MOVES model for idling emission of signalised junction in developing country

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Abstract

Purpose – The purpose of this paper is to estimate total emission during idling of vehicles and validate emission results from real-world data.

Design/methodology/approach – Motor Vehicle Emission Simulator (MOVES)2010b emission model is customised for developing country like India and a case study of the Ashram intersection in Delhi has been selected in order to measure the emissions of vehicles during idling.

Findings – Results show that 3.997 mg/m^3 of hydrocarbon, 1.82 mg/m^3 of NOx and 17.688 mg/m^3 of carbon monoxide is emitted from the cars, trucks and buses, respectively, at Ashram intersection in one day. As there are 600 intersections throughout Delhi, a total of 2,398.055 mg/m^3 of hydrocarbon, 1,087.068 mg/m^3 of NOx and 10,612.612 mg/m^3 of carbon monoxide is emitted from cars, trucks and buses in a day in all of Delhi.

Originality/value – Knowledge of idling emission and fuel loss is very little for Indian traffic condition during delays.

Keywords Public health, Sustainable development, Developing country, Climate change, Emission, Idling

Paper type Research paper

Introduction

With 1.27 billion people, India is the second most populous country in the world, while China is the most populous, with over 1.36 billion people. Developing country like India is also currently experiencing growth in GDP of 4.3 per cent per annum. In 2011-2012, Indian industry produced 20.36 million vehicles of which the share of two wheelers, passenger vehicles, three wheelers and commercial vehicles were 76, 15, 4 and 4 per cent, respectively (Society of Indian Automobile Manufacturer (SIAM), 2013). This strong motorisation has caused increasing concerns about local and long-range air pollution, its impacts on climate change and on the global demand for oil. Indeed, already by the year 2000, India was among the ten countries with the highest exhaust pollutants from the

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road transportation sector (Borken *et al.*, 2007) and road fuel consumption has approximately doubled every ten years since 1980. Delhi has become one of the biggest emitters of atmospheric pollutants from the road transportation sector globally.

Exhaust emissions from idling vehicles at signalised traffic intersections are one of the major problems locally and globally. When the duration of idling is longer than ten to 14 seconds, the engine consumes more fuel than it would take to restart the vehicle. The fuel consumed during five miles of driving is equivalent to just ten minutes idling, which would accumulate large amounts of fuel in a year. In Delhi, 0.37 million kilogrammes of compressed natural gas (CNG), 0.13 million litres of diesel and 0.41 million litres of petrol is wasted every day due to idling vehicles. Converting these figures into monetary terms, the total losses will be equivalent to $0.41 million per day and $151.44 million per annum. In the USA, idling of vehicles causes more than $1 billion increase in fuel consumption per annum (Parida and Gangopadhyay, 2008; Kumar *et al.*, 2013). A relationship between the emissions from bus and truck idling shows that the reductions in idling amongst buses and trucks can reduce a significant amount of black carbon concentration at intersections.

Therefore, estimation of emissions and fuel losses during vehicular idling at signalised intersections is always of interest to researchers, not least to allow them to find a suitable mitigation policy. The rapid growth in vehicles and infrastructure, together with the related technological changes has had a significant impact on idling emissions at intersections. There is therefore a need to study the emissions so that the adverse effects of the pollutants can be controlled. After conducting a literature review on several emission estimating models mentioned by Kumar *et al.* (2013), Pal (2012), Peters (2008) and Den Braven *et al.* (2012), the Motor Vehicle Emission Simulator (MOVES) (MOVES2010b), developed by US Environmental Protection Agency; US EPA (2012) model was found to be the best, as it provides data on emissions due to vehicular idling. This research therefore proceeded with the help of the MOVES2010b.

With this background, the objectives of this paper are: estimation of total emission in the Ashram intersection of Delhi during vehicular idling by customising the emission model MOVES; and validation of emission results from real-world data. The scope of the study is limited to the signalised intersection only. This paper is divided into different sections dealing with: factors that may affect vehicular emission rates, the data collection procedure, the model building, its input parameters, output parameters and the threshold selection.

Modelling methodology

Model development details: MOVES2010b is the latest version of the MOVES emissions modelling tool. MOVES2010b builds on the functionality of previous MOVES versions: MOVES2004, MOVES Demo, DraftMOVES2009, MOVES2010 and MOVES2010a. MOVES2010b can be used to estimate national, state and county level inventories of criteria air pollutants, greenhouse gas emissions and some mobile source air toxins from highway vehicles. Additionally, MOVES can make projections for energy consumption (total, petroleum based and fossil based). MOVES2010b is suitable for official use, although this is not mandatory. MOVES is distributed free of charge by EPA pursuant to the GNU General Public License (GPL). It is written in Java™ and uses the MySQL relational database management system. The Oracle Corporation owns, operates and supports MySQL, and allows distribution of the database system pursuant to the GNU GPL. The principal user inputs and outputs, and the internal working storage locations for MOVES are MySQL databases (US EPA, 2012).

