Empirical Relationship Between Mesoscale Carbon Monoxide Concentrations and Areal Vehicular Emission Rates

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A relatively simple empirical equation is presented that reasonably approximates the relationship between mesoscale carbon monoxide (CO) concentrations, areal vehicular CO emission rates, and the meteorological factors of wind speed and mixing height. The approximation is an extension of rollback modeling and was derived from aerometric data measured at a major urban area in Virginia. A similar equation has been found valid for relatively limited data measured at another major urban area, which indicates that an approximation of this type, although area specific, has wide applicability. Transportation planners can use such an approximation in conjunction with a grid inventory of area vehicular CO emissions to obtain an areal profile of mesoscale CO concentrations. Such an approximation would be preferable to the complex and potentially more-accurate diffusion models when reliable input data are not available, which is often the case. It could be used by air-quality planners involved in project-level analyses to estimate the existing worst-case background levels of CO at a proposed urban highway site.

In estimating the potential carbon monoxide (CO) concentration at critical receptor points along the corridor of a proposed highway project, planners must use microscale modeling to predict the potential CO concentrations to be contributed by the proposed highway under given traffic and meteorological conditions. Then they must add the background CO concentrations representative of the area that surrounds the project to these predicted concentrations. These background (mesoscale) concentrations come from emissions contributed by sources such as motor vehicles and residential and commercial space heaters in the community.

Most often, the available data on CO concentration collected by local and state air-pollution-control agencies cannot be used to establish background concentrations, since the air monitors used are often sited (by necessity) within the strong influences of heavily traveled roads in urban areas. In this situation, planners have two options: They can either monitor the air quality or use mesoscale modeling. Monitoring air quality is expensive and time consuming; it requires sophisticated analytical instrumentation and skilled personnel. Since most state transportation agencies must study numerous projects in a given year, monitoring can substantially increase their workload, even if it is not necessary to monitor every project.

Mesoscale modeling is less expensive and therefore preferable to monitoring; however, it too has drawbacks. Since it attempts to accommodate both microscale and mesoscale phenomena, the rather popular Air Pollution Research Advisory Committee (APRAC) APRAC-2 model (1) is so overly sophisticated that its use is often difficult to justify in view of the errors that exist in its required input parameters. On the other hand, the so-called box model (2) is felt to be too simplistic; it treats the entire air basin over an urban area as a single box of air in which all the emissions are uniformly dispersed.

Until errors in their input parameters have been significantly reduced to warrant the use of potentially highly reliable but complicated mesoscale dispersion models such as APRAC-2 and other less-popular ones, there is need for a method that offers some of the simplicity of the box model together with the spatial resolution of a dispersion model. This method would be particularly attractive if the necessary computations could be performed by using a desktop calculator.

With such a method as a goal, correlations between measured mesoscale CO concentrations and estimated CO emissions were conducted for the metropolitan Richmond and the Tidewater areas in Virginia. In this paper, the correlation process is briefly described. Following the description, the results are presented. How such correlations may be used to estimate mesoscale CO concentrations is then discussed.

EXPERIMENTAL APPROACH

The general research approach consisted of the following steps: (a) preparation of a grid inventory of vehicle kilometers traveled (VKT) in one of the urban study areas, (b) selection from the inventory of several grid squares that represented a wide range of VKTs, (c) location in each grid square of a CO measurement site, (d) simultaneous measurements of hourly CO concentrations at all the sites supplemented by measurements of meteorological variables, (e) calculation of the corresponding hourly CO emissions for each of the selected grid squares, and (f) correlation of the hourly CO emissions, mesoscale CO concentrations, and meteorological variables. A detailed description of some of these steps and pertinent information are presented here.

Grid Inventory of VKT

The first correlation was sought for the metropolitan Richmond area, which is located in the middle of the eastern half of Virginia. Since the area is on the fall line that divides the Piedmont from the coastal plains, its topography varies from 3 to 64 m above mean sea level. A 484-km^2 area that consisted of the city of Richmond in the middle and portions of Henrico County to the north and Chesterfield County to the south was gridded into 2.0x2.0-km squares (Figure 1). Then the total daily VKT (TDV) in each grid square was calculated by the following equation:

$$TDV = \sum_l (\text{length})_l (\text{ADT})_l \quad (1)$$

where $(\text{length})_l$ is the segment length of the primary traffic link l in the square (in kilometers) and $(\text{ADT})_l$ is the average daily traffic on the primary link l. The 1976 traffic data provided by the Virginia Department of Highways and Transportation were used (3). To evaluate the possible effect of using different grid sizes on the correlation being sought, an additional inventory was performed on the same study area by using a grid of 1.4x1.4-km squares (shaded squares, Figure 1). In this inventory, the second grid was laid over the study area in such a manner that many of the smaller squares were almost completely contained in (or

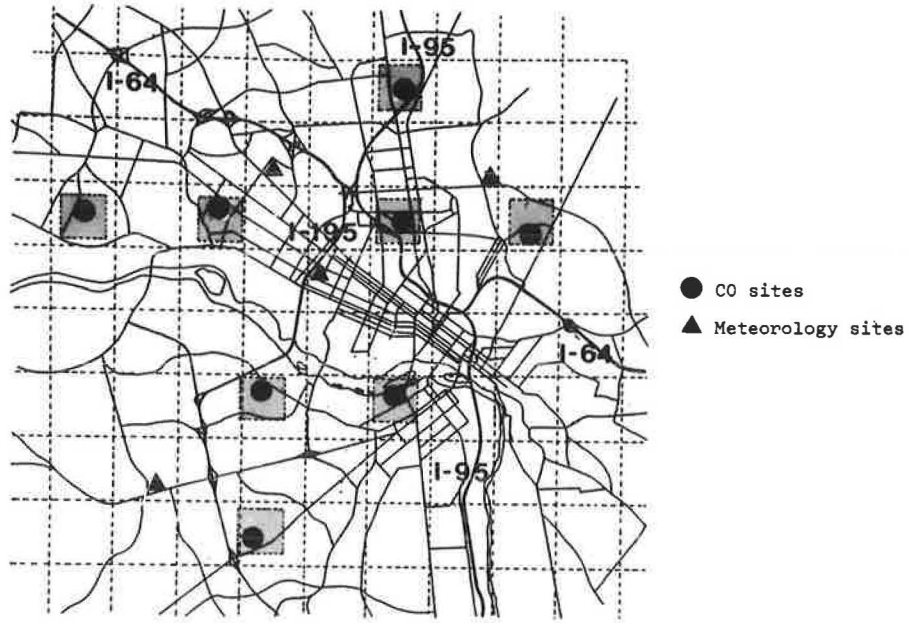


Figure 1. Metropolitan Richmond area gridded into 2.0x2.0-km squares.

