Comparison of Intersection Air Quality Models' Ability To Simulate Carbon Monoxide Concentrations in an Urban Area

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In support of an environmental impact statement for a major transportation project in New York City, an air quality study was undertaken to determine model performance of intersection air quality and to ascertain which model should be applied for impact analyses for this project. Instruments were set up at six intersections to measure carbon monoxide concentrations and meteorological data. Traffic data were collected by videotaping. To date, results from two of the six intersections have been analyzed. Model performance was disappointing. Correlation coefficients of observed to predicted concentrations were low (generally less than 0.1), as were the slopes of linear best-fit curves. The models, on average, underpredicted observed concentrations, with only those models that separate composite emissions into their more discrete components indicating a potential for approaching or overpredicting observed carbon monoxide levels.

The New York State Department of Transportation (NYSDOT), with the participation of the city of New York and the FHWA, is proposing a reconstruction of the southernmost 5 mi of Route 9A in New York City, spanning from Battery Place to West 59th Street along the west side of Manhattan, beside the Hudson River.

Because of uncertainties in carbon monoxide mobile source modeling, a major air quality study was undertaken for this project. This study included multiprobe monitoring of carbon monoxide (CO) and meteorological and traffic data collection at six intersections.

The observed CO concentrations were compared to modeled CO values on the basis of observed meteorological and traffic inputs. The performances of eight different methodologies, established by a model selection protocol that was developed before model runs, were compared to determine which model was best able to simulate high observed CO concentrations.

DESCRIPTION OF SITES

For CO monitoring, six sites were selected at intersections likely to have project-induced traffic increases, and, therefore, possible air quality impacts. Spatial coverage of the study area and different traffic levels and geometries were also important considerations. Results for the first two sites analyzed are described.

Site 1, at West and Chambers Streets, is a T-type intersection directly on Route 9A (see Figure 1). Route 9A (also known as West Street in this area) runs north-south; the cross street, Chambers Street, forms the eastern leg of the intersection. Route 9A has two lanes in each direction, with left-turn lanes in the southbound direction. Chambers Street has one lane in each direction at the intersection. At Site 1, Route 9A generally has volume-to-capacity (*v/c*) ratios of about 0.75. Traffic flows fairly well because of the arterial nature of the roadway and the generally well-spaced intersections. The left-turn movements from southbound Route 9A are heavy. At Chambers Street, the left-turn movements are heavier in the a.m. peak hour.

Site 2, at Eighth Avenue and West 34th Street, is not on Route 9A, but in the secondary impact area, where possible traffic diversions could create air quality impacts. At Site 2, Eighth Avenue is one-way northbound (three lanes), and West 34th Street has two lanes in each direction (see Figure 2). This site is near Madison Square Garden, Penn Station, and the General Post Office. Congestion levels are greater than at Site 1 and more representative of Midtown traffic levels. Often during peak hours, *v/c* ratios approach 1.0. Left turns from 34th Street are not allowed at this location during peak hours.

Near Site 1, a background site was selected on an undeveloped portion of the area filled for Battery Park City, approximately 300 ft from West Street, the nearest source of traffic emissions. CO and meteorological parameters were monitored at this location. Near Site 2, a second background site was established on the roof of the nearby General Post Office, approximately 60 ft above street level and 15 ft above the roof line. At this location, only CO was monitored. This rooftop location was chosen because there were no ground-level locations nearby that would not be directly influenced by adjacent roadways.

DESCRIPTION OF EQUIPMENT

At each intersection site and at the Battery Park City background site, the CO monitoring equipment and associated