The MOVES model includes a "default" input database, which uses national data and allocation factors to approximate results for the 3,222 counties in the USA, District of Columbia, Puerto Rico and the USA Virgin Islands. MOVES is capable of modelling emissions for the calendar years 1990 and 1999-2050. With MOVES2010b, MOVES has been migrated from the 5.1.32 version of MySQL to version 5.5.12, and from the Java Runtime for version 1.6.0_12 to the Java Runtime version 1.7.0. MOVES is set up to run both a "Master" and one or more "Workers". This allows users to operate MOVES on a single computer system or on a network of computers. The flow diagram of the MOVES in Figure 1 shows the type of data used as input, and connectivity with output data. Results produced depend upon the selection of options and the input parameters.

Data collection: the following data were collected to provide input files which were imported to the MOVES2010b model using an XML from both primary and secondary sources for Ashram Chowk in the city of Delhi, India. The typical study area is shown in Figure 2.

Meteorology data: temperature and humidity data for months, zones, counties and hours were collected from the Indian Meteorological Department.

Source type population: the number of vehicles in the geographic area to be modelled for each vehicle or "source type". These data were collected on site using the traffic volume count method and from the Department of Transport, Government of Delhi.

Volume count: a survey was performed for vehicle volume count including a detailed classification of vehicles at Ashram intersection for the 24 hr in the evaluation of Economic Loss due to Idling of Vehicles at Signalised Intersection and Mitigation Measures (ELSIM) project.

Age distribution: the distribution of vehicle counts by age for each calendar year (year ID) and vehicle type (source Type ID). This study used 2013 data.