overlapped by) many of the larger squares from the first grid. Then, by selecting CO measurement sites from some of the overlapping pairs of different-sized squares, the CO concentrations measured at these sites could be correlated with CO emissions estimated on the basis of both grid sizes.

The second study area was in the Tidewater area of Virginia. It consisted of the city of Norfolk in the western half of the area and the city of Virginia Beach in the eastern half. The 448-km^2 area was gridded only into 2.0x2.0-km squares for the inventory of the daily VKT by using recorded 1977 traffic data (4,5).

CO Measurement Sites

Metropolitan Richmond

From the two emission inventories for metropolitan Richmond, eight pairs of overlapping grid squares were selected (Figure 1). Based on 1976 traffic data (3), these squares represented ranges of 15 000 to 206 000 and 11 000 to 144 000 daily VKT in the 2.0x2.0-km grid squares and the 1.4x1.4-km grid squares, respectively:

	Total Daily VKT per Grid Square	
Site	2.0x2.0 km	1.4x1.4 km
1	167 000	90 000
2	89 000	35 000
3	206 000	144 000
4	111 000	46 000
5	15 000	11 000
6	77 000	31 000
7	175 000	79 000
8	53 000	35 000

Then, in each pair of squares, a CO measurement site was located that was (a) beyond the microscale effect of any primary link, (b) accessible to personnel and to air-sampling devices, and (c) fairly safe from vandalism. The exact locations of sites 1 through 8, their Universal Transverse Mercator (UTM) coordinates, and the land uses that surround them are given in Table 1.

Tidewater Area

From the one VKT inventory for this second study area, six 2.0x2.0-km grid squares were selected (Figure 2). As indicated below, these squares provided a range of 60 000 to 386 000 daily VKT based on 1977 traffic data (4,5).

Site	Total Daily VKT
1	260 000
2	171 000
3	113 000
4	386 000
5	204 000
6	60 000

By using the previously mentioned criteria, a CO measurement site was located in each grid square. Table 2 gives the locations of the six sites and the existing land uses in their respective squares.

Since it is usually extremely difficult to find a measurement site in a central business district that is beyond the microscale air-quality effect of a nearby street, none of the sites in the study were located in a central business district.

Measurement of CO Concentrations and Meteorological Variables

CO Concentrations

Hourly average CO concentrations at all measurement sites in a study area were measured simultaneously with the aid of sequential air samplers, each designed to collect hourly air samples in separate Tedlar air bags at some preset sequence. The air samplers were all programmed to collect air samples at the same times. Each air sample was analyzed for its CO concentration by using a gas chromatograph equipped with a flame-ionization detector and calibrated daily with span gases.

In the metropolitan Richmond area, the measurements were made for five consecutive days (December 12-16, 1977). During each day, samples were collected hourly from each of the eight sites from 5:00 a.m. to 9:00 p.m. EST. This yielded a total of 640 samples.

In the Tidewater area, similar measurements were made for only two consecutive days (January 9 and 10, 1979) at the six selected sites. For this site, 192 air samples were collected and analyzed.

Meteorological Variables

Concurrent measurements of meteorological variables such as wind speed and direction and ambient temperature were also made in each study area at selected spots.

In metropolitan Richmond, these variables were measured at a recreational park located along Interstate 195. This station was more or less central to all eight CO measurement sites (Figure 1). A second station was established at the edge of a small airport owned by the state police in the southwest quadrant of the study area to measure only wind speed and direction. The two anemometers used were set up at a standard height of 10 m and with proper exposure. In addition to the data taken at these stations, concurrent data were obtained on wind speed and direction that were being collected continuously by the Virginia State Air Pollution Board at two locations in the area. The anemometer

Table 1. CO measurement sites used in metropolitan Richmond.

Site	Location	UMT Coordinate		City or County	Land Use
1	East of Brook Road between Hilliard Road and I-95	E N	283.667 4165.464	Henrico County	60 percent open space, 30 percent residential, 5 percent multifamily, 5 percent commercial
2	Barrington and Glenthorne Roads	E N	287.476 4160.619	Henrico County	90 percent residential, 10 percent open space, commercial, and industrial
3	West of Brook Road between Westwood and Rennie Avenues	E N	284.000 4161.274	Richmond	80 percent residential, 10 percent institutional, 5 percent multifamily, and 5 percent industrial and commercial
4	St. Christopher Road between Wesley and Henri Roads	E N	277.464 4161.928	Richmond	75 percent residential, 20 percent open space, 5 percent commercial
5	North of River Road and east of Parham Road	E N	273.119 4161.928	Henrico County	100 percent residential and open space
6	Kildare and Westower Drives	E N	278.798 4155.786	Richmond	90 percent residential, 8 percent multifamily, 2 percent commercial
7	24th and Stonewall Avenues	E N	282.630 4155.571	Richmond	50 percent residential, 20 percent river, 10 percent open space, 10 percent commercial, 5 percent multifamily, 5 percent industrial
8	Stansburg and Daytona Drives	E N	278.643 4151.512	Richmond	55 percent residential, 20 percent commercial, 15 percent open space, 5 percent multifamily, 5 percent institutional

Figure 2. Tidewater area gridded into 2.0x2.0-km squares.