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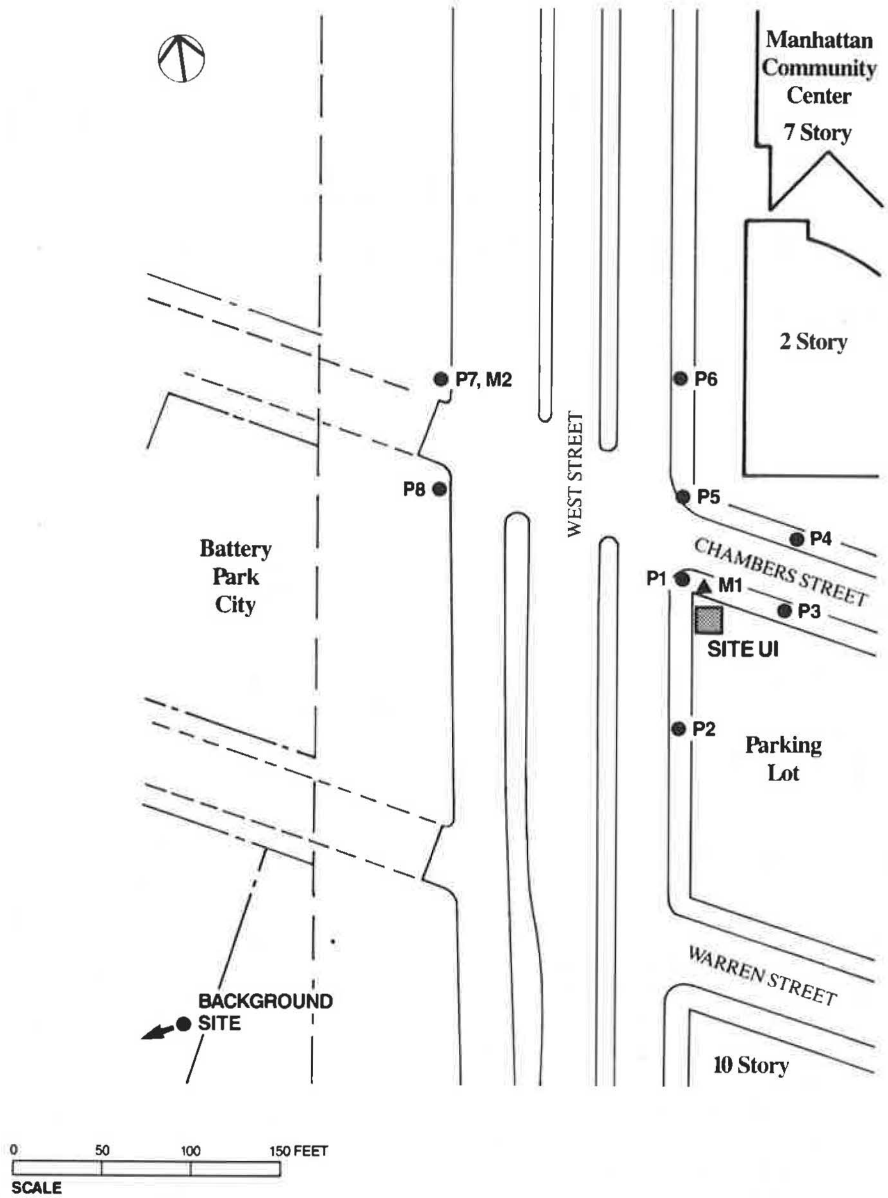

FIGURE 1 Site 1: West and Chambers streets.

instrumentation were placed in environmentally controlled shelters. At the General Post Office background site, the equipment was placed in a small room on the top floor of the building, with only the CO probe exterior to the structure and extending above the roof line.

The shelters at the intersection sites were each equipped with four CO analyzers; one CO analyzer was placed at each background site. Standard CO monitoring equipment was used. Additional details regarding the CO equipment and the probe and intake system design were provided by Sacco and Zamurs (*1*). At each intersection site, eight CO sampling probes were used, requiring that each CO analyzer share two probes. The sample probe and intake systems were designed to meet the specific requirements of each location. The eight probes were placed approximately 9 to 10 ft above street level and approximately 6 ft from the roadway, halfway between the curb and the building line. Figures 1 and 2 show the relative location of the sampling probes and the placement of the meteorological towers at the two intersection sites.

Two meteorological systems were used at Site 1 and three at Site 2. Meteorological monitoring towers of 10-ft height were used. One tower was placed atop the shelters at each of the intersection sites and also at the Battery Park City background site, and one and two additional meteorological monitoring systems were set up on existing light poles at Sites 1 and 2, respectively. The locations of the meteorological equipment are shown in Figures 1 and 2.

At each meteorological monitoring site, wind speed, wind direction, and temperature were measured using standard equipment; standard deviation of the wind direction (σ_θ) was calculated on the basis of an algorithm developed by Nelson (*2*). Initially, the σ_θ values were used to estimate Pasquill Stability Categories using the methodology outlined in EPA guidelines (*3*). However, on the basis of the initial review of

