PREDICTION OF SPATIAL CONCENTRATION DISTRIBUTION OF CARBON MONOXIDE ON URBAN STREET IN DELHI: A COMPARATIVE STUDY

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ABSTRACT
The prediction of carbon monoxide (CO) emitted by vehicular exhausts at urban street is of foremost importance in order to improve ways to mitigate the effects of air pollution. In present study, an average hourly and 8 hourly CO has been predicted using three different models viz. CALINE-4, CAL3QHC and CAL3QHCR. The traffic parameters like volume and emission factors have been monitored for Barakhamba Road, Canaught Place, New Delhi, India. The composite emission factor has been evaluated as described in CALINE-4 manual. All three models have been run for three peak hours (morning, afternoon and evening peak hour) of winter season. The predicted values of CO from different models exhibit the good predicting capability of CAL3QHCR in comparison to CALINE-4 and CAL3QHC. The comparison of results obtained in models prediction with National Ambient Air Quality Standard (NAAQS) shows that the predicted concentration lies within the prescribed permissible limits.

Key Words: Air pollution, Urban street, Prediction models, CO concentrations, Caline-4

INTRODUCTION
The road traffic emissions are the major source of air pollution in urban areas with subsequent adverse human health effects. Although, the improvements in vehicle technologies have played a significant role in reducing traffic emissions at the source, air pollution abatement still remains a challenge in cities. Increasing demand of transportations due to economic growth has triggered a boom in the number and use of motor vehicles. Owing to rapidly increasing numbers and limited use of emission control technologies, vehicular emissions are responsible for about 70% of air pollution in the Indian cities. The pollutants include repairable suspended particulate matter (RSPM), especially PM2.5, nitrogen dioxide (NO2), CO and hydrocarbons (HC). The most affected group of peoples is urban inhabitants especially, the population residing in the vicinity of urban roadways as well as pedestrians. The situation further deteriorates at urban streets, where the ventilation is insufficient. Therefore, the prediction of pollutants emitted in the vicinity of urban roadway is of foremost importance in order to improve ways to mitigate vehicular pollution effect. Various dispersion models are available for predicting the air pollution concentration. The most widely used dispersion models are the Gaussian models, which are based on two modified Gaussian distributions of the plume in the vertical and horizontal directions. In the present study, Gaussian models, CALINE – 4, CAL3QHC and CAL3QHCR, are used to predict CO concentrations near roadways. The CALINE
– 4 model is widely used to predict near road vehicle emissions. This model has been tested and validated for predicting pollutants concentration of several vehicles emitted near road under certain conditions, such as CO, oxides of nitrogen (NOx), and additional gases. The performance of CALINE-4 model for transportation related CO has been examined for a free flowing motorway and a periodically congested roundabout in Ireland and it has been established that CALINE-4 functions well under stable atmospheric conditions but performs poorly under low wind conditions. The CALINE-4 model together with emission factors predicted by COPERT III is found suitable for near road NOx concentration prediction in open urban and rural sites in Israel. Though, such predictions may not be extended to dense urban center locations. For near road NOx and nitrogen monoxide concentrations prediction the CALINE-4 performed well. CALINE-4 may predict NOx and NO2 concentrations well probably due to assumptions but under predict NO2 imbedded in the model. It has been observed that the CALINE-4 predicts well for day time 12 hours average concentrations of transportation related benzene, toluene, ethyl benzene and xylene in urban areas. A large number of studies have been carried out done to examine CALINE-4 capabilities in predicting five transportation related emissions of seven inert gases – nPentane, Isopentane, Ethane, Propene, 1,3Butadiene, Acetylene and Benzene under low wind speeds and showed that CALINE-4, together with emission factors predicted by COPERT III give good long term estimations but underestimates higher percentile concentrations when evaluating short term conditions. CALINE-4 has also been tested in predicting particle concentrations in two studies by using a modified version of CALINE-4 to estimate motor vehicle emission factors of fine and ultra fine particles near a busy road in the Brisbane area in Australia. The study reported that CALINE-4 model results are in agreement with the observed rate of dispersion with distance from the road. CAL3QHC yielded unsatisfying results under conditions involving low wind speeds and nearby tall buildings. The mixed traffic and road surroundings by high rise buildings cause CAL3QHC to poorly predict CO concentrations. With open areas and less intensive monitoring CAL3QHC showed good performance with moderate traffic volume. This study is focused on one of the most congested urban street of Barakhamba Road in New Delhi, which is considered as business centre district and has many high rise buildings surrounding the road with poor ventilation.

**Brief description of models**

CALINE-4, CAL3QHC and CAL3QHCR are Gaussian based steady state models. These models assume that the dispersion process takes no time to achieve the steady state. The materials and equations presented in this section are based on available model documentation.