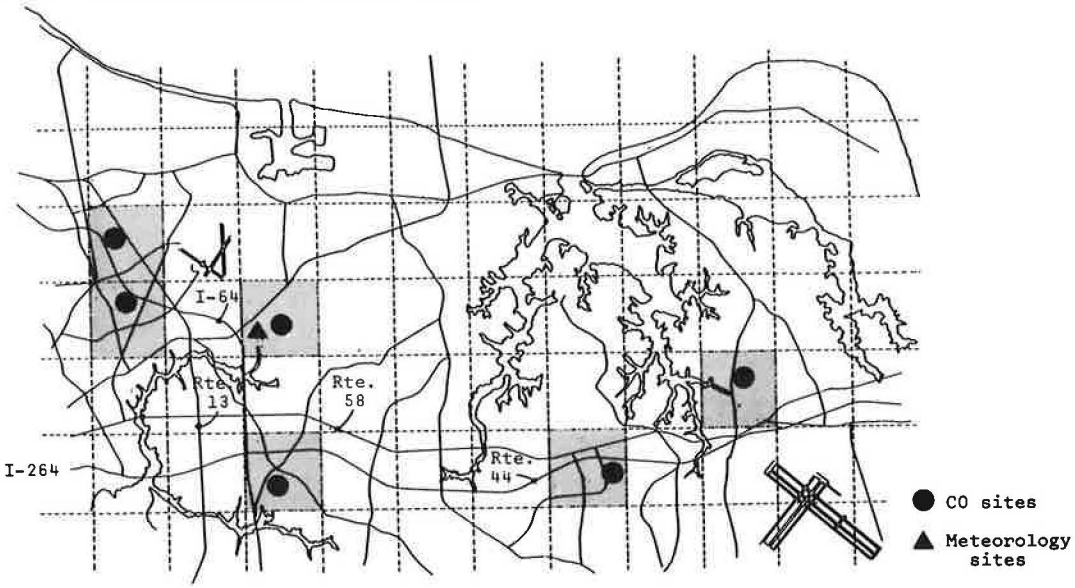
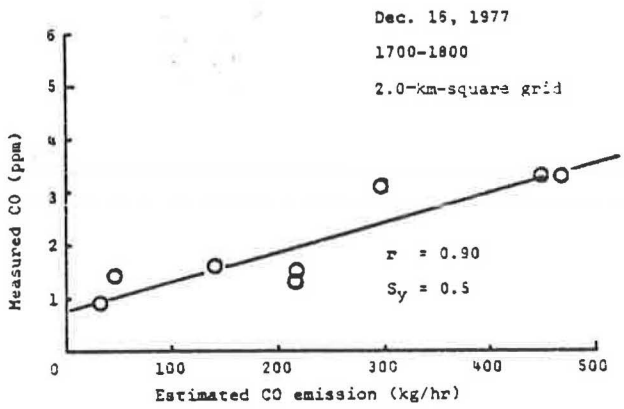


Table 2. CO measurement sites used in Tidewater area.

Site	Location	UTM Coordinate		City	Land Use
1	On East Tanner Creek Drive in Rosemont area east of I-64	E N	390.180 4084.301	Norfolk	50 percent residential, 20 percent multifamily, 20 percent commercial, 5 percent institutional, 5 percent open space
2	At 5171 Kennebeck Avenue in Elmhurst area south of I-64	E N	390.704 4082.419	Norfolk	70 percent residential, 15 percent multifamily, 10 percent commercial, 5 percent institutional
3	At 1029 Anoka Avenue in Diamond Lake Estate south of Route 13	E N	394.426 4081.594	Virginia Beach	72 percent open space, 20 percent residential, 5 percent institutional, 3 percent commercial
4	At 5606 Colter Court in Arrowhead area south of Route 44	E N	394.286 4077.398	Virginia Beach	40 percent open space, 35 percent residential, 15 percent commercial, 8 percent multifamily, 2 percent institutional
5	At Lynnhaven School on Dillon Drive	E N	403.349 4075.896	Virginia Beach	55 percent residential, 27 percent open space, 11 percent commercial, 5 percent multifamily, 2 percent institutional
6	At 701 Earl of Warwick Court in Wolfsnare Plantation east of Great Neck	E N	406.674 4079.077	Virginia Beach	50 percent open space, 37 percent residential, 12 percent multifamily, 1 percent commercial

Figure 3. Relationship between measured mesoscale CO concentrations and estimated emissions.



at one location, a Continuous Air-Monitoring Program (CAMP) station in the northwest quadrant, was calibrated against one of the two previously mentioned anemometers for purposes of standardization. The wind-speed data collected at these four stations were averaged for use in the correlation.

In the Tidewater area, measurements of wind speed and direction and ambient temperature were made on the grounds of the Norfolk Academy, which is located in the western half of the study area.

Concurrent hourly mixing heights at the study areas were calculated from morning radiosonde data recorded at the nearest National Weather Station (NWS) upper-air station and hourly averaged ambient temperatures were observed at the study area by using methods described by Ludwig and others (1). Radiosonde observations at NWS upper-air stations in Sterling (station 72 403) and Wallops Island (station 72 402) were used for the metropolitan Richmond and Tidewater areas, respectively.

Calculation of CO Emission Rates

For each measurement hour in a study area, the CO emission rates for all the selected grid squares were calculated. The CO emission rate in a square was calculated as the sum of emission rates from all individual primary links in that square; i.e.,

$$E_{ih} = (1/1000) \sum_l (ADT)_l (length)_l F_{lh} e_{lmstwm} \quad (2)$$

where

E_{ih} = CO emission rate (kg/h) for grid square i during hour h,

F_{lh} = fraction of ADT on link l during hour h, and

e_{lmstwm} = composite emission factor (g/km) for link l, calendar year m, average traffic speed s, ambient temperature t, percentage cold operation w, and mixture m of VKT by vehicle type.

F_{lh} for each link that occurred during the hour of interest cannot be measured in a practical way. Instead, an average diurnal distribution derived from recorded diurnal distributions for typical downtown streets, city arterials, suburban arterials, and suburban expressways was used for all the links of interest in metropolitan Richmond, and a similarly derived distribution was used in the Tidewater area.