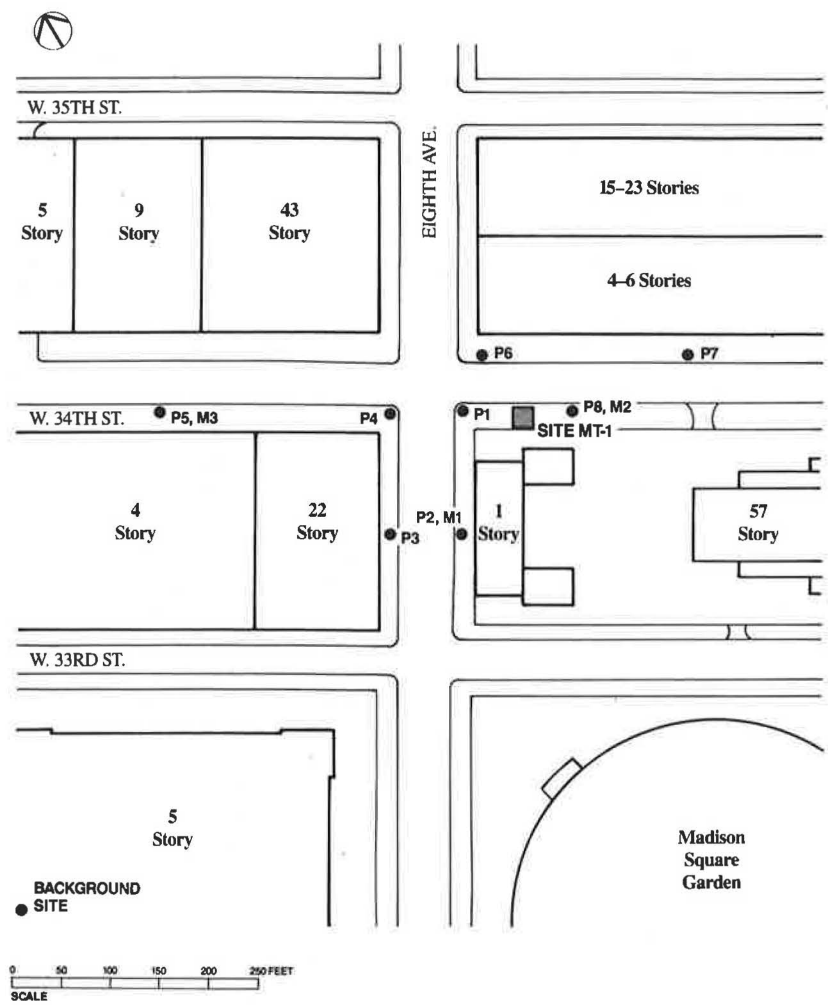

FIGURE 2 Site 2: 34th Street and Eighth Avenue.

σ_θ values and resultant stability determinations (with many excessively high values of σ_θ), and considering the siting of the meteorological sensors (which failed to meet unobstructed distance criteria), the methodology was revised. The stability classes used in the modeling analysis were based on cloud cover data from La Guardia Airport and the on-site wind speed measurements at the intersections (*4*). Except for stability inputs, all meteorological inputs for the modeling were derived from data collected at the intersection sites.

Data acquisition and validation were governed by strict standard operating procedures through a quality assurance program. The operation, data processing, and quality assurance–quality control practices conformed as closely as possible to the provisions of EPA prevention of significant deterioration (PSD) monitoring guidelines (*5*). However, the meteorological measurement systems' locations did not meet EPA siting criteria with respect to the required distance from a structure. On the basis of building heights in Manhattan, it was highly unlikely that a location that met the siting requirements could be obtained. No simple adjustment was readily available to compensate for this. Twice during the monitoring operation, the CO analyzers were audited by representatives of New York State Department of Environmental Conservation. Each of the intersections was monitored until 3 months of valid data were obtained. The background sites were monitored continuously during the intersection site monitoring program.

Traffic data to be used in the air quality prediction modeling scenarios were obtained through the use of videotaping and field surveys. All roadway links within 1,600 ft of the intersection where CO data were being collected were modeled, requiring a substantial traffic data collection effort. Because traffic signals in New York City can be as little as 100 ft apart, and are typically spaced every 250 ft along a north-south avenue, a substantial number of roadway links were required. For Site 1, 17 separate links were used for the analysis; for Site 2, 26 links were used.

The majority of the data collection effort used videotaping to gather real time detailed traffic information. Because an aim of the study was to determine model performance when high levels of CO were observed, videotaping of traffic data was preferred because only some of the hours would be reduced for model input. At both intersection sites, numerous videocameras and recorders were positioned strategically atop buildings and other structures to obtain the various traffic parameters.

The following traffic data were obtained from the videocameras: hourly traffic volumes, average travel speed, average stopped delay, average queue length, average travel speed excluding stopped delay (modified speed), vehicle classification, and traffic signal information. Once the hours of concern were determined from the CO monitoring, the videotapes were replayed to obtain the necessary traffic data. Statistical testing was performed to determine the proper hourly sample size required to obtain accurate hourly average values.

For the first five parameters, a value was obtained for each individual roadway link. Vehicle classification data were obtained on a corridor basis (i.e., northbound, southbound, eastbound, westbound), using data from the intersections where the monitoring was being conducted.

Some of the traffic parameters that were required for one or more of the modeling methodologies could not be obtained from the videotapes. These parameters—acceleration and deceleration rates, cruise speeds, and thermal conditions (i.e., hot or cold start mode)—were obtained from field surveys. The data for each of these parameters were obtained for four different averaging periods—morning peak, midday, evening peak, and the late-night, low-volume period. Each hour of concern that was examined for detailed analysis was assigned to one of these categories and the appropriate thermal state, cruise speed, etc., was used.

DESCRIPTION OF MODELING

Emission Scenarios

The study evaluated the performance of four different emission scenarios using both the HIWAY-2 (*6*) and CALINE3 (*7*) line source dispersion models—a total of eight modeling scenarios, or models. The four emission scenarios, which differed in their spatial and quantitative representation of emissions, were as follows:

- Average speed,
- Modified average speed plus idle,
- Modal emissions, and
- CAL3QHC.

Each of these scenarios is discussed in the following paragraphs, along with a brief description of the line sources used in each application.

Average Speed

The average speed emissions scenario used an average source strength over the entire link, which was based on the total travel time from stop line to stop line for each individual link. A link was defined as a roadway segment (i.e., Eighth Avenue northbound from West 33rd to 34th Street) between two traffic signals. At both sites, each roadway link was modeled using the traffic information from the videotapes and emission factors from the EPA's mobile source emission model MOBILE4 (*8*). This scenario is similar to the FHWAINT model, as described by PEI Associates (*9*).