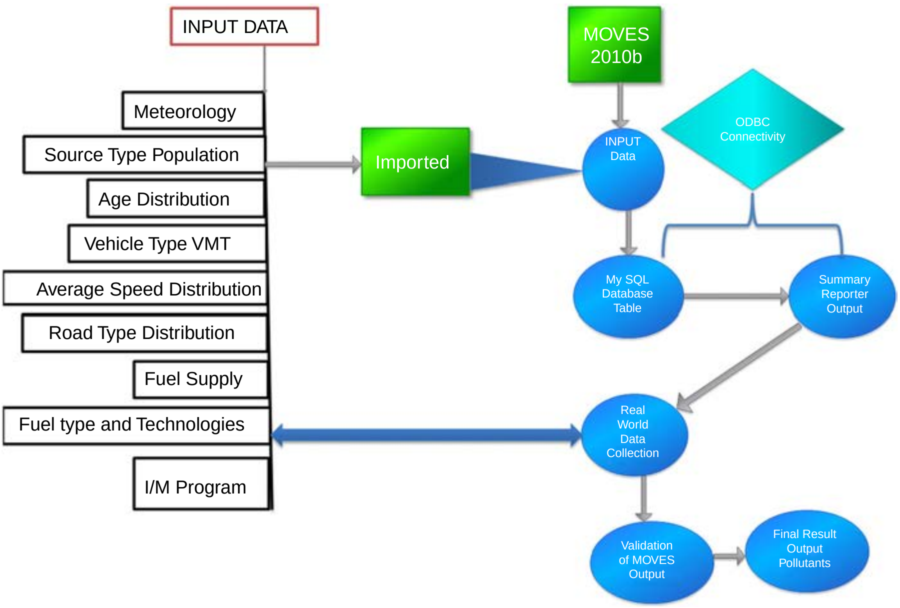

Figure 1.
Flow diagram for idling emission of MOVES

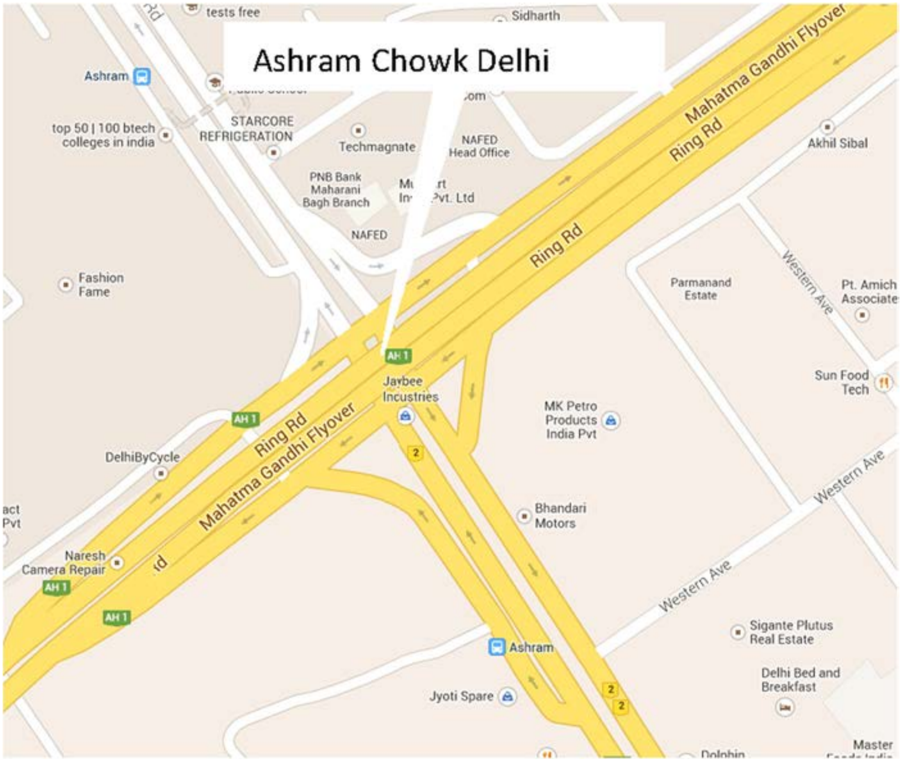

Figure 2.
Location of study area – Ashram Chowk-New Delhi

Source: © Google Maps (2014)

Vehicle type VMT (vehicle miles travelled) and VMT fraction: yearly VMT and the monthly, type of day and hourly VMT fractions data were collected from questionnaires completed by drivers at fuel stations in a survey carried out during the ELSIM project.

Average speed distribution: average speed data specific to vehicle type (source Type ID), road type (road Type ID) and time of day/type of day (hour day ID), customised according to speed data available for Delhi city.

Road type distribution: VMT by road type (road type VMT fraction) was collected from MOVES default database and customised according to Delhi road type and VMT data in Excel sheets, then imported to the Road Type Distribution Importer.

Ramp fraction: the fraction of ramp driving time on selected road types. Only limited access road types (freeways and interstates) may have their ramp fractions modified. MOVES automatically applies default values of 0.08 (8 per cent) for this parameter if we do not provide input. The data are collected from the MOVES default database. The intersection was chosen in this case, so the fraction was zero. Data were then edited in the Excel sheets and imported in the Ramp Fraction Importer. Import of this parameter in the county database is optional. In this study, the ramp fraction was not imported.

Fuel (formulation and supply): MOVES has two tables titled: Fuel Formulation and Fuel Supply. These interact to define the fuels used in the area being modelled. The fuel formulation table defines the attributes (such as Reid Vapour Pressure (RVP), sulphur level, ethanol volume, etc.) of each fuel; the fuel supply table identifies the fuel formulations used in an area and each formulation's respective market share. Values for some fuel properties were interpolated in the gap between 2005 and 2012 to generate a consistent trend.

Fuel type and technologies: the distribution of fuel types in the model. Specifically, this category deals with the fleet distribution fraction by fuel type, source type, model year and engine technology. Data are collected from the fuel station survey and customised in a database.

Inspection and maintenance (I/M) programs: data are collected from the MOVES default database. The default I/M program is reviewed and necessary changes to match the actual local program are made in the Excel sheet, which is then imported to the I/M program importer. I/M data are available from the Transport Department, Delhi.

Input parameter: County Data Manager (CDM) is a user interface that includes multiple tabs, each one of which opens importers that are used to enter specific local data. Data files can be exported to an Excel spread sheet or text file using either the Export Default Data or Export Imported Data button. A typical importer for the Meteorology Data Importer shown in Figure 3 allows the user to import temperature and humidity data for the months, zones, counties and hours that are included in the RunSpec. The MOVES model contains 30-year average temperature and humidity data for each county, month and hour and data specific to the modelled location and time is entered.

