USING CALINE4 TO ESTIMATE AIR QUALITY IMPACTS NEAR INTERSECTIONS

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ABSTRACT

The application of the CALINE4 line source dispersion model to signed and signalized intersections is discussed in detail. Recommendations are made for acceleration rates and queue length. The issue of receptor location is discussed. Modeling procedures for handling overcapacity conditions, signed intersections, "T" and "Y" intersections and street canyons are described.

INTRODUCTION

The Clean Air Act Amendments of 1990 require transportation agencies to demonstrate that proposed projects will eliminate or reduce violations of ambient air quality standards in nonattainment areas. To demonstrate conformance with the carbon monoxide (CO) standards, computer models are used to predict concentrations at "hot spot" locations either directly or indirectly impacted by a project. Because CO concentrations tend to be highest near area of heavy traffic congestion, signalized intersections in urban and suburban areas are often the focus of this modeling effort.

The CALINE4 line source dispersion model contains a specialized intersection link option that can be used to model signalized or signed intersections. The option provides for an accurate spatial allocation of deceleration, idle, acceleration and cruise emissions. Resolving emissions by operating mode is important because fuel enrichment during heavy accelerations can result in extremely high emissions of CO and hydrocarbons.[2] Even modest accelerations typical of the FTP-75 test procedure can result in emission rates 2 to 5 times higher than average route speed rates.

Intersection models that do not specifically treat acceleration emissions are operating at a significant handicap. While they may account for the same total emissions, they will tend to underpredict CO concentrations near intersections because they evenly distribute emissions over the entire length of the modeled roadway. In reality, most emissions are concentrated in the idle and acceleration zones near the intersection.

This paper will briefly review the variables used in the CALINE4 intersection link option and then discuss ways to apply the model to a variety of situations.

MODEL VARIABLES

A CALINE4 intersection link encompasses the acceleration, queue and deceleration zones created by the presence of an intersection. The link represents one direction of travel with approach (vph_i) and depart (vph_o) traffic volumes assigned relative to the stopline location. A full intersection can be modeled using four of these links.

Cumulative modal emissions algorithms representing the average deceleration, idle, acceleration and cruise emissions per signal cycle per lane are constructed for each intersection link. These algorithms require the following input variables:

v = Cruise speed
t_a = Acceleration time
t_d = Deceleration time
t_1 = Maximum idle time
t_2 = Minimum idle time
n_c = Average number of vehicles clearing the intersection per signal cycle per lane
n_d = Average maximum number of vehicles queued per lane.

The variable t_a is of critical importance and will be discussed in a later section. It defines the average acceleration rate for the vehicles. The maximum idle time, t_1, is also important. It represents the typical time at rest for the first vehicle in the queue. The minimum idle time, t_2, represents the idling time of the last vehicle in the queue and is usually set to zero. The zero value indicates that the last vehicle to stop pauses only momentarily before starting again. Positive values of t_2 can be assigned to model a platooned arrival of vehicles or a steady-state queue.

The traffic parameters, n_c and n_d, are chosen to represent the dominant movement for the link. The variable n_d can exceed n_c if the intersection is operating over capacity (i.e. vehicles require more than one cycle to clear the intersection). The model assumes a uniform vehicle arrival rate, constant acceleration and deceleration rates, and an "at rest" vehicle spacing of 7 m.

Turn movements are not dealt with explicitly by CALINE4. Instead, the cumulative emissions profile per cycle per lane for the dominant approach movement is prorated by the approach or depart volume, depending on the relative location of the stopline. This method implicitly assigns a turning vehicle's deceleration, idle and part of its acceleration emissions to its approach link. The remainder of its emissions are assigned to its depart link. The method assumes that the acceleration patterns for turning and through vehicles are similar.

The user must supply each intersection link with two composite emission factors: an idle rate in grams/minute and a traveling rate at 16 mph in gram/mile. Modal emissions algorithms contained in CALINE4 use the composite emission factors and the input values for v, t_a, and t_d to generate deceleration, acceleration and cruise emission rates. The algorithms were developed using data from hot-stabilized, light-duty automobiles. In the absence of evidence to the contrary, it is assumed that their extension to other operating modes and vehicle types is valid.