Modified Average Speed plus Idle

This scenario was used to simulate the effects of idling vehicles at each intersection where a traffic signal was located. The modification refers to the methodology used in calculating the average speed: the vehicle's stop time in a queue (or stopped delay) was subtracted from the total travel time, resulting in a higher average speed. The higher average speed was used with MOBILE4 emission factors to determine the emission source strength over the entire link. This procedure was the same as that discussed for the average speed scenario, but minimized double counting of idle emissions. (The MOBILE4 emission factors were based on a drive cycle in which the proportion of idle emissions increased with decrease in speed.) This scenario is similar to the EPAINT model, as described by PEI Associates (*9*).

The modified average speed for a given roadway segment was still less than the cruise speed, because it included delays caused by slowing, merging, side frictions, etc. The stopped delay was used in this scenario rather than the approach delay, because it was more conducive to quantification from either videotapes or field surveys. It is also a direct output of the *1985 Highway Capacity Manual* (HCM) (*10*), which was being used for the transportation analysis within the overall Route 9A environmental impact statement.

The idle emissions were distributed over a line source that was based on the information obtained from the videotapes. The queue length as measured at the end of the red cycle, averaged over the hour, was used to position this link on the roadway network. It extended back from the stop line of the intersection for the distance computed from the videotapes for each link for each hour of concern. The length was computed assuming a conversion of 8 m per vehicle in queue.

The idle emissions yielded from MOBILE4 were used with the measured stopped delay to estimate the emissions from the queue line source. However, because MOBILE4 only provides idle emission factors for hot-stabilized vehicles at 75°F, the idle emissions were adjusted for the given thermal conditions and measured temperature by developing ratios of MOBILE4 emission factors at 2.5 mph for actual conditions and the hot-stabilized condition.

Modal Emissions

For this scenario, emissions were computed for the four modes of vehicular operation—cruise, deceleration, idle, and acceleration. The idle emissions were obtained from MOBILE4, and the cruise, acceleration, and deceleration emissions were obtained from the modal emission subroutines of the Intersection Midblock Model (IMM) (*11*), which were based on the EPA Modal Analysis Model (*12*).

The modal emissions were distributed along the link in close approximation to where they actually occurred. The idle emissions were computed on the basis of the average vehicle stopped delay, and distributed along the average queue length obtained from the videotapes (the same as discussed for the modified average speed plus idle scenario). The cruise emissions were distributed over the entire roadway link, whereas an additional pseudolink was developed for each segment to simulate acceleration-deceleration emissions. The length of each acceleration-deceleration pseudolink was based on the upstream and downstream cruise speeds and the acceleration and deceleration rates obtained from the field surveys. The method used in the IMM model of placing this pseudolink upstream from the stop point of the link was followed for this scenario.

The subroutines from the IMM model that generate cruise, acceleration, and deceleration emissions for hot-stabilized automobiles at 75°F in 1977 were utilized in the analysis. The 1977 emissions were updated for present-day conditions using correction factors generated by MOBILE4, on the basis of ratios of 1977 conditions to present-day observed conditions. These correction factors also accounted for differences in thermal conditions, temperature, vehicle mix, etc. The MOBILE4 idle emission factors were updated in the same manner as those used in the modified scenario. As indicated, this scenario is similar to IMM. It is also similar to Volume 9 (*13*), because, in many respects IMM is a computerized version of Volume 9. By having acceleration-deceleration emissions included, this scenario is the most similar to TEXIN2 and CALINE4 (*14,15*). These two models, although popular, were not directly evaluated in this study because using videotaped traffic information such as queue lengths and delay would have substantially eliminated some of the significant differences between these two models and among the other models represented by the modal emissions scenario. However, the performance of the modal emissions scenario relative to the other emissions scenarios would be expected to apply to TEXIN2 and CALINE4 as well.

CAL3QHC

A fourth emission scenario was studied that simulated the techniques used in the EPA's CAL3QHC model (*16*). This scenario differed from the modified average speed plus idle scenario in only two respects. First, instead of using the measured stopped delay from the traffic videotapes, the idle time was based on the percent red time at each traffic signal. Second, in the calculation of the queue length, this scenario used six meters per vehicle as opposed to the eight meters used in modified and modal scenarios. This scenario, while similar to the EPA's CAL3QHC, still differed significantly from that model in that the traffic input parameters were based on field-measured data and were not part of the model.

MOBILE4

For all scenarios except the modal scenario, calendar year 1989 vehicular emission factors were solely obtained from EPA's Mobile Source Emission Factor Model MOBILE4. For the modal scenario, the idle emission factors were obtained using MOBILE4, but the cruise and acceleration-deceleration emissions were based on the 1977 Modal Analysis Model. However, MOBILE4 emission factors were used to update and correct the modal emissions to the present-day scenario, as described.

Common parameters for the four emission scenarios used with MOBILE4 included thermal conditions, based on field surveys; ambient temperature; vehicle classification, obtained from the videotapes; inspection-maintenance (I/M) and antitampering credits, obtained from New York State Department of Environmental Conservation (DEC); mileage accrual and vehicle age distribution, obtained from the New York City Department of Environmental Protection (DEP); and fuel volatility (Reid vapor pressure), based on data obtained from DEC. Because of the significant numbers of medallion (yellow) taxicabs on New York City streets, different classes of light-duty gasoline vehicles were used in MOBILE4. Mileage accumulation and vehicle turnover are significantly different for taxis than for privately owned automobiles. Because of the nature of their operation (i.e., cruising), they are predominantly in a hot-stabilized thermal state. Therefore, separate MOBILE4 executions were made to develop the data base of light-duty emission factors at any given speed.