Similarly the software comprises the Source Type Population Importer, Age Distribution Importer, Vehicle Type VMT and VMT Fractions, Average Speed Distribution Importer, Road Type Distribution Importer, Ramp Fraction Importer,

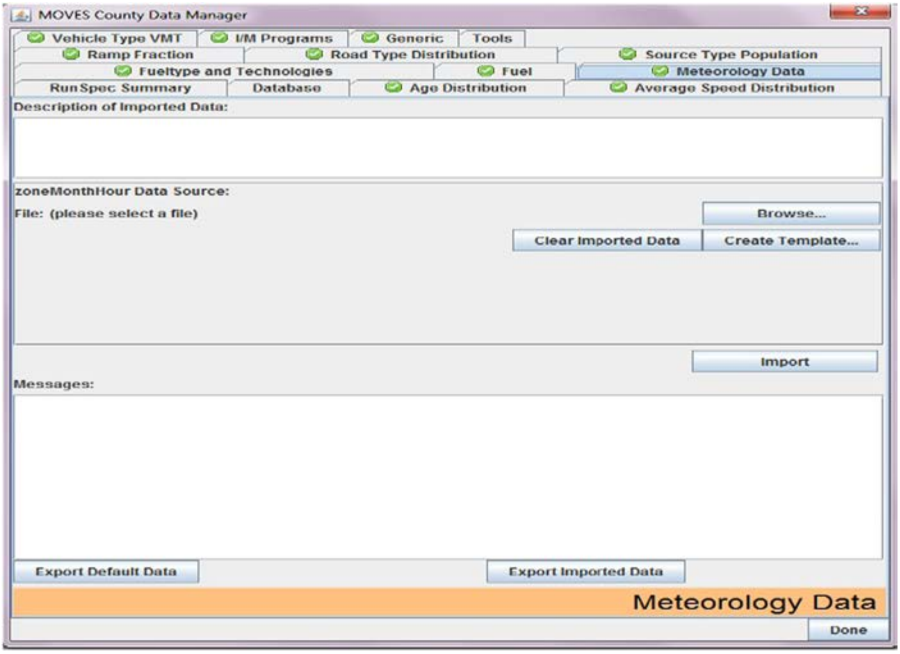

Figure 3.
Meteorology data importer

Fuel Importer, Fuel type and Technologies Importer and I/M Programs Importer, which are used to build the model input.

Validation of results

Validation of data is carried out via the following two methods.

Validation of emission data with traffic volume count

A traffic volume count, delay study and fuel station survey were carried out by the Central Road Research Institute (CRRI) team for vehicle volume count including a detailed classification of vehicles at Ashram intersection for 24 hr in April 2013 under the 12 Plan Five Year Plan (Evaluation of Economic Loss Due To Idling of Vehicles at Signalized Intersection and Mitigation Measures (ELSIM), 2013) project. One approach was to check the trend of emissions as per traffic volume count. It assumed that emission is likely to be increasing or decreasing in similar proportions of traffic volume at that intersection. Therefore the first assumption was validated by comparing the emission results obtained from MOVES for passenger car, passenger truck and transit bus with the traffic volume count of car, truck and bus to see the trends of emissions coming from vehicles. It should also be noted that a calibration factor was used to examine the trends of emissions due to idling at intersections by vehicles.

Validation of emissions of hydrocarbon, NOx and CO for cars, trucks and buses with traffic volume count

The comparison shown in Figures 4-6 validate the finding that with increase in vehicle volume count, hydrocarbon emission is also increasing in all cases. This indicates that the model is producing emission trends that are similar to the trend of traffic volume count (Table I).

An exception was observed between 12 and 2 p.m. for buses where the model does not fit the trend of classified volume count. From the comparison shown in Figures 7-9 it has been confirmed that with the increase in vehicle volume count, NOx emission also increases in all cases. For passenger cars, trucks and buses, the NOx pattern was similar to the number of vehicles. The comparisons in Figures 10-12 show that with

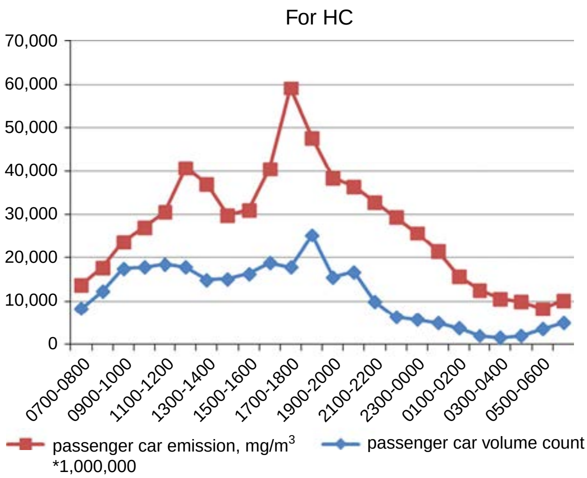

Figure 4. Comparison of passenger car emission (HC) with traffic volume

increased vehicle volume, CO emission also increases in all cases. Table II represents the 24 hr vehicle count data of passenger cars, passenger trucks and transit buses at Ashram intersection. As in the case of hydrocarbon, a similar problem was observed with buses in the case of CO emissions by model. The reason may be attributed to temperature changes at noon.