The composite emission factors were computed by a method described by Kircher and Williams (6). A nationwide mixture of VKT that consisted of 80 percent from automobiles, 12 percent from light trucks, 5 percent from heavy gasoline trucks, and 3 percent from heavy diesel trucks was used for both study areas. These figures are close to the average vehicle count of 84 percent automobiles, 11 percent light trucks, and 5 percent heavy trucks observed on some major arterials in the Richmond area in 1975.

Because reliable values for the percentage of vehicles that operated cold and hot-transient were not available, it was decided to use no cold operation or hot-transient for expressways and rural arterials and 20 percent cold operation and 27 percent hot-transient for all other roads and for all hours of the day and for both study areas. These figures were suggested as best estimates by S.F. Curling, Jr., of the Environmental Quality Division, Virginia Department of Highways and Transportation.

The average traffic speeds for the links were provided by the Virginia Department of Highways and Transportation and, in the absence of detailed estimates, were assumed to be uniform throughout each day.

RESULTS AND DISCUSSION

Correlation of Mesoscale CO Concentrations with Areal Emission Rates

In the derivation of an empirical relationship among the mesoscale CO concentration, vehicular CO emissions in each grid square, and the meteorological variables, some assumptions were made. These assumptions were that (a) motor vehicles were by far the largest contributor of the pollutant in question, so that one could ignore the effect of other sources of CO; (b) the hourly mesoscale CO concentration in a grid square of a finite size was reasonably uniform; and (c) this concentration was linearly proportional to the hourly vehicular CO emission rate in the grid square. This may be expressed as follows:

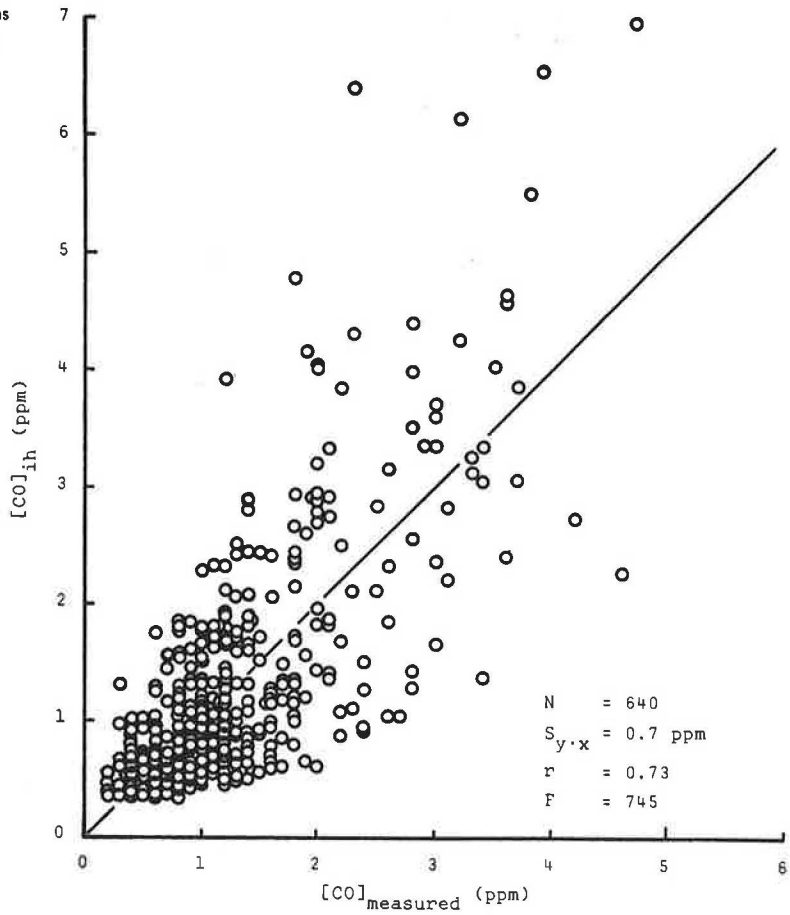
$$[CO]_{ih} = m_h E_{ih} + b_h \quad (3)$$

where $[CO]_{ih}$ is hourly mesoscale CO concentration (ppm) in grid square i during hour h and and m_h, b_h are constants for hour h, which may be related to meteorological variables.

The third assumption is similar to that made in simple and practical rollback modeling (2,7,8). Under the above assumptions, each set of hourly CO concentrations measured at the sites in Richmond was correlated, through regression analysis, with the calculated concurrent hourly CO emission rates to yield the best linear relationship among the variables for a given hour. An example of such an analysis is shown in Figure 3, in which the correlation is extremely good. The best-fit straight line is displayed. An examination of all the resulting correlations that correspond to the Richmond data for only the rush hours revealed an average correlation coefficient of 0.66 and an average standard error of estimate of 0.4 ppm by using emissions calculated when the grid of 2.0x2.0-km squares was used. For emissions calculated when the grid of 1.4x1.4-km squares was used, an average correlation coefficient of 0.61 and an average standard error of estimate of 0.4 ppm were obtained. These statistics indicated that the assumed linear relationship between the mesoscale CO concentration and vehicular CO emission rate was reasonably valid.

The set of proportionality factors m_h that resulted from the above linear regression analyses

Figure 4. Plot of measured versus calculated CO concentrations for Richmond when a 2.0x2.0-km emission inventory grid was used.



was subsequently correlated with the meteorological variables such as wind speed and mixing height. It was found that the proportionality factor is best correlated to wind speed by the following equations:

$$\log m_h = a_2 + a_1 \log(1/\mu)_h \quad (4)$$

or

$$m_h = 10^{[a_2 + a_1 \log(1/\mu)_h]} \quad (5)$$

where μ_h is the hourly average wind speed (in kilometers per hour) for hour h, and a_1, a_2 are constants.

The set of factors b_h may be viewed as residual pollutant concentrations from previous hours and are uninfluenced by concurrent emission and meteorology, since they were found to correlate best with the previous hour's wind speed and mixing height. That is,

$$b_h = b_2 + b_1(1/\mu H)_{h-1} \quad (6)$$

where

μ_{h-1} = wind speed (km/h) during hour (h-1),
H_{h-1} = mixing height (km) during hour (h-1), and
b_1, b_2 = constants.

