Review of U.S. Environmental Protection Agency Guidelines for Evaluating Indirect Sources and Carbon Monoxide Hot Spots

George J. Schewe*, Monitoring and Data Analysis Division, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina

Two guides have been developed to aid in identifying locations where significant carbon monoxide concentrations can be attributed to mobile source emissions. Both guides use state-of-the-art traffic engineering practices, emission factors, and dispersion techniques to provide a comprehensive yet manageable analysis of carbon monoxide concentration impacts. One guideline is oriented to indirect sources (e.g., shopping malls or sports stadiums) and provides a comprehensive manual methodology for assessing both 1- and 8-h average carbon monoxide concentration impacts corresponding to the national ambient air quality standards time averages. The second, or hot-spot guidelines, is designed to assess urban problems and employs a more general approach for estimating carbon monoxide concentrations at individual roadways and intersections. The term hot spot is used to indicate locations where carbon monoxide concentrations are estimated to be above the national ambient air quality standards. Both guidelines use a series of annotated worksheets, graphs, and tables, which are supplemented by background information on technique development and applications. Results of limited validation studies are included in each guide. These guidelines are particularly useful in evaluating indirect sources, planning transportation controls, assessing new roadway projects, and evaluating and selecting air quality monitoring sites.

Mobile source emissions produce virtually all carbon monoxide (CO) emissions at street level (1) and thus are primarily responsible for the magnitude of CO concentration levels in the immediate vicinity. People live and work near indirect sources of CO, roadways, and intersections, so such locations are priority locations where acceptable air quality should be maintained. Planners of air quality maintenance programs, however, have limited resources for ambient air quality monitoring and limited resources for detailed computer analysis and interpretation.

A simple yet comprehensive screening technique is needed for assessing the air quality impact of CO attributable to mobile sources. Past studies indicate that simple hourly traffic counts do not adequately represent variations in source strength or subsequent roadside CO concentrations (2, 3). CO concentrations are highly variable from one location to another (4); therefore, the few existing sites for which detailed modeling or monitoring have been conducted are believed to reflect CO levels only in the immediate vicinity. They provide a poor indication of CO levels at other sites, especially when traffic and location configurations are different.

The two guides discussed in this paper are referred to as the indirect source guidelines (ISG) (5) and the hot spot guidelines (HSG) (6). These guides provide comprehensive, easy to use manual techniques for preliminary screening of mobile source CO impacts. This concept depends on current traffic engineering practices, current and projected emission factors, and state-of-the-art dispersion modeling techniques.

ISGs evaluate indirect sources. An indirect source is any facility that attracts mobile sources but is not itself a source, such as a new major intersection, a recreational area, or a sports stadium. The guideline allows for detailed consideration of variable meteorology, traffic, and emission factors. The procedures are best applied to an evaluation of a well-defined scenario (present or future) for a specific facility, including the nearby roadway network, in order to estimate quantitatively the CO impact near these sources.

In contrast, the HSG document is useful for quick screening of individual roadways and intersections on an urban basis. Instead of the detail and flexibility that ISGs employ to refine the concentration estimates, HSG use realistic worst-case assumptions to identify potential CO hot spot locations.

HSG and ISG provide powerful screening tools for a preliminary analysis of existing or potential CO impacts on air quality near mobile source locations.

TECHNIQUES

Both HSG and ISG employ current techniques to calculate emissions and estimate pollutant concentrations. The difference between the techniques is in the level of detail of input information, calculation procedures, and subsequent concentration estimates. The procedures are based on

1. Mobile source emission factors—techniques for estimating CO emissions for current and future years (7);
2. Modal model—a model used to estimate automobile emissions under a set of base conditions for any driving cycle (1);
3. HIWAY—a line source dispersion model (8);
4. Traffic engineering theory and practice for estimating the interplay of various roadway and traffic parameters (9, 10, 11, 12);
5. Local observations of traffic parameters, meteorological conditions, and air quality; and
6. Available information from local planning and transportation agencies on specific roadway designs, vehicle usage, and current and future alternative network plans.