Validation of emission data from real-world data collected by Delhi Pollution Control Board (DPCB)

A further assumption was that the pattern of emissions should be similar to the real-world data available from Delhi Pollution Control Board (DPCB) (2013). In this regard, a similar type of intersection was chosen (RK Puram) where DPCB provided real-time emission data for each 60 minutes interval. Therefore, a comparison of total emission obtained from the MOVES2010b model for passenger car, passenger truck and transit bus for NOx in $\mu g/m^3$ was carried out with real-time NOx emission data obtained from DPCB. Figure 13 shows this comparison. Similarly, a comparison of total emission obtained from the MOVES2010b model for passenger car, passenger truck and transit bus for CO in mg/m^3 has been carried out with real-time CO emission data obtained from DPCB. Figure 14 shows the comparison, and it can be observed that the result is somewhat similar. Deviations in the results exist because the comparison was done between emission data of all vehicles and ambient air quality data at a similar type of intersection in Delhi.

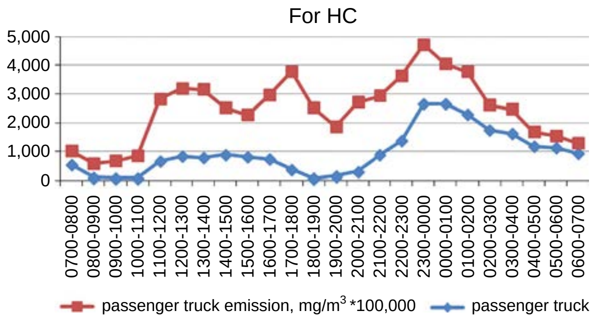

Figure 5.
Comparison of passenger truck emission (HC) with traffic volume

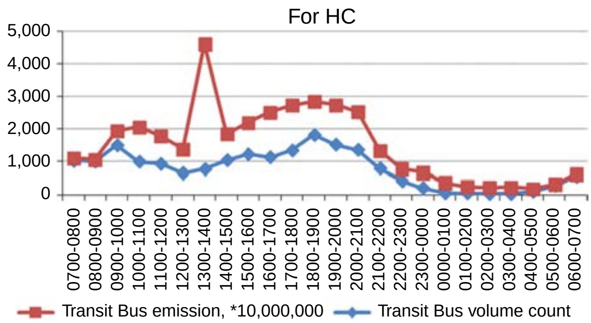

Figure 6.
Comparison of passenger bus emission (HC) with traffic volume for HC

Table I. Emission of CO, HC and NOx from MOVES2010b for cars, trucks and buses

Time	CO emission Car/day (mg/m^3)	Truck/day (mg/m^3)	Bus/day (mg/m^3)	Total emission (mg/m^3)	HC emission Car/day (mg/m^3)	Truck/day (mg/m^3)	Bus/day (mg/m^3)	Total emission (mg/m^3)	NOx emission Car/day (mg/m^3)	Truck/day (mg/m^3)	Bus/day (mg/m^3)	Total emission (mg/m^3)
0700-0800	0.014	0.003	0.000	0.017	0.056	0.005	0.00001	0.060	0.002	0.000	0.000000	0.002
0800-0900	0.035	0.005	0.023	0.063	0.055	0.005	0.00001	0.060	0.004	0.000	0.000000	0.004
0900-1000	0.052	0.013	0.081	0.147	0.062	0.006	0.00004	0.068	0.005	0.001	0.000002	0.006
1000-1100	0.198	0.024	0.063	0.285	0.092	0.008	0.00011	0.100	0.017	0.002	0.000012	0.018
1100-1200	0.433	0.164	0.053	0.650	0.122	0.021	0.00009	0.144	0.037	0.011	0.000010	0.048
1200-1300	1.189	0.185	0.337	1.710	0.231	0.024	0.00007	0.254	0.099	0.014	0.000008	0.113
1300-1400	1.065	0.180	0.048	1.293	0.222	0.002	0.00039	0.225	0.097	0.015	0.000048	0.112
1400-1500	0.573	0.111	0.066	0.750	0.148	0.016	0.00008	0.164	0.062	0.012	0.000012	0.074
1500-1600	0.635	0.098	0.099	0.832	0.218	0.014	0.00010	0.233	0.073	0.011	0.000018	0.083
1600-1700	0.800	0.140	0.074	1.014	0.414	0.022	0.00014	0.437	0.095	0.016	0.000024	0.112
1700-1800	0.981	0.113	0.052	1.146	0.227	0.034	0.00014	0.261	0.124	0.013	0.000022	0.137
1800-1900	0.672	0.139	0.085	0.896	0.228	0.024	0.00010	0.253	0.087	0.015	0.000014	0.102
1900-2000	0.992	0.101	0.089	1.183	0.197	0.017	0.00012	0.214	0.119	0.011	0.000022	0.130
2000-2100	0.849	0.191	0.089	1.129	0.230	0.024	0.00012	0.254	0.107	0.019	0.000020	0.126
2100-2200	1.097	0.152	0.276	1.524	0.231	0.020	0.00006	0.251	0.132	0.016	0.000008	0.148
2200-2300	1.128	0.178	0.005	1.311	0.201	0.023	0.00004	0.223	0.133	0.018	0.000002	0.151
2300-0000	0.921	0.155	0.002	1.078	0.166	0.021	0.00005	0.187	0.113	0.015	0.000004	0.128
0000-0100	0.729	0.094	0.008	0.831	0.120	0.014	0.00003	0.133	0.094	0.010	0.000002	0.104
0100-0200	0.484	0.109	0.000	0.594	0.108	0.015	0.00002	0.123	0.060	0.011	0.000000	0.071
0200-0300	0.395	0.044	0.000	0.439	0.091	0.009	0.00002	0.099	0.048	0.005	0.000000	0.053
0300-0400	0.305	0.050	0.000	0.355	0.080	0.008	0.00002	0.089	0.036	0.005	0.000000	0.041
0400-0500	0.257	0.015	0.000	0.273	0.047	0.005	0.00001	0.052	0.027	0.001	0.000000	0.029
0500-0600	0.061	0.009	0.000	0.070	0.053	0.004	0.00000	0.057	0.008	0.001	0.000000	0.009
0600-0701	0.095	0.004	0.000	0.099	0.053	0.004	0.00000	0.056	0.010	0.000	0.000000	0.011
Total emission CO				17.688	Total emission HC			3.997	Total emission NO_X			1.812