Substituting Equations 5 and 6 into Equation 3 yields the following relationship:

$$[CO]_{ih} = kE_{ih} \cdot 10^{[a_2 + a_1 \log(1/\mu)_h]} + b_1(1/\mu H)_{h-1} + b_2 \quad (7)$$

where all the variables and constants except k are as previously defined. The adjustment factor k is introduced to optimize the agreement between the measured CO concentrations--[CO] measured--and those calculated--$[CO]_{ih}$--by using Equation 7, i.e., to let $[CO]_{ih}$ = [CO] measured. The optimum values for the various factors or constants, as derived from regression analyses, are given below for the two grid systems used in metropolitan Richmond.

Constant	Grid 2.0x2.0 km	Grid 1.4x1.4 km
k	2.11	2.18
a_1	1.31	1.17
a_2	-1.75	-1.56
b_1	0.38	0.46
b_2	0.28	0.24

By using Equation 7 and the appropriate constants, the hourly mesoscale CO concentrations at each of the eight Richmond sites during the measurement period were calculated from emission rates estimated when the two inventory grids were used. Figures 4 and 5 show comparisons of the measured and calculated mesoscale CO concentrations that correspond to the 2.0x2.0-km and the 1.4x1.4-km grid systems, respectively. As is evident in the overall agreement between the measured and calculated concentrations, the empirically derived Equation 7 should reasonably relate the areal vehicular CO emission rate and meteorology to mesoscale CO concentrations.

Considering only the overall agreement shown in the above comparison, no discernible difference is found between the estimated emission rates from the

Figure 5. Plot of measured versus calculated CO concentrations for Richmond when a 1.4x1.4-km emission inventory grid was used.

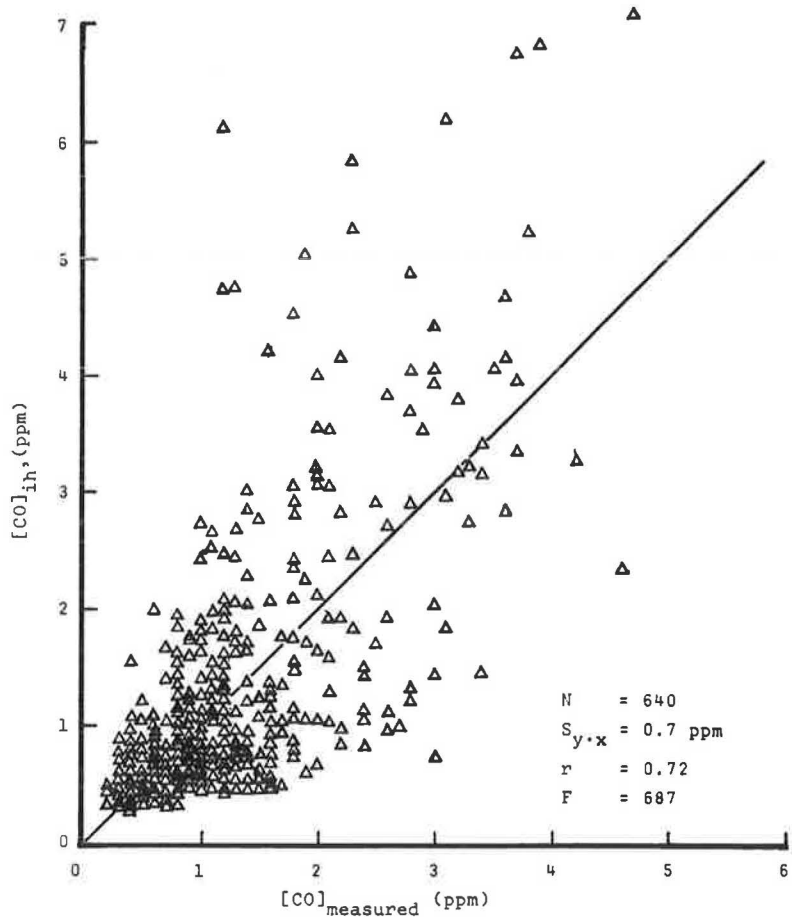


Table 3. Linear regression characteristics for individual Richmond sites.

Site	Correlation Coefficient	Sy – x (ppm)	$Sy - x/\bar{C}_0$ Value	$Sy - x/\bar{C}_0$ Order[a]
2.0x 2.0-km Grid				
1	0.48	0.7	0.6	3
2	0.74	0.5	0.5	2
3	0.77	0.8	0.6	3
4	0.68	0.7	0.6	3
5	0.66	0.4	0.5	2
6	0.83	0.5	0.4	1
7	0.83	0.8	0.6	3
8	0.77	0.4	0.4	1
1.4x 1.4-km Grid				
1	0.48	0.9	0.8	5
2	0.73	0.5	0.5	2
3	0.77	0.8	0.6	3
4	0.58	0.9	0.8	5
5	0.66	0.5	0.7	4
6	0.83	0.4	0.4	1
7	0.83	0.7	0.6	3
8	0.77	0.5	0.5	2

[a] Order of increasing ratio of $Sy - x/\bar{C}_0$, where $\bar{C}_0$ is the average measured CO concentration for each site.

two inventory grids. However, when consideration is given to the performance of Equation 7 for the eight individual measurement sites (Table 3), the grid that has the larger squares may be slightly preferable. As shown in Table 3, when the 2.0x2.0-km grid was used, the differences between $Sy - x/\bar{C}_0$ (i.e., standard error of estimate per unit of average CO concentration measured at a site) for the different sites were smaller or more uniform. This slight difference between the two grids probably arose because the 1.4x1.4-km squares were so small that, because of the way in which the inventory grid was laid over the study areas, the CO emissions from some primary links that contributed to the mesoscale CO concentrations at some of the sites were not covered or included in the estimates of total emission rates as sufficiently as they were when the larger squares were used.

