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Benchmarking vehicle and passenger travel characteristics in Delhi for on-road emissions analysis

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ABSTRACT

In a mega-city like Delhi, vehicle exhaust emissions play a central role for urban air quality management, and measuring these on-road emissions in an environment with mixed fuels, mixed engine sizes, mixed technologies, and mixed usage patterns, is a challenging task, which means a better understanding of the vehicle and the passenger characteristics in the city is necessary. In this paper, we present a series of survey methods – vehicle owners' interviews at fuel stations, on-road observational studies, and use of data resources like vehicle registrations and pollution under check program, which can be utilized to benchmark parameters linked to an emissions inventory methodology (Activity–Share–Intensity–Factor – ASIF). We present estimates for fuel efficiency, age profiles, annual mileage, and number of in-use vehicles for cars, motorized two-wheelers (2Ws), three-wheeled scooter rickshaws (3Ws), and buses and modeled survival functions for cars and 2Ws using log-logistic distribution function. In addition, using GPS data logging, we evaluated speed distribution of buses, cars, 2Ws and 3Ws, which resulted in evaluating the modal idling times, all of which were utilized to develop a robust vehicle exhaust emissions inventory for Delhi – segregated by vehicle type, fuel type, and age group. The survey methods and analytical techniques are simple and fast to implement, which when replicated, can provide a useful data source to estimate on-road transport emissions in urban areas.

1. Introduction

As India's capital, Delhi has grown across all sectors - industry, transport, and housing, all of which have contributed to an increase in city's air pollution problems (Narain and Bell, 2006; Goswami and Baruah, 2008; Firdaus and Ahmad, 2011; Sahu et al., 2011; Guttikunda, 2012; Guttikunda and Gurjar, 2012; Ahmad et al., 2013; Guttikunda and Calori, 2013; Guttikunda and Goel, 2013). For the period of 2008 and 2011, the ambient concentrations in the city, averaged over nine monitoring stations, ranged 123 ± 87 μg/m^3 for $PM_{2.5}$ and 208 ± 137 μg/m^3 for PM_{10}. The variation is one standard deviation of daily average concentrations over the period. The national annual standard for $PM_{2.5}$ is 40 μg/m^3 and for PM_{10} is 60 μg/m^3. The Central Pollution Control Board (CPCB) of India and the Ministry of Environment and Forests (MoEF) studied the source contributions to ambient particulate matter (PM) pollution in Delhi and concluded that the vehicle exhaust is a major contributor to the overall PM_{10} (PM with aerodynamic diameter less than 10 μm) and $PM_{2.5}$ (PM with aerodynamic diameter <2.5 μm) pollution in Delhi (CPCB, 2010).

The city of Delhi has one of the highest vehicle ownership levels in India, with a total registered fleet of 2.5 million cars and 4.5 million 2-wheelers (2Ws), in 2012. During 1991–2000, on an average, 50,000 cars and 100,000 2Ws were registered every year which almost doubled in the following decade (2001–2010) to 110,000 and 180,000 per year, respectively, and has increased even further to 150,000 and 300,000 per year, respectively for 2011–2013 (DES, 2012; 2013). Fig. 1 shows the time series of cumulative vehicle registration numbers of cars and 2Ws in Delhi. With only 21% of the households owning cars and 38% of the households owning 2Ws (Census-India, 2012), there is a large proportion of population without access to private vehicles.

Earlier studies have documented the methods to estimate total emissions and the impact of growing transport emissions in Delhi (Gurjar et al., 2004; Mohan et al., 2007; CPCB, 2010; Sahu et al., 2011; Guttikunda and Calori, 2013). Since the studies focusing on the measurement of tail pipe emissions of on-road vehicles in Delhi are limited, we have to rely on such bottom-up emission inventory estimates. Typically, the ASIF (Activity–Share–Intensity–Factor) methodology was applied to calculate the vehicle exhaust emissions (Schipper et al., 2000; Yan et al., 2011), in

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which, the parameters are defined as total travel activity (A), modal shares (S), fuel intensity (I), and appropriate emission factor (F) as mass pollutant emitted per vehicle-km travelled. For the vehicle exhaust emissions in a city like Delhi, all types of vehicles are used, equally, to move people and freight, under varying loads. This and a vibrant age mix of the fleet presents a challenging task in understanding how each of the ASIF parameters behave to estimate the total emissions.

For PM, nitrogen oxides (NO_x), carbon monoxide (CO), and volatile organic compounds (VOCs), the ASIF methodology translates to

$$E_{v,f,g,p} = NV_{v,g} \times S_v \times VKT_{v,g} \times EF_{v,f,g,p} \tag{1}$$

For sulphur dioxide (SO_2) and carbon dioxide (CO_2) emissions, the ASIF methodology translates to

$$E_{v,f,g,p} = NV_{v,g} \times S_v \times VKT_{v,g} \times FE_{v,f,g} \times PC_{f,p} \tag{2}$$

where, $E_{v,f,g,p}$ is the total emissions by pollutant, calculated by vehicle type, fuel type, and by age; $NV_{v,g}$ is the total number of vehicles on-road by vehicle types and by age; S_v is the share of vehicles on-road for each vehicle type; $VKT_{v,g}$ is the annual average vehicle kilometers traveled by vehicle type and by age; $EF_{v,f,g,p}$ is the fleet average emission factor by vehicle type, fuel type, age group, and by pollutant; $FE_{v,f,g}$ is the fuel economy by vehicle type, fuel type, age group; $PC_{f,p}$ is the pollutant content (for example, carbon and sulfur content of the fuel) v = vehicle; f = fuel; g = age group; p = pollutant.