Dispersion Models

The four emission scenarios were used with the HIWAY-2 and CALINE3 dispersion models. Because more than one meteorological data set was obtained at the two intersection sites, the wind speed and direction used in the dispersion model depended on the probe being analyzed. Each of the eight CO probes was assigned to the closest meteorological tower. A mixing height of 1,000 m was used throughout the analysis, as was source heights of 0 m.

For the CALINE3 model, a surface roughness value of 3.2 m was used for both sites. As recommended in the CALINE3 User's Guide (*7*), 3 m was generally added to each side of the line source to account for the width of the mixing zone. However, for all idling links and a left-turn bay at the Chambers Street site, the 3 m was not added to the width of the line source. For CALINE3, six stability classes, A through F, were used in the modeling, whereas HIWAY-2 uses three classifications—unstable, neutral, and stable.

MODELING PROCEDURE

Evaluation studies have typically addressed both the scientific and operational performance of the candidate models (*17,18*). Scientific performance deals with the cause-and-effect relationships within each model and an understanding of how the model components contribute to the various errors. Operational performance deals with how the various models compare within a particular application, such as the prediction of high concentrations. For this study, the performance of the various modeling scenarios at predicting high concentrations, an operational characteristic, was the main concern. However, scientific evaluation of the modeling scenarios added to the understanding of their performance. The predicted versus observed concentrations for the various modeling scenarios under different spatial, meteorological, and traffic conditions were also analyzed.

Data Set Selection

The data set was first developed by subtracting the concentrations measured at the background monitoring locations from concentrations measured at each intersection site probe on an hourly basis. All the hourly CO values for each month were then rank ordered. Each hour appeared only once in the data set, regardless of the number of probes that experienced high CO values. The top 50 hr from each of the 3 months with the highest observed concentrations were then chosen for inclusion into the data set and subsequent traffic reduction.

Performance Measures

The primary goal of the study was to determine which modeling scenario most accurately predicted the highest measured CO concentrations at congested urban intersections. This model would then be used as the predictive air quality model for the Route 9A environmental impact statement's air quality study. Answers were also sought for many other questions, such as: Does one scenario consistently overpredict or underpredict by a constant percentage whereas another has no pattern to its error? Is there a difference in predicting midblock versus intersection concentrations between the various modeling scenarios? Do the scenarios exhibit good correlation but poorly predict the magnitude of the peak levels? Are the mean errors small because of the balancing of large underprediction with large overprediction? etc. With these questions in mind, a variety of statistical measures and graphics were used to evaluate the scenarios (*19–24*).

The modeling scenario predictions were compared with the observed data both in paired and in unpaired form. A paired analysis was used to evaluate each scenario's ability to replicate measured concentrations both temporally and spatially. The unpaired analysis was used to determine each scenario's ability to predict accurately the magnitude of the peak without regard to location or time. These comparisons analyze the scientific and operational performance of each scenario, respectively. The unpaired analysis is often given more weight by regulatory agencies, because it is thought to be more likely to represent the worst-case condition (i.e., the rare event) and, thus, be more protective of the ambient air quality standards.

Unpaired Comparisons

In the unpaired tests, the observed values were compared to the highest predicted concentrations without regard to probe location or time of occurrence. For the top 150 values, the following standard statistical parameters were calculated: (a) bias, (b) absolute gross error, (c) mean square error, (d) variance, and (e) cumulative frequency distribution plots of both the entire data set and the top 25 percent of the data set. (These plots were useful in evaluating the overall, or operational, performance of each modeling scenario. Each modeling scenario's performance in replicating the cumulative frequency distribution was evaluated for goodness-of-fit using a Kolmogorov-Smirnov test.)

Paired in Time and Space

The paired statistical tests were used to assess each scenario's ability to predict concentrations on the basis of the hourly traffic and meteorological conditions and to predict the location and time of distinct concentrations. The following standard statistical analyses were performed:

1. Scatter plots of predictions versus observed measurements, the correlation coefficient, and the slope and intercept of the linear least-squares regression line;
2. The bias and variance of the concentration difference where this difference is paired both in space and in time; and
3. The gross variability, which is a measure of the size of the error produced by each scenario.

Paired in Time Only

The last set of performance measures used in the study involved pairing the observed and predicted data in time, irrespective of probe location. These measures were used to determine if the various scenarios' performances differ when the pairing in space is eliminated from the analysis. The performance measures used for this analysis were correlation coefficient, slope of regression line, bias, and variance. These measures were recomputed using the highest predicted and observed values for each hour.

Results

The results of the statistical analysis for both sites are presented in Tables 1 and 2. In the tables, some of the statistics for the unpaired tests were computed for both the entire data set and the top 25 percent of the data. The latter were used to evaluate each scenario's performance at the highest observed concentrations.

Unpaired Basis

Two sample cumulative frequency plots for the unpaired data are shown in Figures 3 and 4. All the modeling scenarios indicated a negative average bias on an unpaired basis. For Site 1, all the HIWAY-2 scenarios and three of the CALINE3 scenarios significantly underpredicted observed concentrations. At Site 2, two of the CALINE3 scenarios indicated overpredictions on a cumulative unpaired basis (at approximately the 95th percent frequency).