Table 3 also indicates that some sites seemed to have consistently better results (i.e., a relatively lower $Sy - x/\bar{C}_0$) by using Equation 7 than did the other sites in both grid systems. Specifically, sites 2, 6, and 8 appeared to have better results than did sites 1 and 4. These differences between sites are, to a certain extent, illustrated in Figure 6. An examination of Table 1 does not reveal any discernible relationship between regression characteristics and land use. The intentional omission of grid cell-to-cell transport and the assumption of uniform wind flow and mixing height throughout the entire study area certainly contributed to these differences.

A similar analysis of the Tidewater data indicated that the relationship expressed in Equation 7 is reasonably valid, as illustrated in Figure 7. Although it does not compare favorably with the Richmond results, the agreement between the measured and calculated CO concentrations for the Tidewater area is nevertheless reasonable if we consider that the Tidewater data are relatively limited. The optimum constants for Equation 7 that correspond to

the Tidewater data when the 2.0x2.0-km grid was used are given below:

Constant	Value
k	3.16

Constant	Value
a_1	0.48
a_2	-2.34
b_1	5.74
b_2	-1.08

Figure 6. Comparison between measured and calculated CO concentrations for Richmond on December 12, 1977.

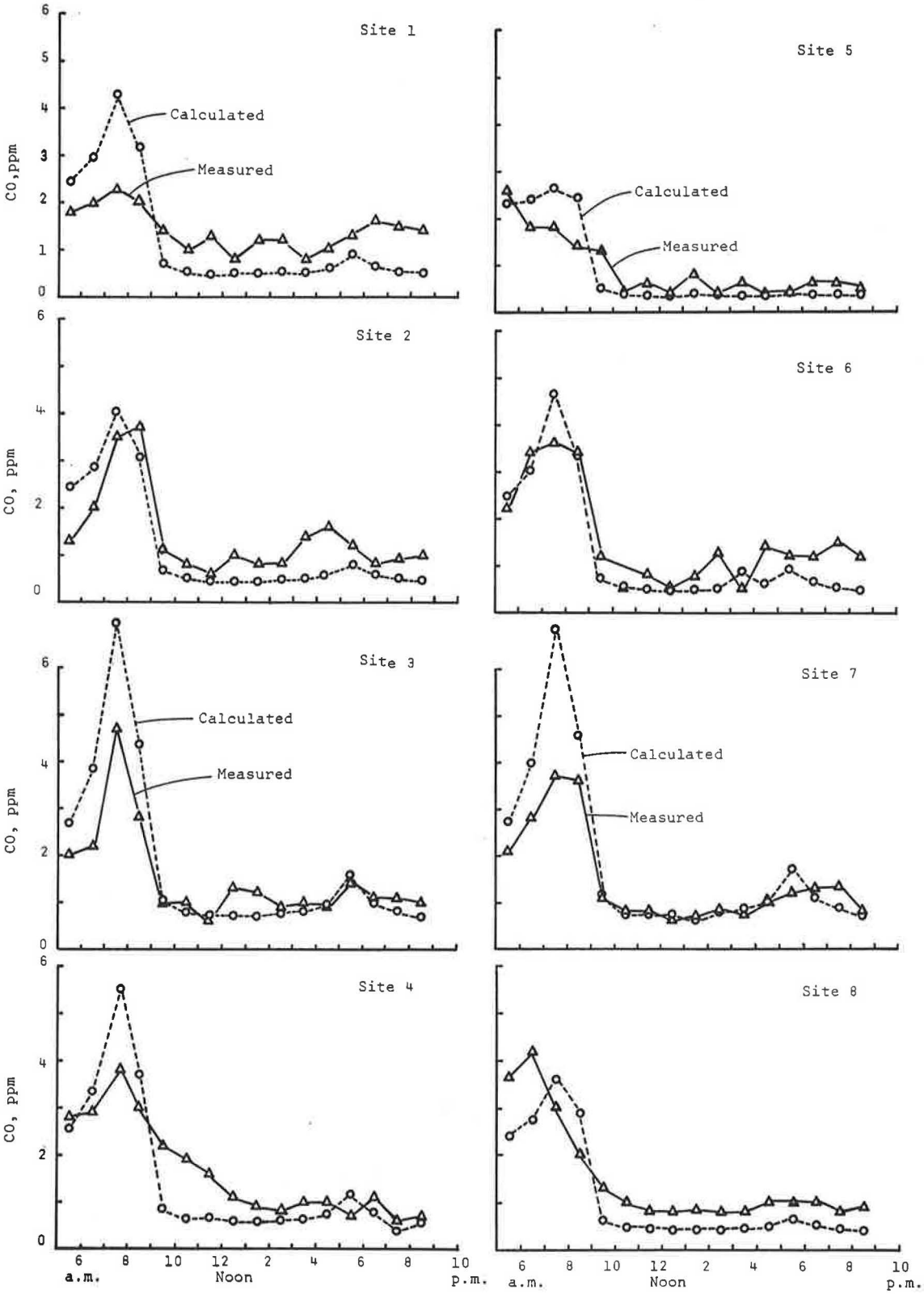
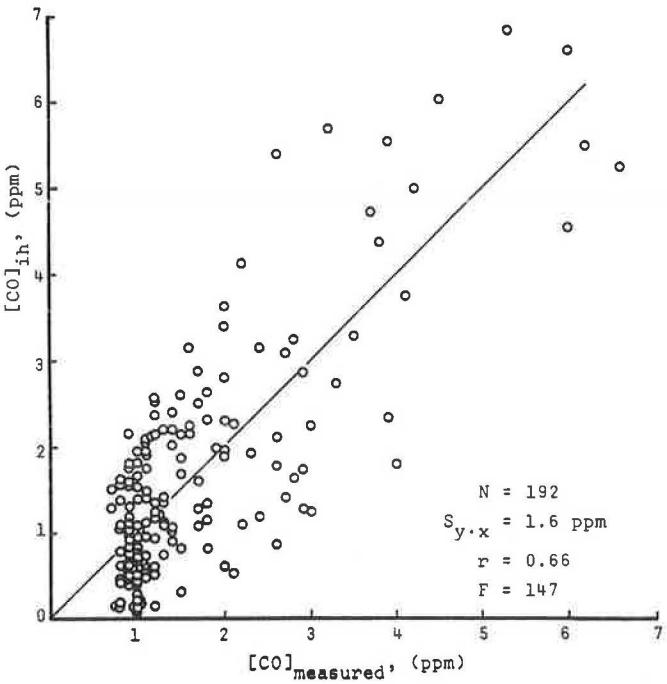


Figure 7. Plot of measured versus calculated CO concentrations for Tidewater when a 2.0x2.0-km emission inventory grid was used.