Each of the parameters tell us (a) how people travel in the city and what is the average VKT for each mode (b) how old or how young is the vehicle fleet and what are their compliance levels (c) given the road and driving conditions, what is the likely wear and tear of the engine (d) how fast or how slow is the movement of vehicles in the city and (e) what are the idling rates in the city, all of which determine the overall vehicle exhaust emission rate for the city. A clear understanding of how each of these parameters is essential in establishing a credible emissions inventory for a city.

In India, few studies have been carried out to investigate vehicular characteristics such as fuel efficiency, annual mileage, and size of in-use fleet. Traditionally, information on the total number of vehicles in the city is available from the regional transport offices (RTOs), as the vehicles are registered every year. A major drawback linked to these databases is an overestimate of the actual number of vehicles on-road and in-use (Auto-Fuel-Policy, 2002; Mohan et al., 2009). This is the primary concern for the private vehicles as the owners are required to pay a lifetime tax at the time of purchase. The vehicles are often not de-registered when they are retired or sold to a second or third party. This is common for many low-income countries. In contrast, in high-income countries, such as the United States, the United Kingdom, France, Australia, and Japan, national authorities carry out field surveys of drivers for estimating fuel efficiency and annual mileage (Schipper, 2008).

The vehicular characteristics were developed for the city of Pune using video camera recording of traffic, to determine the type of vehicles on road (Barth et al., 2007). The study team also conducted parking lot surveys (visual inspection only) for odometer readings, engine size, and model year and on-board GPS recording to determine vehicle speeds. Huo et al. (2009) also utilized similar methods to establish vehicular characteristics in Beijing. Both the studies did not report real-world fuel efficiency values, which needs interviewing the driver or the owner. In addition, surveys involving visual inspection are unable to record other information, such as fuel type in case a car is retrofitted with Compressed Natural Gas (CNG), and odometer readings for cars and 2Ws with digital display.

The fuel-efficiency values of a vehicular fleet can be largely classified into two categories. Firstly, fuel efficiency of new vehicles, which are being added to the existing fleet, which depends on the availability of latest technology in the market and prevailing consumer preference. These numbers are often declared by the manufacturers based on controlled tests and not on-road measurements under real driving conditions (Iyer, 2012). Secondly, average fuel-efficiency of in-use fleet, is a more complex estimate as it is dependent on characteristics of vehicle models sold in the past and also needs to account for the degradation in fuel-efficiency over time. Unlike the former category, information for in-use fleet is much more difficult and needs to be estimated using driver/owner surveys. There are few examples of online portals which provide estimates of on-road values of fuel efficiency. For Chinese vehicles, Huo et al. (2011) reported an online portal in which Chinese drivers voluntarily post fuel efficiency of their cars. In the case of US, in 2005, the Department of Energy's fuel economy information website (<http://www.fueleconomy.gov>) began allowing users to voluntarily share fuel economy estimates. Further, the "spritmonitor" website (<http://www.spritmonitor.de/en/>) has a fuel consumption database of more than 250,000 vehicles. A similar system is not in place for Indian cities.

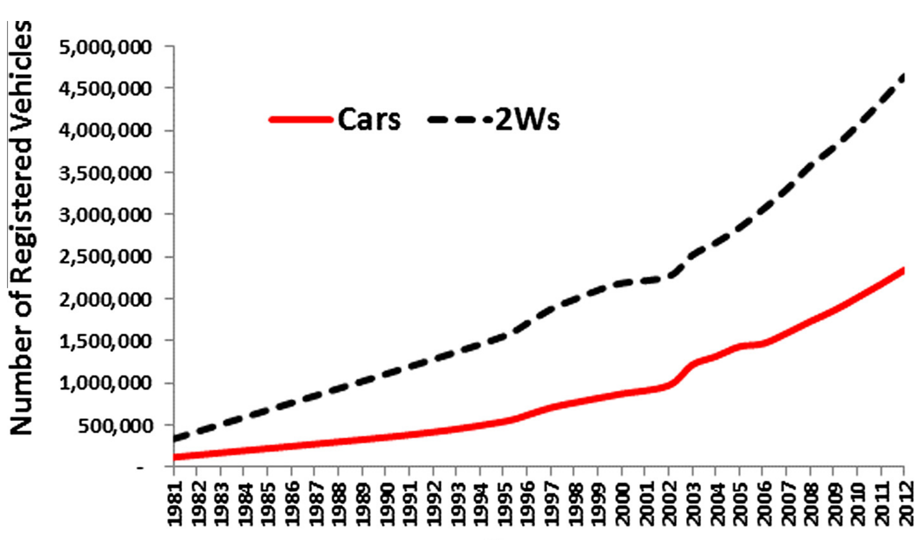

Fig. 1. Time series of vehicle registration in Delhi.