Ambient air quality data are whole ambient data from all different sources including vehicle, household, dust, industrial dispersion and other dispersions in flux at intersections. Since source apportion data were not easily available, a simple comparison was conducted with emission data from MOVES2010b at Ashram intersection with RK Puram.

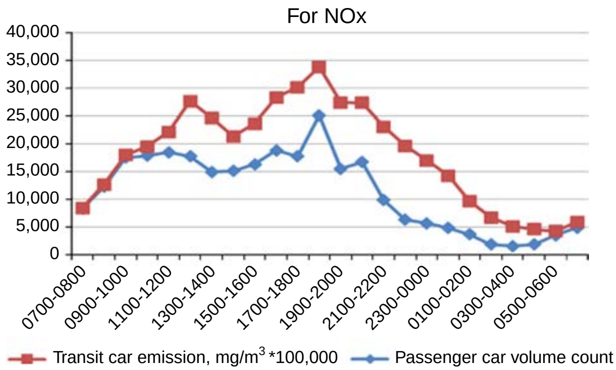

Figure 7. Comparison of passenger car emission (NOx) with traffic volume

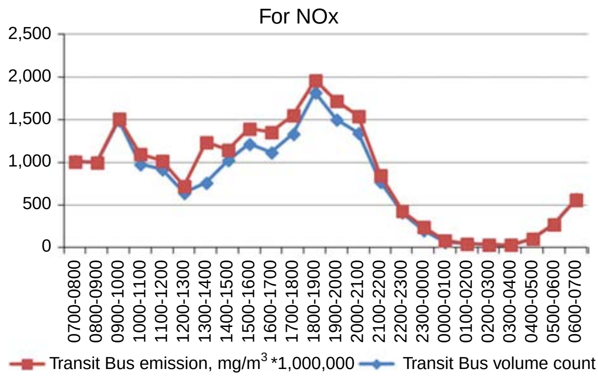

Figure 8. Comparison of passenger bus emission with traffic volume for NOx

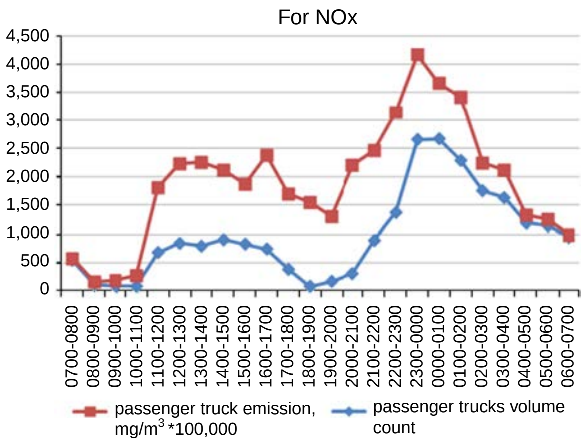

Figure 9. Comparison of passenger bus emission with traffic volume for NOx

It was interesting to note that MOVES2010b predicted a similar type of trend when plotted against timescale. The gap between DPCB and the model certainly showed the limitations in our data. In this case only car, bus and truck vehicles were considered for analysis, whereas in the case of the DPCB, the whole ambient air was evaluated.