ISG are primarily facility oriented; therefore, more detail about the facility design and the nearby roadway network is required in order to estimate CO impacts. The project developer can generally supply these data, which are then combined with information on model year, calendar year, vehicle mix, ambient temperature, and automobile starting characteristics to derive emissions estimates for the desired scenario from emission factor tables. Receptor location, atmospheric stability, wind speed and direction, and type of source are then entered into nomographs (such as Figure 1) derived from HIWAY model simulations to estimate the CO impact of the source.

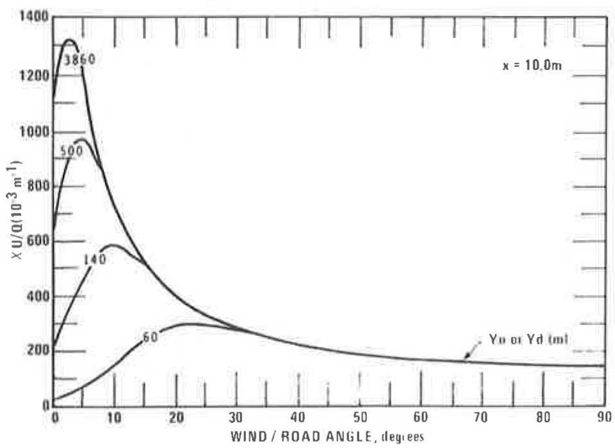
The document gives guidance for examining total CO impacts at intersections (all approaches) as well as whole parking lots, including entering and exiting ve-

Mr. Schewe was on assignment from the National Oceanic and Atmospheric Administration when this paper was written.

hicles. Intersection and roadway validations in the ISG agree within the limits of the modeling procedures, but the techniques for analyzing parking lots need further evaluation. Worksheets, such as the one in Figure 2 (5), are provided for performing calculations. The user, however, is expected to become familiar with the bases for the techniques, their applications, and limits before proceeding to an analysis. ISG are designed for persons who have some prior experience in traffic and air quality analysis.

The level of detail required for ISG methods hinders their usefulness in an iterative fashion when many sources or locations are being evaluated. To facilitate such a procedure another set of guidelines, HSG, were developed. HSG are similar to ISG in emissions, traffic, and dispersion modeling methods but differ in detail of input data, ease of use, and intended use of the results. Instead of the one-level detailed analysis, HSG employ two levels of screening that are based on worst-case receptor locations (i.e., traffic and meteorology interact to yield a maximum estimate of CO concentration). This allows many roadways and intersections to be evaluated in a reliable manner consistent with worst-case assumptions. HSG provide adequate identification of potential hot spots in less time and with less effort than do more complex techniques. HSG are designed to be useful to persons who have limited background in either traffic or dispersion modeling.

Figure 1. Variation of the normalized CO concentration with roadway length, road/receptor separation (x), and wind/road angle, for stability = D and σ_{z_0} = 5.0 m.



The two screening levels in HSG include a simple yes-no determination as to whether the estimated ambient CO concentration is likely to be above the national ambient air quality standards (NAAQS) and a method to rank such locations (Figure 3 is an example of the type of nomograph used in the yes-no determination). HSG techniques were derived from ISG through iterative applications of ISG procedures to find maximum concentration estimates for worst-case conditions. Limited validation of HSG shows that estimates are conservative and that they adequately identify potential CO hot spots.

Applications and Uses

HSG allow an initial assessment of a whole network of streets and intersections and the possible interplay between them in terms of increasing or decreasing CO hot spot potential. This type of analysis will assist in evaluating whether existing CO monitoring locations are representative and in planning new ones. HSGs also provide procedures for assessing the impact of inspection and maintenance and other transportation control plan measures on emissions and, therefore, on CO impacts. Alternative traffic routing and signaling effects on worst-case network CO impacts may also be assessed through the HSG screening techniques.