**CALINE-4**

CALINE-4 model is a fourth-generation line source air quality dispersion model that is based on the Gaussian diffusion equation and employs a mixing zone concept to characterize pollutant dispersion in the proximity of roadways. The model employs source strength, meteorology, site geometry and site characteristics as input parameters and predicts pollutant concentrations for receptors located within 150 meters either side of the roadways. The CALINE-4 model allows roadways to be broken into multiple links that can vary in traffic volume, emission rates, height, width, etc. CALINE-4 is capable of specifying links at heights above grade (z = 0), links as bridges (allowing air to flow above and below the link) and links as parking lots (which should be defined by the user as having a height of zero). Also, unlike CAL3QHCR, CALINE-4 is capable of analyzing the dispersion of pollutants in wind speeds of less than 1 m/s. In addition, Caltrans makes available to users a simplified version of CALINE-4. The limitation of CALINE-4 includes a feature for analyzing the effects of nearby canyons or bluffs on pollutant dispersion and is only recommended for use in rare circumstances by very experienced modelers. The concentration at a point with coordinates (x, y, z) is calculated based on the following equation.
CAL3QHC is a multi-source model and was developed by the U.S. EPA in 1990. CAL3QHC was intended to be used for estimating vehicle emissions near roadway intersections, specifically for CO. Although, it can also be used for analyzing other inert type of pollutants such as particulate matters. CAL3QHC is based on the same line-source dispersion algorithm as used in CALINE3, with an added algorithm to provide simple vehicle queuing estimates. According to the CAL3QHC user’s guide, CALINE3 was designed to predict emissions from vehicles under free-flow conditions but does not account for emissions from idling vehicles. The queuing theory added to CALINE3 to produce CAL3QHC reportedly allows for the consideration of idling vehicle emissions by estimating queue lengths. The CAL3QHC can accommodate up to 120 roadway links, each of which can be specified as either a free flow or queued link. The program allows for 60 receptor sites and automatically sums the contribution of all links to each receptor site. Link widths should include 10 feet on either side of the traveled roadway to include vehicle plume interactions. But, there is also limitations of this model that does not allow link width to be greater than the link length and wind speed must be greater than 1 m/s. CAL3QHC is not intended for modeling sites with complex geometries, topography or atmospheric instability. Additionally, CAL3QHC is also not valid for analysis of link heights greater than 30 feet.

**CAL3QHCR**

CAL3QHCR is intended to be a more refined version of CAL3QHC. This model uses meteorological data for one year (on-site) or five year (local airport) period rather than using worst-case meteorological assumptions. CAL3QHCR was the solution to a New York lawsuit concerning the tendency of the original version to over predict carbon monoxide concentrations. Concentration estimates produced by CAL3QHCR are lower because calm periods, which tend to have the highest concentrations, are not included in multi-hour averages (effectively tossing out the peak concentrations). Some EPA staff have voiced concern over CAL3QHCR, but acknowledge that the model is unlikely to be updated since it was created to satisfy a legal settlement.

**Study area**

The Barakhambha Road, New Delhi has been selected for the present study. It is one of the busiest road of the city having poor ventilation. In fact, it is central business district and surrounding by tall buildings. The buildings are high rise and are closely spaced either side of the road. The brief description of the study area has been shown in Fig. 1 and Fig. 2. The data from one sampling site is used to evaluate the capabilities of the all three models described earlier. The Barakhambha Road consists of two links, each link having 450 meter length and 50 meter width, which is surrounding by high rise buildings from both side as given in Fig. 1(a) and Fig. 1(b).
Traffic Analysis
Traffic Volume
The traffic data of hourly morning peak, afternoon peak and evening peak were collected on 10th January 2008. Traffic volume comprises of heavy commercial vehicles (Bus/Trucks), light commercial vehicles, car, three wheelers (M3W) and two wheelers (M2W). The number of vehicles had been counted at an hourly basis for all the categories. The continuous traffic counts were performed from 8:00AM to 22:00 PM morning to 22:00 on hourly basis. The 8 hourly average traffic volumes and its composition with respect to different categories of vehicles along with their age have been carried out. The vintage of vehicles has been ascertained from survey at fuel stations (petrol pumps). Additionally, the hourly traffic count has also been taken from 09:00 AM to 10:00 AM (morning peak traffic volume), 12:00 hrs to 13:00 hrs (afternoon peak traffic volume) and 18:00 hrs to 19:00 hrs (evening peak traffic volume). The evaluation of composite emission factor has been discussed in the following subsequent sections.
Emission Factors

One method was used for quantifying the emission factors. In the Sacramento case the emission factor is calculated as a weighted average and Composite emission factor over different vehicle categories.

