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Traffic flow pattern and meteorology at two distinct urban junctions with impacts on air quality

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ABSTRACT

Traffic during operation at a junction undergoes different flow conditions and modal events which result into dynamic fleet characteristics generating more emissions and stronger vehicle-induced heat and wakes generating obscure dispersion. Traffic in a manner operated at junctions often creates pockets of higher concentrations the locations of which shift as a result of the combine effects of traffic dynamics and random airflow. This research examined the impacts of traffic dynamics and meteorology on the levels and locations of higher concentrations of pollutant CO, NO_2 and PM within the influence of signalized traffic intersection and a conventional two-lane roundabout in a response to varying flow conditions and emissions resulted from the traffic operations. Three line source dispersion models have been used to determine the impact on air quality. Emissions have been calculated for different scenarios developed from different combinations of semi-empirical and field based time and space-mean speeds and lane-width based density when traffic undergoes free, interrupted and congested-flow conditions during operation. It has been found that the locations of highest concentrations within the domain change as traffic with different modal share encounters different flow conditions at different times of a day.

1. Introduction

Traffic has increased unprecedentedly in recent times in several developing countries as a result of a rise in incomes and rapid urbanization. Since the growth is mostly centered in urban areas, times for commuting and queuing at junctions have increased by multifold causing more emissions and higher concentrations (Pandian et al., 2009). In particular, at junctions, queuing time has increased unprecedentedly, resulting in more idling emissions and higher pollutant concentrations (Gokhale and Pandian, 2007). In order for traffic flow to remain smooth, different junction types are needed in road networks. Such junctions result in flow interruptions, either vehicle to vehicle or vehicle to pedestrian, producing different modal points generating varying levels of emissions within the junctions as discussed in the study of Coelho et al. (2006). The problems of traffic and associated impacts of different nature are more severe in developing countries due to lack of adequate infrastructures and heavy traffic fleets. Several developing countries have similar traffic operation system and road networks. Traffic system is mostly of non-homogeneous nature in which mixed fleets with all types of vehicles ply together without any strict-lane discipline. Fleets mostly share a large volume of two wheelers. Two-wheeler riders and pedestrians are more prone to exposure to a higher level of concentrations in urban centers (WHO, 2009). The frequency of concentration exceedances over standards has been increased during peak as well as non-peak hours (Gokhale and Khare, 2007). Outdoor pollution exposure assessment particularly in traffic corridors has been of special interest to developing countries in light of the haphazard growth in urban centers and heavy growth in traffic.

Traffic at a junction undergoes different flow conditions due to different modal events (Dirks et al., 2003) and as a result produces vehicle flow dynamics. Traffic of non-homogeneous nature further adds in-homogeneities. A junction with multi-lanes where the continuous vehicular movements in different directions of entry and exit approaches often creates a zone responsible for re-circulating emissions within the realm. In this zone, the normal wind flow is often obstructed due to buildings around the junctions and continuous movement of vehicles. This modified advective transport of pollutants creates complex wind structures, and more effective mixing and recirculation of air. The relationship between wind and concentration becomes less clear and the concentrations of pollutant more spatially inhomogeneous. Beyond this zone, however, these effects diminish and the wind effect dominates once again. Because of this, certain pockets of higher pollutant concentrations are formed at locations where the traffic flows and

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meteorology are conducive to high levels. Higher concentrations may also be observed particularly at places where there is an interaction of vehicle to vehicle or vehicle to pedestrian. The heterogeneity in the vehicle fleet characteristics further complicates this phenomenon. It may therefore be useful to identify the likely locations of higher concentrations under varied meteorological conditions and traffic flow characteristics to make accurate exposure assessments and design monitoring studies for episodic air quality management. Pollutants like CO, NO_2 and PM are primary contaminants found at traffic corridors and junctions. Health effects as a result of exposure to such pollutants are well documented.

The results presented in this research provide emission scenarios under different traffic flow conditions at two distinct junctions and identify the prominent locations of higher pollutant concentrations as an impact of traffic flow which may be useful for exposure and extreme event monitoring studies particularly in developing countries where similar traffic situations and patterns exist.