ISG are designed for a preliminary assessment of CO concentrations near an indirect source. Instead of worst-case estimates at each source-receptor location, however, the user may use on-site conditions or projections to estimate the combined impact at a receptor of nearby parking, exit lanes, intersections, or streets.

Both guidelines allow adjustments to automotive emissions for future years, cold starts, hot starts, temperature, and speed. This, along with nomographs for various road and lane configurations, allows alternative scenarios to be modeled and compared. Alternatives

Figure 2. Example worksheet from ISG.

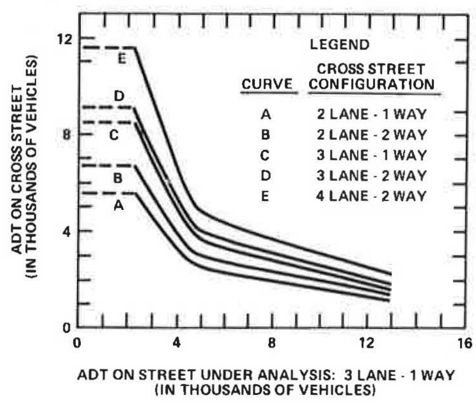
WORKSHEET 2 -- LINE SOURCE EMISSION RATE COMPUTATION
(SEE INSTRUCTIONS FOLLOWING)

PROJECT NO.:______________ ANALYST:______________

SITE:______________ DATE:______________

STEP	SYMBOL	INPUT/UNITS	TRAFFIC STREAM
1	i	ROAD SEGMENT (OR APPROACH IDENTIFICATION)	
2	V_i	DEMAND VOLUME (vph)	
3	C_i	FREE-FLOW CAPACITY (vph)	
4	S_i	CRUISE SPEED (mph)	
5	Ef_i	FREE-FLOW EMISSIONS (g/veh-m)	
6.1	M_i	NUMBER OF LANES IN APPROACH i	
6.2	j	SIGNALIZED INTERSECTIONS PHASE IDENTIFICATION	
6.3	$Cs_{i,j}$	CAPACITY SERVICE VOLUME OF APPROACH i FOR PHASE j (vph OF GREEN)	
6.4	$V_{i,j}$	DEMAND VOLUME FOR APPROACH i, PHASE j (vph)	
6.5	C_Y	SIGNAL CYCLE LENGTH (s)	
6.6	$G_{i,j}$	GREEN PHASE LENGTH FOR APPROACH i, PHASE j (s)	
6.7	c_i	CAPACITY OF APPROACH i (vph)	
6.8	$P_{i,j}$	PROPORTION OF VEHICLES THAT STOP	
6.9	$N_{i,j}$	NUMBER OF VEHICLES THAT STOP PER SIGNAL CYCLE	

Figure 3. Critical volumes at signalized intersections.



may include changes in network design and ambient conditions and subsequent impacts on emissions.

These guidelines allow the user to screen through receptor sites at three levels of detail:

1. Initial screening to identify potential CO hot spot locations (HSG).
2. Secondary screening to estimate worst-case CO concentrations at potential hot spots (HSG).
3. Manual detailed techniques to consider other than worst-case conditions (ISG).

Supplementary computer techniques are also available (13) to enable a user to perform levels 2 and 3 above for roadways and intersections.

Advantages and Disadvantages

These guidelines attempt to fill a gap in modeling mobile sources by providing simplified preliminary estimates. Advantages over detailed modeling or over simple traffic characterizations include

1. The guidelines are easy and quick to use for the level of detail discussed above;
2. They do not require computer resources;
3. They provide the best methods for treating intersections in a manageable and logical way;
4. They are comprehensive because even the simplest HSG technique uses a variety of assumed inputs to relate emissions to CO concentrations;
5. Alternatives or future years may be analyzed;
6. The guidelines can be used to screen many sources (HSG) and many receptor sites (ISG); and
7. They are based on state-of-the-art modeling techniques.