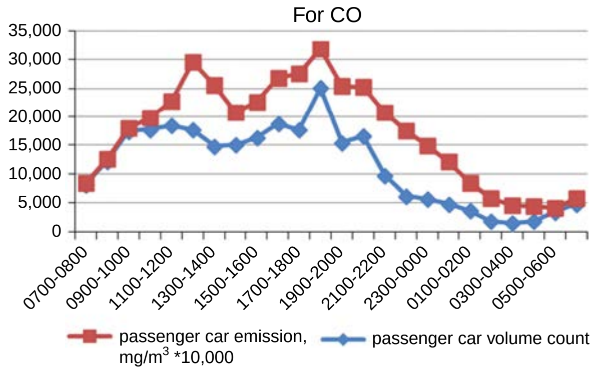

Figure 10. Comparison of passenger car emission (CO) with traffic volume for CO

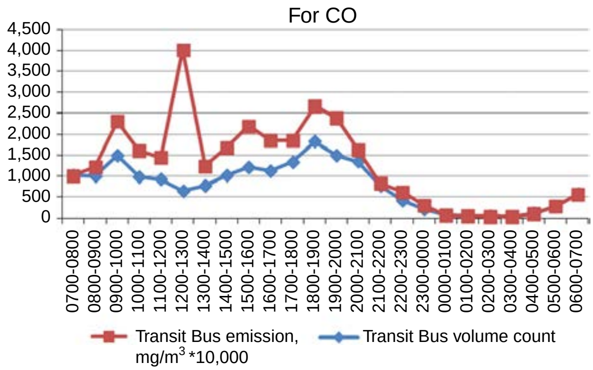

Figure 11. Comparison of passenger bus emission (CO) with traffic volume for CO

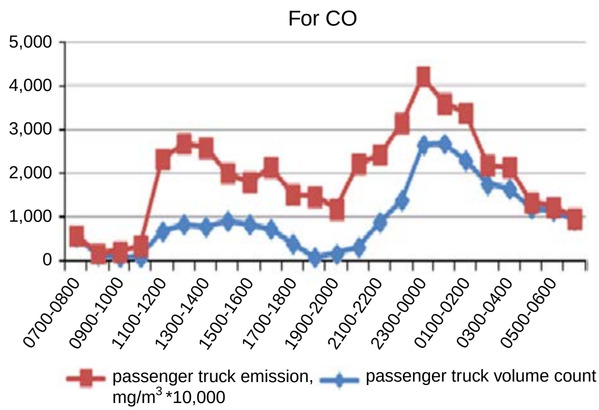

Figure 12. Comparison of passenger truck emission (CO) with traffic volume

Table II.
Vehicle count at Ashram intersection

	Traffic volume count/24 hr							
Time	0700-0800	0800-0900	0900-1000	1000-1100	1100-1200	1200-1300	1300-1400	1400-1500
Car	8,277	12,246	17,510	17,835	18,456	17,737	14,900	15,086
Truck	542	120	89	93	678	840	791	902
Transit bus	1,014	996	1,500	981	922	641	763	1,025
Time	1500-1600	1600-1700	1700-1800	1800-1900	1900-2000	2000-2100	2100-2200	2200-2300
Car	16,319	18,808	17,740	25,076	15,515	16,683	9,825	6,288
Truck	824	824	738	384	170	311	896	1,378
Transit bus	1,217	1,217	1,120	1,334	1,505	1,346	774	415
Time	2300-0000	0000-0100	0100-0200	0200-0300	0300-0400	0400-0500	0500-0600	0600-0701
Car	5,683	4,840	3,692	1,838	1,534	1,855	3,493	4,866
Truck	2,657	2,667	2,290	1,754	1,636	1,189	1,142	940
Transit bus	208	66	45	38	31	106	276	567