At the highest predicted concentrations, the overpredictions were sometimes quite significant. For example, the CALINE3 modified scenario overpredicted the highest observed concentration by about 55 percent. Finally, at Site 2, at the highest end of the concentration distribution (greater than 75 percent), the HIWAY-2 modified scenario came closer to replicating the observed concentration distribution than the other scenarios.

Paired Basis

The results on a paired basis were even less encouraging. The paired-in-time-and-space regression analyses indicated basically no correlation for any of the modeling scenarios. The slopes of the best-fit linear regression lines were nearly zero in many instances and at times were actually negative. Figure 5 shows a typical scatter plot and regression line.

As expected, the regression analysis on a paired-in-time-only basis indicated some improvement over the analysis paired-in-time-and-space. However, neither the correlation coefficients nor the slopes of the regression lines attained a satisfactory level.

TABLE 1 SUMMARY STATISTICS—WEST AND CHAMBERS STREETS

Statistics	HIWAY-2				CALINE3			
	Average	Modified	Modal	CAL3QHC	Average	Modified	Modal	CAL3QHC
UNPAIRED								
All Data								
Bias	-4.26	-3.15	-3.19	-1.58	-4.64	-3.71	-3.82	-2.58
Absolute Gross Error	4.25	3.15	3.19	1.58	4.63	3.71	3.82	2.58
Mean Square Error	18.27	10.05	10.31	2.79	21.72	13.82	14.64	6.93
Variance	0.15	0.12	0.13	0.28	0.22	0.06	0.04	0.27
Goodness-of-Fit	6.70	5.10	5.70	4.00	7.50	4.40	5.00	3.70
Top 25 Percent								
Bias	-8.98	-6.35	-6.53	-2.94	-9.90	-7.31	-7.67	-4.64
Absolute Gross Error	8.98	6.34	6.53	2.94	9.90	7.71	7.67	4.66
Mean Square Error	40.77	20.39	21.66	4.66	49.64	26.85	29.50	11.45
Goodness-of-Fit	6.70	5.10	5.70	2.00	7.50	4.00	5.00	2.60
PAIRED IN TIME AND SPACE								
Correlation	0.03	0.04	0.06	0.03	0.10	0.09	0.13	0.06
Slope	0.02	0.05	0.07	0.05	0.06	0.08	0.12	0.09
Intercept	1.04	1.48	1.45	2.48	0.49	0.81	0.61	1.53
Bias	-4.67	-4.06	-3.98	-3.09	-5.00	-4.55	-4.52	-3.79
Variance	1.50	2.21	2.02	3.62	1.20	1.71	1.64	2.78
Gross Variability	23.31	18.71	17.88	13.18	26.18	22.43	22.07	17.14
PAIRED IN TIME ONLY								
Correlation	0.14	0.12	0.18	0.31	0.18	0.05	0.10	0.35
Slope	0.09	0.12	0.17	0.41	0.10	0.05	0.10	0.23
Bias	-4.26	-3.15	-3.19	-1.58	-4.64	-3.71	-3.82	-2.58
Variance	1.22	1.74	1.50	1.83	1.07	2.12	1.71	2.40

TABLE 2 SUMMARY STATISTICS—34TH STREET AND EIGHTH AVENUE

Statistics	HIWAY-2				CALINE3			
	Averrge	Modified	Modal	CAL3QHC	Average	Modified	Modal	CAL3QHC
UNPAIRED								
All Data								
Bias	-3.47	-2.44	-2.61	-2.70	-4.12	-2.76	-3.22	-3.25
Absolute Gross Error	3.47	2.62	2.62	2.70	4.12	2.83	3.24	3.25
Mean Square Error	12.17	6.56	6.56	7.51	17.06	9.11	10.97	10.94
Variance	0.10	0.59	0.36	0.20	0.06	1.51	0.61	0.36
Goodness-of-Fit	4.60	4.30	4.30	4.20	4.70	4.70	4.70	4.40
Top 25 Percent								
Bias	-6.86	-4.00	-4.76	-5.10	-8.09	-3.90	-5.49	-5.71
Absolute Gross Error	6.85	4.00	4.76	5.10	8.09	4.29	5.59	5.71
Mean Square Error	23.68	9.04	11.99	13.40	32.87	11.95	16.68	17.11
Goodness-of-Fit	4.60	2.20	3.10	3.50	4.70	4.10	2.70	2.60
PAIRED IN TIME AND SPACE								
Correlation	0.03	0.04	0.02	-0.01	-0.03	0.01	-0.02	-0.03
Slope	0.03	0.05	0.03	-0.02	-0.03	0.02	-0.03	-0.04
Intercept	2.05	2.20	2.32	2.60	1.89	2.15	2.25	2.40
Bias	-4.33	-4.00	-4.03	-4.05	-4.88	-4.30	-4.49	-4.44
Variance	2.86	3.86	3.55	3.52	2.70	4.90	3.89	4.03
Gross Variability	21.59	19.86	19.8	19.95	26.50	23.37	24.05	23.71
PAIRED IN TIME ONLY								
Correlation	0.06	0.10	0.08	0.05	0.02	0.12	0.09	0.03
Slope	0.07	0.16	0.11	0.06	0.03	0.24	0.15	0.05
Bias	-3.47	-2.62	-2.61	-2.70	-2.70	2.76	-3.22	-3.25
Variance	2.84	4.03	3.65	3.27	3.27	6.32	4.51	4.10