The data relating to the vintage of the vehicle have been obtained by survey at Barakhamba and the adequate number of vehicle owners have been interviewed in each category. It can be seen that the currently operating vehicles are much younger in age and use comparatively new technology. Therefore, it can be seen that the pollutants emitted by the vehicles mix actually operating are much lower. To estimate the air pollution loads from different vehicle types the emission factors with appropriate deterioration coefficients as employed by the CRRI in their report have been employed in the present study\(^1\). The weighted average emission factor for CO has been calculated by using individual emission factor of different categories of vehicles including appropriate deterioration factors as mentioned in Transport Fuel Quality for the year 2006 to 2010.

**MATERIAL AND METHODS**

The traffic parameters (hourly traffic volume, traffic composition, vintage of vehicles of different categories and their corresponding emission factors) have been estimated in situ for Barakhambha Road for 8 hours. The traffic estimation includes morning peak, noon peak and the evening peak. The site conditions, roughness data for near road CO concentrations all three models need vehicle related data, meteorological information and data such as link geometry and receptor locations. For CALINE 4 model it require run type here we have chosen worst case wind angle for 1 hourly and multi worst case wind angle for 8 hourly with roughness length 400 meter for central business district. The road geometries for all the software as given above in Fig.1 (a) with length 450 m and width 50 m of the road by considering two links grid receptors were used along with the road with 176 receptors and mixing zone 25 meter as the average of building height. Composite Emission factors have been obtained and given in Table 1. Wind speed and direction have been provided from CRRI (Central Road research institutes) Delhi, Report For 2005. From these metrological data the worst angle direction has been chosen for CAL3QHC and CAL3QHCR. After preparing all the input parameters for all three models, we can run the models and get the CO Concentration along the road for three models in each receptor position.

### Table 1 : Traffic emission factors

<table>
<thead>
<tr>
<th>Month</th>
<th>Time(hr)</th>
<th>Composite Emission factor g/mile/vech.</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>1 hr</td>
<td>3.72</td>
</tr>
<tr>
<td></td>
<td>8hr</td>
<td>3.92</td>
</tr>
</tbody>
</table>

**RESULTS AND DISCUSSION**

The comparative study of the three models has been thoroughly discussed. From Table 2 we can observe the CO concentration with 1 and 8 hourly average (mg/m3). The table exhibits the variation of CO concentration with respect to the three models employed in the study. By comparing these results with the national ambient air quality standards it is clear that all concentrations are under permissible limit and the max. Concentration was observed with (2243 mg/m3) in case of CAL3QHCR.

The Fig. 3 shows the 1 hourly CO concentration which has been predicted along the road using grid receptor. Further, from the Fig. 3 Variations of CO concentration along the road have been clearly shown. The prediction has been done in order and we can obtain at any point of the road...
the maximum concentration also to know about the behavior of the pollutant with high rise buildings. Fig. 3 and Fig. 4 shows the running of CALINE-4 model from which we can observe the maximum concentration of 2213.5 mg/m³ for 1 hourly. Fig. 4 also shows the CO concentration and the variation along the road for 8 hourly averages and depicts the Max. Concentration of 2097 mg/m³. The comparisons between these three models have been obtained with respect to the experimental value for 1 hourly and 8 hourly in order to test these three models. From Fig. 5 we can see CALINE-4 and CAL3QHC are nearly and above the experimental value. CAL3QHCR predict sometimes above the experimental value and sometimes under the experimental value. In Fig. 6 CALINE-4 and CAL3QHC were found in the same line. But, CAL3QHCR was above the experimental value only at one point. But in any condition all the three models were above the experimental value.

Table 2: Comparative results of the models

<table>
<thead>
<tr>
<th>Month</th>
<th>Pollutant</th>
<th>Time</th>
<th>Maximum predicted values, mg/m³</th>
<th>National ambient air quality standard*, mg/m³</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>CALINE4</td>
<td>CAL3QHC</td>
</tr>
<tr>
<td>January</td>
<td>CO</td>
<td>8 hr</td>
<td>2097</td>
<td>2038.75</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 hr</td>
<td>2213.5</td>
<td>2213.5</td>
</tr>
</tbody>
</table>

Fig. 3: 1 Hourly mesh view of spatial CO concentration distribution on road
Fig. 4: 8 Hourly mesh view of spatial CO concentration distribution on road

Fig. 5: Comparison between three softwares for different receptor position 1hr basis in January

Fig. 6: Comparison between three software in different receptor position basis in 8hr January
CONCLUSION

The models prediction shows the variation in predicted CO concentrations with time at different peak periods (morning peak hours, afternoon peak hours and evening peak hours) for month of January. The prediction of CO clearly reflects the increase in traffic volume at evening peak hours and other hours of the day. The comparison of predicted CO concentrations with the USEPA standards shows that predicted values are higher side, but the standard has been set for 24 hourly average concentrations; however predictions in the present study have been made only for 1 hourly and 8 hourly average concentration and for peak traffic hours.

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REFERENCES