As is evident, these are significantly different from those for Richmond. The difference may be due to differences in factors such as the topography and the effect of the land-sea breeze.

Without the adjustment factor k, Equation 7 predicted lower CO concentrations for both urban areas when the measured concentrations were greater than 2 ppm. This discrepancy is believed to have been caused by an underestimation of the areal emission rates--especially for the traffic rush hours--because of the small amount (or, in some cases, total lack) of reliable data on primary and secondary traffic volumes and speeds, the diurnal traffic distribution at each link, vehicle mixes, and percentage of cold operation.

Sensitivity Analysis

A sensitivity analysis of Equation 7 was conducted to assess how each of the input variables affects the calculated CO concentrations by using the following conditions as the base case and the optimum values for the constants listed for Richmond earlier: CO emission rate, 100 kg/h; concurrent wind speed, 10 km/h; previous hour's wind speed, 10 km/h; and previous hour's mixing height, 1 km. Figures 8 and 9 illustrate that, with the exception of the CO emission rate (E_{ih}), all parameters inversely affect the calculated CO concentrations. The estimated relative importance of each input parameter (IP) is shown in Table 4 as it applies to

Figure 8. CO emission rate (top) and concurrent wind speed (bottom) versus CO concentration.

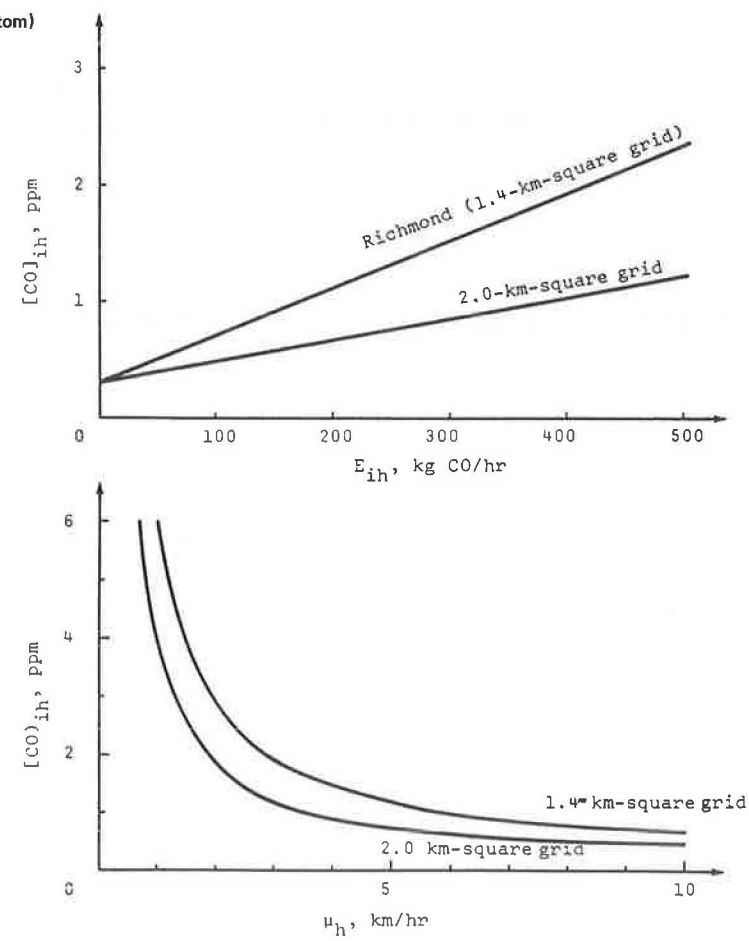


Figure 9. Previous hour's wind speed (top) and previous hour's mixing height (bottom) versus CO concentration.

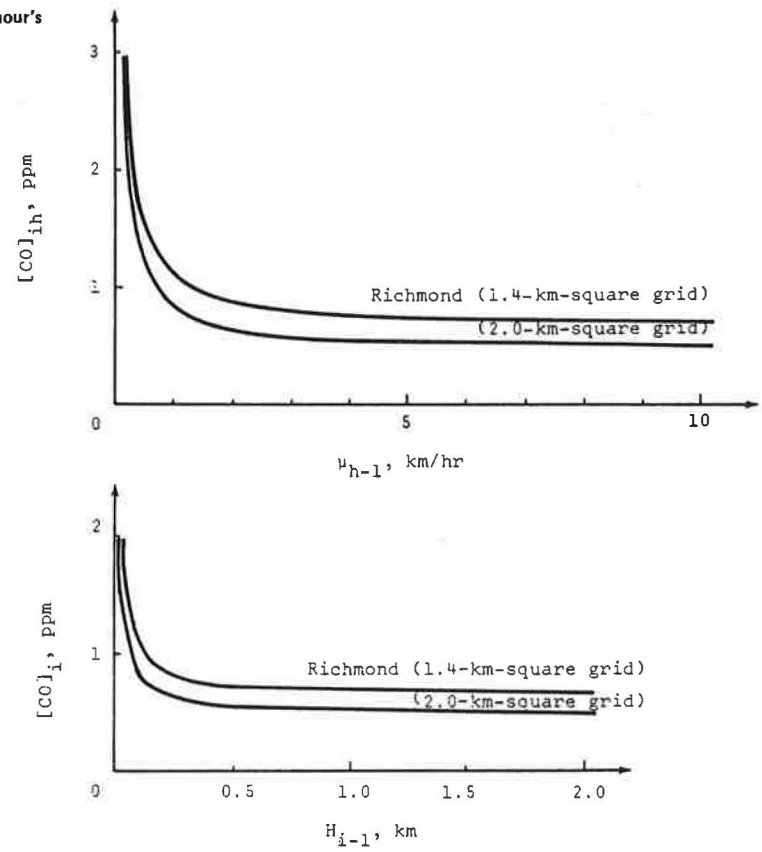


Table 4. Sensitivity rankings of input parameters.