Disadvantages include

1. Neither guideline can handle complex situations (e.g., intersections that have more than four approaches or tunnels);
2. Neither guideline can treat congested conditions; and
3. Validation is limited to several cases. The HSG are validated only to the extent that they identify locations of potentially high CO concentrations.

SUMMARY

Two documents designed for screening locations of potentially high CO concentrations due to mobile sources have been developed. ISG are facility oriented, require detailed data inputs, and are designed for an experienced engineer. They provide the capability to estimate CO concentrations at any location under variable traffic, emissions, and meteorological conditions. HSG are oriented to areawide analyses, require limited data inputs, and are designed for use by a general technical audience to estimate maximum potential CO concentrations under assumed worst-case traffic and meteorological conditions.

Both guidelines are based on current emissions information and modeling practices but are subject to changes as new emissions data become available or as federal motor vehicle control schedules are revised.

An application of HSG has been completed for Washington, D.C. (14). Midurski and Mills describe the experiences of applying HSG to Washington and the role that CO concentration estimates played in analyzing transportation and air pollution control strategies. A similar, more detailed study is under way in Providence, Rhode Island.

REFERENCES

1. P. Kunselman and others. Automobile Exhaust Emission Modal Analysis Model. U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA-460/3-74-005, Jan. 1974.
2. R. A. McCormick and C. Xintaras. Variation of Carbon Monoxide Concentrations as Related to Sampling Interval, Traffic, and Meteorological Factors. Journal of Applied Meteorology, Vol. 1, June 1962.
3. H. W. Georgii, E. Busch, and E. Weber. Investigation of the Time and Space Distribution of Carbon Monoxide Emission Concentrations in Frankfurt-am-Main. Rept. of the Inst. for Meteorology and Geophysics, Johan-Wolfgang-Goethe-Universitat (Frankfurt-am-Main Univ.), No. 11.
4. R. M. Patterson and F. A. Record. Monitoring and Analysis of Carbon Monoxide and Traffic Characteristics at Oakbrook. U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA-450/3-74-058, Nov. 1974.
5. Guidelines for Air Quality Maintenance Planning and Analysis, Vol. 9: Evaluating Indirect Sources. (Revised) Draft, U.S. Environmental Protection Agency, Research Triangle Park, NC, Aug. 1977.
6. Guidelines for Identification and Evaluation of Localized CO Hot Spots. Draft, U.S. Environmental Protection Agency, Research Triangle Park, NC, Oct. 1977.
7. Compilation of Air Pollutant Emission Factors, 2nd ed. U.S. Environmental Protection Agency, Research Triangle Park, NC, AP-42, April 1975.
8. J. R. Zimmerman and R. S. Thompson. User's Guide for HIWAY, A Highway Air Pollution Model. U.S. Environmental Protection Agency, Research Triangle Park, NC, EPA 650/4-74-008, 1975.
9. Highway Capacity Manual. HRB, Special Rept. 87, 1965.
10. C. F. Newell. Approximate Methods for Queues With Application to Fixed Cycle Traffic Light. Society for Industrial and Applied Mathematics Review, Vol. 7, No. 2, 1965.
11. F. V. Webster. Traffic Signal Settings. Road Research Laboratory, H. M. Stationary Office, London, Technical Paper 39, 1958.
12. R. M. Patterson and E. L. Meyer. An Approach for Relating Traffic to Ambient Carbon Monoxide Concentrations at Signalized Intersections. Paper (APCA 75-44.4) presented at 68th Annual Meeting

of the Air Pollution Control Association, Boston, June 1975.
13. V. L. Corbin and M. T. Mills. User's Manual for the Intersection-Midblock Model. Draft Rept., U.S. Environmental Protection Agency, Aug. 1977.
14. T. P. Midurski and M. T. Mills. Characterization of the Washington, DC,Carbon Monoxide Problem. U.S. Environmental Protection Agency, Research Triangle Park, NC, Final Rept. 68-02-1376, Sept. 1977.