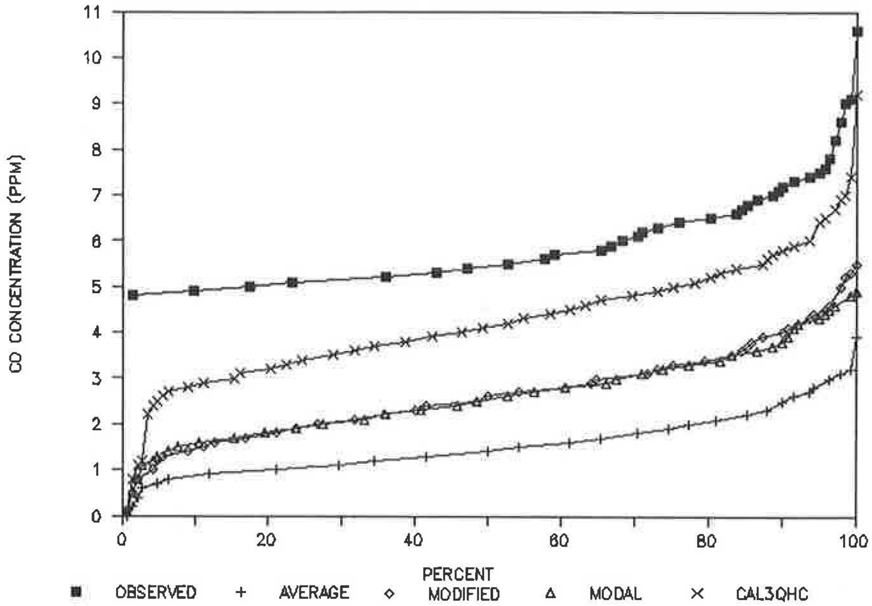

FIGURE 3 Cumulative frequency distribution, Site 1, HIWAY-2.

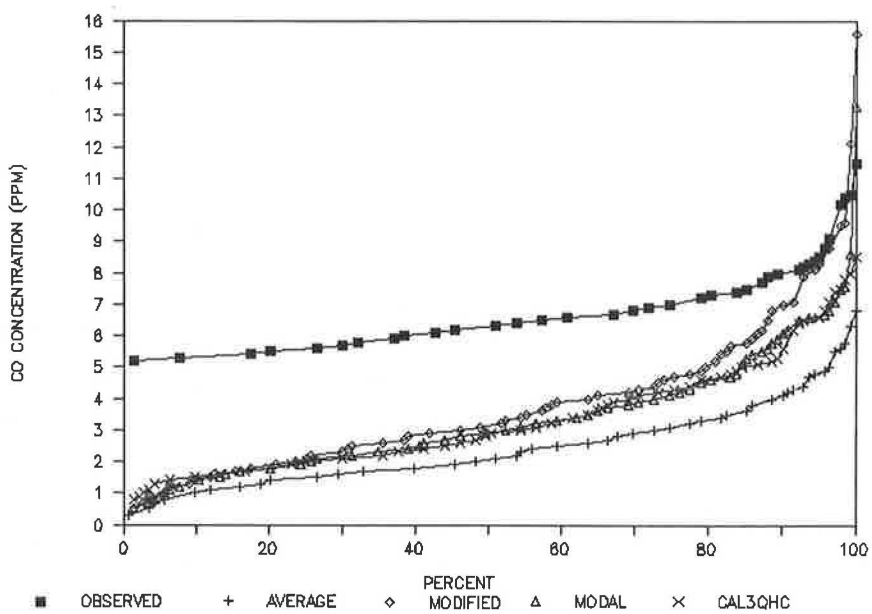

FIGURE 4 Cumulative frequency distribution, Site 2, CALINE3.

Sensitivity Analysis

Various sensitivity analyses were conducted to determine if any systematic error of bias that was affecting model performance could be discovered and corrected.

The stratified data sets for both sites included

- Three wind speed groups (<1.5 m/sec, 1.5 to 3 m/sec, >3 m/sec);
- Three wind direction groups (near parallel, near perpendicular, and other);
- Probe location (midblock versus intersection); and
- Three ranges of standard deviation of wind direction σ_θ (<25 degrees, 25 to 50 degrees, and >50 degrees).

Wind direction appeared to be the most likely source of error that could produce poor correlations for all the modeling scenarios. This fact was corroborated by the actual wind direction data measured at the different meteorological towers. Wind direction was measured at two locations at Site 1 and three locations at Site 2. In many instances, within the data set the average hourly wind direction measured was different from one location to another at the same site. At times, the winds were being channeled along each approach of the intersection toward one another. The variability of the wind direction was also reflected by σ_θ values that exceeded 25 degrees approximately 80 percent of the time, and exceeded 50 degrees approximately 33 percent of the time.