2. Field work and calculation methodology

Two traffic junctions in two different cities of India, a signalized intersection near Income Tax Office (ITO, Fig. 1a) in New Delhi (28°35′N, 77°12′E) and non-signalized roundabout at Jaluk Bari (JB, Fig. 1b) in Guwahati (26°11′N, 91°44′E) having different climates[1] with a commonality of traffic conditions and operations were selected. Both junctions are heavily trafficked with average daily traffic (ADT) of about 113,000–176,000 at ITO in New Delhi and 55,000 at JB in Guwahati. The dimensions of lanes, entry, and exits are different which result in dissimilar traffic flow characteristics on each specific lane in terms of speed and density, as well as the nature of the mechanical and thermal turbulence produced by the vehicles. The traffic flow rates were measured manually and video recordings were made for analyzing the traffic flows. The traffic counting was carried out for two weeks from between 09:00 and 21:00 h separately for week and weekend days. Other traffic characteristics were analyzed at both junctions with the help of 30 min video tapes, field measurements and observations. Traffic analysis included every minute calculation of space-mean speed which represents the average of time mean speed of individual vehicles passing through a junction or plying on a road, and average fleet speed, approximating fleet average speed by observation when traffic in free representing no-stop condition, interrupted representing traffic flow when a vehicle interacts with other vehicles or pedestrian obstructing a smooth free-flow, kind of stop-and-go condition and congested-flow conditions means when traffic density is closer to jam with much reduced speed. These data were used to calculate lane-width based traffic density with standard traffic flow theory and the density method detailed in the study of Tiwari et al. (2007). Lane-width based density provides relatively better estimates of traffic density on roads where mixed traffic exists as has been discussed and verified in the study of Tiwari et al. (2007). Hourly flow rates were classified under four different categories depending on the vehicle, vintage and fuel type that included two wheelers – motorcycle, moped and scooter (2WH), three wheelers – auto rickshaw (3WH), passenger cars and medium utility vehicles – car, van, and jeep (PC-MUV) and light and heavy commercial vehicles – minibus, urban bus, truck (LHCV), and other details such as a signal cycle time, stoppage time during red signals at intersection, waiting and delay time during maneuvering at the junctions, time required for vehicle to pass through the junction, speed of a vehicle, were observed and analyzed from video tapes. Hourly average meteorological measurements of parameters wind speed, direction, solar radiation, temperature, pressure, and relative humidity were carried out near the roundabout at Guwahati and for the intersection at Delhi, were procured from the Indian meteorological department and web sources for the year 2008. The annual average hourly wind roses have been shown in Fig. 1a and b at both sites. The predominant wind direction at intersection was North West and West and East at roundabout.

Traffic characteristics have been estimated by two approaches, first with three different flow conditions at different speeds that traffic may encounter different times of a day and second, with observed average flow conditions at a particular situation. Emissions have been calculated for three different scenarios developed by various combinations of field and semi-empirical methods under free, interrupted and congested-flow conditions using field observed fleet speeds and estimated space-mean speeds. The dispersion calculations for three pollutants CO, NO_2 and PM have been carried out by CALINE4 and CAL3QHC (FHWA, 1989; US EPA, 1995) and a general finite line source model with a suggested improved approximation by Horst and Venkatram, HV-GFLSM (Venkatram and Horst, 2006). The air quality has been evaluated for 1 (09:00 am to 09:00 pm) and 8 (10:00 am to 06:00 pm) hour averages at measurement points of the respective sites for an annual meteorology of the year 2008. Besides, the highest concentrations and their locations within the domains have been found out for different flow conditions and emission scenarios. The distribution of pollutant concentrations estimated at the measurement locations with respect to different wind angles. Furthermore, the vertical profiles of concentrations have been calculated at the locations of highest concentrations to examine the effects of turbulence generated by vehicles on the vertical dispersion of pollutants within the zone. The detailed methodology has been described below and outlined in Fig. 2.

In the first approach of traffic analysis, traffic flow was observed at the sites various times of a day, for example, free-flow representing no-stop, interrupted-flow representing stop-and-go condition and congested-flow conditions. The traffic speeds for each vehicle classification which differentiate these flow conditions were approximated based on the field observations (Table 1) and densities were calculated under each of them and in the second approach, the space-mean speeds were calculated at observed flow condition, which were used to calculate lane-width based density. The lane-width based density represents the non-homogeneous traffic conditions mix of all types of vehicles of significantly different physical dimensions plying together without any strict-lane discipline. It is a modified form of Highway Capacity Manual density of homogeneous traffic (Tiwari et al., 2007) as it takes into account the available space that is lane-width for the vehicle to move. This is significant from a view in that mixed traffic has different physical dimensions so the homogeneous traffic in which vehicle dimensions do not vary significantly provide erroneous density. Because in case of mixed traffic, where two wheelers also move with a large vehicles like buses, cars and so on occupy space differently. For this reason, it was practically not possible to get accurate picture on jam density or queue length. Equation (1) shows traffic density in three flow conditions calculated in the first approach.

$$D_j = \sum_{i=1}^{N} \frac{T_i}{u_{i,j}} \tag{1}$$

[1] New Delhi (200–300 m above msl) has humid subtropical climate with extreme temperature range from 7 °C to 46.7 °C with annual average of 25.3 °C and relative humidity of about 49% while Guwahati (55 m above msl) is subtropical humid with extreme temperature range from 6 °C to 38 °C with annual mean of 24 °C and relative humidity of 82%.