment, 43: 95-106.

Gulia, S., Nagendra, S.S., Khare, M. and Khanna, I. 2015. Urban air quality management-A review. Atmospheric Pollution Research, 6: 286-304.

Guttikunda, S.K. and Mohan, D. 2014. Re-fueling road transport for better air quality in India. Energy Policy, 68: 556-561.

Iyer, N.V. 2003. Three-wheelers take to South Asian streets. Smart Urban Transport, 2(2).

Iyer, N. V., Posada, F. and Bandivadekar, A. 2013. Technical assessment of emission and fuel consumption reduction potential from two and three wheelers in India (No. 2013-26-0050). SAE Technical Paper.

Joumard, R., Philippe, F. and Vidon, R. 1999. Reliability of the current models of instantaneous pollutant emissions. Science of the Total Environment, 235: 133-142.

Marsden, G., Bell, M. and Reynolds, S. 2001. Towards a real-time microscopic emissions model. Transportation Research Part D: Transport and Environment, 6(1): 37-60.

Mohapatra, S.S. 2012. Level of service criteria of urban streets in Indian context using advanced classification tools. M.Tech. Thesis.

Ntziachristos, L. and Samaras, Z. 2000. Speed-dependent representative emission factors for catalyst passenger cars and influencing parameters. Atmospheric Environment, 34(27): 4611-4619.

Ntziachristos, L., Samaras, Z., Eggleston, S., Gorissen, N., Hassel, D. and Hickman, A.J. 2000. COPERT III, Computer programme to calculate emissions from road transport, methodology and emission factors (version 2.1). European Energy Agency (EEA), Copenhagen.

Pandian, S., Gokhale, S. and Ghoshal, A.K. 2009. Evaluating effects of traffic and vehicle characteristics on vehicular emissions near traffic intersections. Transportation Research Part D: Transport and Environment, 14(3): 180-196.

Ramachandra, T. 2009. Emissions from India's transport sector: state wise synthesis. Atmospheric Environment, 43(34): 5510-5517.

Reddy, B. S. and Balachandra, P. 2012. Urban mobility: A comparative analysis of megacities of India. Transport Policy, 21: 152-164.

Reynolds, C. Grieshop, A. and Kandlikar, M. 2009. Measuring auto-rickshaw emission to inform air quality policy. University of British Columbia. Accessed on 5th March 2016, http://indiaenvironmentportal.org.in/files/EmissionTestinginInda.pdf.

Reynolds, C.C., Grieshop, A.P. and Kandlikar, M. 2011. Climate and health relevant emissions from in-use Indian three-wheelers fueled by natural gas and gasoline. Environmental Science & Technology, 45: 2406-2412.

Robertson, H.D. 1994. Queuing studies. In: Robertson, H.D., Hummer, J.E., Nelson, D.C. (Eds.), Manual of Transportation Engineering Studies, Washington, DC, pp. 347-358.

Singh, S. K. 2006. Future mobility in India: Implications for energy demand and CO_2 emission. Transport Policy, 13(5): 398-412.

Singh, S.K. 2012. Urban transport in India: Issues, challenges, and the way forward. European Transport/Trasporti Europei, Issue 52.