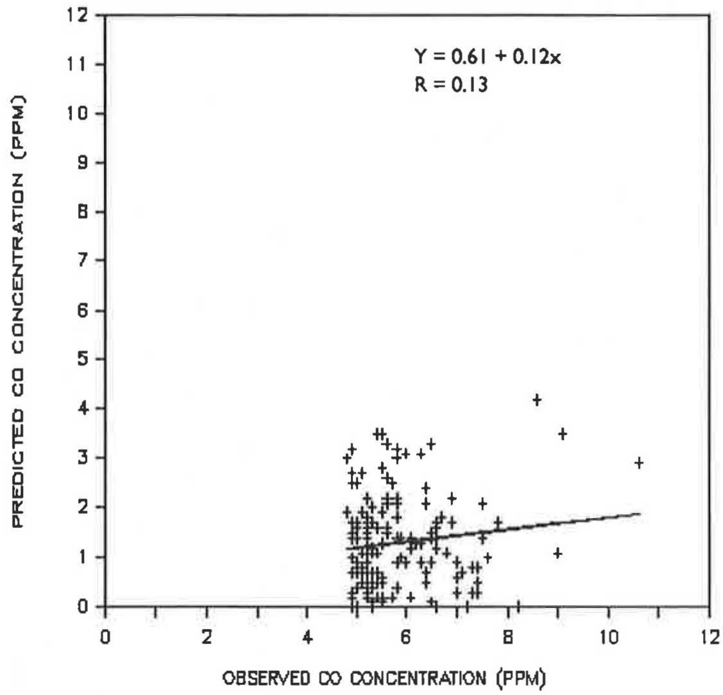

FIGURE 5 Scatter plot and regression line, CALINE3/Modal at Site 1.

It was not possible to determine to what extent this phenomenon was related to the siting of sensors that did not meet PSD monitoring guidelines. It was also possible that the street-level winds were quite different at the various approaches to the intersection of concern. Because both of the dispersion models required a single average wind direction for all the roadway links, this was a possible source of the error.

The results of the regression analysis indicated no improvement when the data were stratified by probe location or by wind direction. However, under low wind speed conditions, some of the modeling scenarios did exhibit better correlation than what occurred under the entire data set. The modeling scenarios also indicated some improvement for one of the σ_θ categories. However, this occurred for the high σ_θ set, which was expected to have the worst performance.

CONCLUSIONS

The performance of the models at the two monitoring sites was disappointing. On average, the models were not able to replicate observed concentrations and tended to underpredict.

At Site 1, the average speed model underpredicted most, typically by about a factor of 5. The performances of modified average speed and modal approaches were similar, with typical underprediction of about a factor of 4. The CAL3QHC method followed, with a typical underprediction of approximately a factor of 2.5. This model was the only one that was able to approach and exceed observed concentrations at the upper end of the concentration distribution. This range is where models need to predict best, so as to be able to predict CO concentrations reasonably, with a degree of conservatism. For this reason, the CAL3QHC model scenarios seemed to come closer to replicating the observed concentration distribution than the other scenarios at this site.

The performance outcome at Site 2 was basically the same in terms of general underprediction. The modal and modified average speed scenarios overpredicted at the upper end of the concentration distribution. Also, the modified average speed and CAL3QHC scenarios were reversed in terms of underprediction. At this site, CAL3QHC underpredicted more than the modified average speed scenario, for the reasons discussed. This approach is probably conservative at intersections that are not seriously congested (such as Site 1), yet is not conservative enough at those intersections where vehicles cannot get through the light in one cycle (such as Site 2).

Although the outcome from the first two intersection sites (work is ongoing at the other four study sites) indicates that the performance of the CAL3QHC, modal, or modified average speed models could yield conservative approximations of air quality, it is clear that the performances of all the models were less than desirable. Clearly, additional research needs to be done to determine how to improve intersection air quality modeling.

There are many uncertainties associated with this type of air quality modeling (*26–27*) and not enough resources and research have been devoted to this area over recent years. In this modeling effort, the uncertainties can be broken down into two basic areas—emissions and dispersion. The uncertainties of emissions modeling at intersections include whether or not modal emissions based on mid-1970s vehicle types are sufficiently accurate to depict today's vehicle fleet. (Indeed, some question whether the level of detail associated with modal emissions is necessary.) Regarding dispersion uncertainties, the proper characterization of dispersion in urban areas with dispersion models that were developed from test track data is a potential shortcoming, as is the proper characterization of meteorological parameters such as stability, wind speed, and direction in a highly turbulent and fluctuating urban environment. In addition, modeling efforts without the benefit of all necessary measured traffic data input have further uncertainties. For example, given the geometry, volume, and speed conditions, are the queue lengths and delay algorithms properly replicating those parameters? One, all, or some combination of the emission and dispersion (as well as traffic) uncertainties may be the cause of the models' apparent difficulty in replicating observed CO concentrations.

Immature CO mobile source modeling has tremendous implications for a variety of concerns. As more and more environmental scrutiny is given to various sources, such as shopping centers, highways, and housing developments, it could become needlessly more difficult to site these sources. In terms of state implementation plans, many unpopular and difficult measures may be implemented to reduce CO concentrations on the basis of modeling that is not up to the task.

Obviously, there are many benefits to be gained from improved CO model performance. These models should be able to perform at the same level of sophistication and confidence as stationary source models.

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