An Overview of the General Motors Sulfate Dispersion Experiment

David P. Chock, Environmental Science Department, General Motors Research Laboratories, Warren, Michigan

The General Motors sulfate dispersion experiment was conducted in October 1975 at the General Motors Milford Proving Ground. The experiment simulated a four-lane freeway; 352 catalyst-equipped automobiles were driven at 80 km/h, resulting in a traffic volume of 5462 vehicles/h. The runs were conducted in the morning to obtain the most adverse conditions for pollutant dispersion. The maximum catalyst sulfate exposure near the roadway averaged 8 $\mu g/m^3$ for sixty-six 0.5-h runs. The average sulfate emission rate for each vehicle was 0.023 g/km. Near the roadway, mechanical mixing due to the traffic dominated the mixing caused by the ambient turbulence. At low cross-road winds, plume rise becomes important. The U.S. Environmental Protection Agency's HIWAY model was found to overestimate the concentrations at the pedestrian level under stable conditions. These overestimates become worse as the wind speed decreases, as the wind direction approaches parallel to the road, and as the distance from the road increases. A simple line-source model was constructed to remedy many of the limitations of the HIWAY model. The new model takes plume rise into account at low cross-road winds. It also avoids a cumbersome numerical integration required in the HIWAY model. An advection-diffusion model was also constructed in which the eddy diffusivity was determined from dynamic considerations. The influence of traffic was approximated by an additive component in the diffusivity tensor. Good agreements with observations were found, even when the off-diagonal terms of the diffusivity tensor were neglected. It is also expected that when the vehicle velocity is reduced, the extent of pollutant dispersion would also be reduced.

The General Motors sulfate dispersion experiment was conceived out of the concern about possible high sulfuric acid exposures near busy roadways. Such exposures would result from the conversion of sulfur dioxide (SO_2) in automobile exhaust to sulfur trioxide (SO_3) by the oxidation catalysts installed in most post-1974 automobiles. A further concern regarded the validity of the U.S. Environmental Protection Agency's (EPA) HIWAY dispersion model (1, 2), which had been used to predict sulfuric acid concentrations near roadways under adverse meteorological conditions. A controlled experiment simulating a busy highway provided a unique opportunity to study the influence of traffic on atmospheric dispersion, and thereby enabled the construction of more reliable dispersion models. The purposes of the General Motors sulfate dispersion experiment, therefore, were as follows:

1. To characterize the SO_4 exposures from a fleet of catalyst-equipped automobiles;
2. To assess the EPA's HIWAY model;
3. To study the influence of traffic on pollutant dispersion; and
4. To construct more reliable dispersion models.

The experiment was conducted in October 1975 at the General Motors Milford Proving Ground.

EXPERIMENT

The proving ground is located in rural southeastern Michigan. The north-south straightaway at the proving ground was selected as the test track to simulate a 5-km long, 4-lane freeway. The terrain around the test track is relatively flat, especially at the sampling site. The automobiles driven in the experiment were provided by the four major domestic automobile manufacturers and equipped with catalysts and air pumps. After a lengthy preconditioning schedule (3), they were driven on 0.032 weight percent sulfur Amoco 91 gasoline during the experiment.

During the experiment, 352 automobiles were grouped into 32 packs. The packs were then grouped into parallel pairs, which occupied both lanes in each direction. The pairs were evenly spaced in both directions. The traffic speed was maintained at 80 km/h, resulting in a traffic density of 5462 vehicles/h. The traffic was controlled so that each pair of packs passed a fixed point every 29 s, thus maintaining a stationary flow. Figure 1 shows the traffic pattern during the experiment. A pickup truck is also visible in the figure. In fact, eight automobiles were replaced by pickup trucks, which were evenly distributed in the traffic and used to release a tracer gas, sulfur hexafluoride (SF_6), at a known emission rate.

Figure 1. The traffic pattern viewed from the south.