	Rate of Change in			Percentage Change in			Absolute Sensitivity |C/IP| per Grid	
		C (ppm) per Grid			C per Grid			
IP	IP	2.0x2.0-km	1.4x1.4-km	IP	2.0x2.0-km	1.4x1.4-km	2.0x2.0-km	1.4x1.4-km
E_{ih}	100-500 (kg/h)	0.50-1.22	0.70-2.34	+400	+144	+234	0.36	0.58
μ_h	4-20 (km/h)	0.93-0.39	1.48-0.47	+400	-58	-68	0.14	0.17
μ_{h-1}	4-20 (km/h)	0.55-0.48	0.75-0.66	+400	-13	-12	0.03	0.03
H_{h-1}	0.4-1.5 (km)	0.56-0.48	0.76-0.67	+275	-14	-12	0.05	0.04

Note: IP = input parameter; C = CO concentration.

improvement in accuracy of calculated CO concentration (C). As expected from the assumptions used to derive the relationship, the CO emission rate is the most important input, and the concurrent wind speed (μ_h) is next. The least important are the previous hour's wind speed (μ_{h-1}) and the mixing height (H_{h-1}). This, of course, means that improvement in the estimation of the emission rate, which involved CO emission factors and various types of traffic data (especially those for the traffic rush hours), would provide the most improvement in the accuracy of the calculated CO concentrations. The same situation applies to μ_h, although to a slightly lesser extent. It is interesting to note that there are no significant differences in the relative rankings of the input parameters between the two grids except for the emission rate. This parameter apparently affects the calculated CO concentrations that are based on the 1.4x1.4-km grid significantly more than those based on the other grid. This suggests that a grid that consists of squares that are large but still of reasonable size so as not to lose spatial resolution would be preferable, since reliable or accurate traffic data are extremely scarce.

CONCLUSIONS

As indicated by the agreement between the measured and calculated mesoscale CO concentrations for two Virginia urban areas, the relationship between the mesoscale CO concentrations and areal vehicular CO emission rates is reasonably approximated by Equation 7.

The correlations made in the study indicated that the various constants a_1, a_2, b_1, b_2, and k are fairly area specific; i.e., their values differed for different urban areas because of differences in topography, the effect of the land-sea breeze, and other factors. This finding implies that optimum constants for an urban area must first be determined by using a methodology similar to that described above. Once calibrated, Equation 7, along with a set of assumed meteorological conditions, can be used to estimate background CO concentrations at any receptor point in any highway project within the

urban area from estimated CO emission rates within a grid square that surrounds the receptor. The calculation, of course, can be achieved with a desktop calculator. At present, when the reliability of the necessary input parameters is questionable, the use of such an approximation may be preferable to the use of the more-complex dispersion models.

Of the two emission inventory grids tested, the 2.0x2.0-km square grid (which had the larger squares) is probably preferable from two standpoints. First, a sensitivity analysis showed that calculated CO concentrations were relatively less sensitive to an error in emission rates when estimated by using the grid that consisted of the larger squares. Second, an examination of the performance of Equation 7 for the eight individual measurement sites in Richmond also favored that grid.

ACKNOWLEDGMENT

I wish to express my appreciation for the assistance provided by personnel of the Virginia State Air Pollution Control Board and the Environmental Quality and Traffic and Safety Divisions of the Virginia Department of Highways and Transportation. The valuable assistance given by various personnel of the Virginia Highway and Transportation Research Council is also acknowledged. The study was conducted with Highway Planning and Research Program funds administered through the Federal Highway Administration of the U.S. Department of Transportation. The contents of this paper reflect my views and do not necessarily reflect the official views and policies of the sponsoring agencies.

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Publication of this paper sponsored by Committee on Transportation and Air Quality.

Evaluation of the Federal Highway Administration Procedure for Highway Traffic Noise Prediction

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Procedures for predicting traffic noise are used in the design of new highways to determine whether noise is limited to specific levels. A previous study evaluated the procedure outlined in National Cooperative Highway Research Program (NCHRP) Report 117 and developed a correction factor that was incorporated into Kentucky's noise-prediction procedure. This adjusted NCHRP 117 procedure has been used in Kentucky for the past several years. The Federal Highway Administration has developed a new procedure to predict traffic noise levels. The objective of this study was to evaluate the new prediction procedure, designated Simplified Noise Analysis Program (SNAP 1.0). Comparisons of measured and predicted noise levels showed that better predictions are obtained from SNAP 1.0 than from the adjusted NCHRP 117 procedure. Therefore, it was recommended that the SNAP 1.0 prediction procedure be adopted. There was no need for a general correction factor; however, adjustments in specific portions of the procedure may be necessary to optimize the predictions.

A policy and procedure memorandum from the Federal Highway Administration (FHWA) directed that, after July 1, 1972, all highways constructed must conform to specific design noise levels (1). Several procedures have been developed to predict future noise levels of highways. The prediction procedure originally used in Kentucky was developed in the National Cooperative Highway Research Program (NCHRP) Report 117 (2). The accuracy of this procedure was questioned and therefore an evaluation was conducted. The evaluation revealed significant discrepancies between measured and predicted values; a correction nomograph developed in this study was incorporated into Kentucky's procedure (3). This nomograph used roadway-to-receiver distance, truck volume per hour, and car speed to determine a correction factor to be applied to values as determined by the method outlined in NCHRP 117. Approval was granted by FHWA in October 1974.

Research has continued toward the objective of developing a more-accurate procedure. A new procedure was reported in NCHRP 174 (4), and a traffic-noise-prediction model was developed by FHWA (5). FHWA then developed computer programs (6,7);