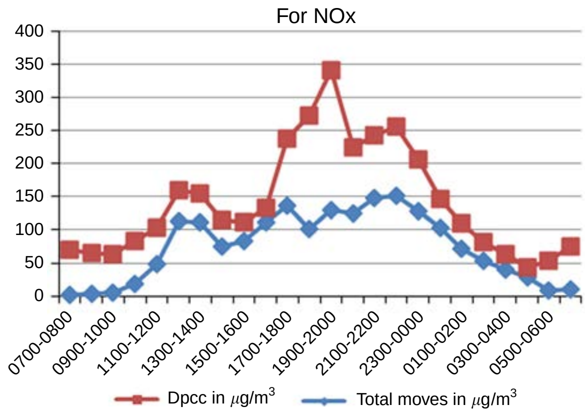

Figure 13.
Comparison of passenger truck emission (CO) with traffic volume – DPCB

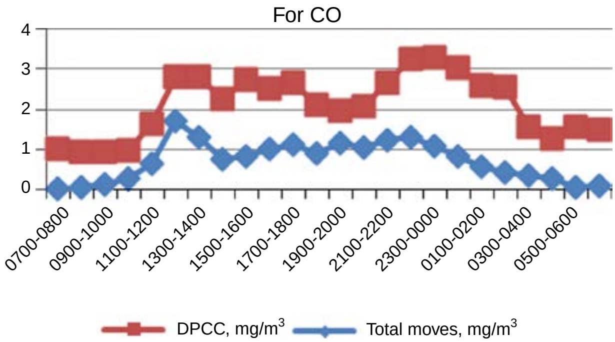

Figure 14.
Comparison of passenger truck emission (CO) with traffic volume – DPCB

However, it can be ascertained that if a complete set of vehicles and different parameters are taken, it is possible that the MOVES2010b prediction would be very close to real-world data. This shows that customised MOVES2010b for Indian conditions is a valid model, but at the same time, it requires extensive databases, computational arrangements and exercises.

Results and discussion

After customising the MOVES according to Indian traffic, road, vehicle, meteorological data and other data as mentioned above, the final results are obtained in the text formats which are further edited in the Excel sheets in order to create a better understanding. Results are obtained in gm/kilometre for weekdays (i.e. for five days), which are further converted in mg/m^3 for a single day. Table I shows the result for hydrocarbon emissions in mg/m^3 for a day in hourly intervals. Table I also shows total hydrocarbon emissions in mg/m^3. From the MOVES2010b model it has been deduced that 3.997 mg/m^3 of hydrocarbon is emitted from the cars, trucks and buses at Ashram intersection in a day. There are 600 intersections in Delhi. Therefore 2,398.055 mg/m^3 of hydrocarbon is emitted from the cars, trucks and buses in a day in the city. Similarly, results for oxides of nitrogen are obtained in g/kilometre for weekdays (i.e. for five days), which are further converted to mg/m^3 for a single day. Table I shows the results for NOx emission in mg/m^3 for a day in hourly intervals. From the MOVES2010b model it has been deduced that 1.82 mg/m^3 of NOx is emitted from the cars, trucks and buses at Ashram intersection in one day. There are 600 intersections in Delhi, therefore 1,087.068 mg/m^3 of NOx is emitted from the cars, trucks and buses in one day in Delhi. Results for CO are obtained in gm/kilometre for weekdays (five days), which are further converted in mg/m^3 for a single day. Table I shows the results for CO emission in mg/m^3 for a day in hourly intervals, and the MOVES2010b model shows that 17.688 mg/m^3 of CO is emitted from the cars, trucks and buses at Ashram intersection in one day. There are 600 intersections throughout Delhi, therefore 10,612.62 mg/m^3 of carbon monoxide is emitted from the cars, trucks and buses in a day in Delhi. The data were obtained from the input data supplied by the CRRI team New Delhi; however, it was difficult to validate.

Conclusions and recommendations

To estimate the fuel loss at signalised intersections in Delhi, an intersection called Ashram was selected and the model MOVES2010b was used to quantify idling emissions. A successful execution of the model found that 3.997 mg/m^3 of hydrocarbon, 1.82 mg/m^3 of NOx, and 17.688 mg/m^3 of carbon monoxide is emitted from the cars, trucks and buses, respectively, at Ashram intersection in one day. As there are 600 intersections in Delhi, 2,398.055 mg/m^3 of hydrocarbon, 1,087.068 mg/m^3 of NOx, and 10,612.612 mg/m^3 of CO is emitted from the cars, trucks and buses in a day in the whole of Delhi. Deviations in the results exist because the comparison was carried out between emission data from different locations at a similar type of intersection in Delhi. The MOVES2010b model is very extensive and suitable for estimating the idling emissions at intersections. This study also shows that that customised MOVES2010b model for Indian conditions is valid, but requires a significant database and extensive computational arrangements and exercises. Studying idling emissions can reduce the adverse effects of pollutants; therefore such models can be used to control pollutants and find suitable exploratory mitigation measures in cities.

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