Queue Length

The length is calculated by CALINE4 using the input value for n_d and the assumed 7 m vehicle spacing. It represents the average maximum length of queue for the time period and lanes modeled. The model is extremely sensitive to nd because it determines the overall idle and acceleration emissions attributed to the link. These are by far the largest emissions components in an intersection analysis.

There are important differences in how the terms "queue length" and "delay" are defined for CALINE4 and for conventional traffic models. The queue length in CALINE4, as determined by n_d, represents the maximum length from the stopline to the last vehicle stopped by the action of the signal and residual start-up delay of the queued vehicles. It is a representative measure of maximum lengths averaged over signal cycles and lanes.

The term "delayed as used in CALINE4 is defined as a fully stopped vehicle. The model does not recognized partially delayed vehicles included in the conventional definition of average or total vehicle delay. To CALINE4 the difference, n_c - n_d, represents the average number of vehicles per cycle per lane that travel through the intersection unimpeded (i.e. in cruise mode). When n_c - n_d is negative, and overcapacity condition is modeled. For example, in a case where an intersection operating overcapacity reaches a quasi-steady state queue varying from a minimum of 10 to a maximum of 25 vehicles in length, the appropriate CALINE4 values for n_c and n_d, respectively, are 15 and 25. If, on the other hand, 25 vehicles per lane cleared the intersection per cycle and 15 were stopped, the values would be reversed and a queue varying from a minimum of 0 to a maximum of 15 vehicles in length would be modeled.

Because the definitions of queue length and delay used by CALINE4 are non-standard, outputs from conventional traffic models may need modification for use in CALINE4. This problem is often moot, however, since the information needed to perform and conventional analysis is typically unavailable at the time of the environmental study. Fortunately the level of rigor needed to properly design a modern signalized intersection is much higher than that required to perform the air quality analysis. This is not because air quality is less important, but because the other inputs to the air quality modeling process (e.g. meteorology, future year emissions) are so uncertain. So-called "back-of-the-envelope" calculations should suffice for determining n_c and n_d. However, even these approximations require some estimated or assumed inputs.

The minimum information needed to estimate n_c and n_d for CALINE4 is vph_i for all links and an assumed total cycle length in seconds. With this information, the user can apportion the amount of green (and red) time for the two intersecting streets based on their maximum values of vph_i. The most basic version of this approach ignores the refinements of signal phasing and turn movements, and simply estimates the average number of vehicles stopped per cycle per lane to accommodate the conflicting travel on the intersecting street. A uniform vehicle arrival rate per thru lane is assumed. The number of vehicles stopped during the red phase should be augmented by the additional vehicles that are stopped by the queue because of start-up delays. Under ideal conditions, two seconds per queued vehicle plus a one time 2 second start-up delay should be added to the red phase time to make this determination.[3] Supplemental intersection links can be used to model turn movements if this information as available and deemed significant to the outcome of the analysis.

Acceleration Rates

The CALINE4 intersection link option is extremely sensitive to the acceleration rate variable (i.e. v/t_a in mphs). The algorithm used to adjust the 16 mph composite emission rate to an acceleration emission rate is an exponential function of the acceleration-speed product. Small changes in the acceleration rate can lead to much greater changes in the emission rate. It is critical that accurate values be used for v/t_a.

A source sometimes used for acceleration rates is the ITE Handbook.[4] It recommends an acceleration rate of 3.3 mphs. However, this figure is not representative of average acceleration rates at signalized intersections. In fact, according to the original investigator for this work, it was based on a single car and driver on a low-volume road and was established as a standard acceleration rate for an energy study.[5]

Much newer and more appropriate data is available. A study of five signalized intersections by Bonneson resulted in an average acceleration rate of 2.26 mphs.[6] An earlier study by Evans and

Rothery reported an average acceleration of 2.05 mphs.[7] A recent study conducted on 14 New York City streets through 111 intersections yielded average accelerations of about 2.0 mphs.[8]

Based on these studies, Caltrans now recommends an acceleration rate of 2.2 mphs for most urban and suburban intersections and 2.0 mphs for heavily congested central business district locations.

If measured acceleration rates are available for the intersection being modeled, they should be used. However, it is important that the average acceleration rate over the complete event is used, not a spot check rate. Both the Bonneson and Evans and Rothery studies proved conclusively that actual acceleration rates decrease linearly from a maximum at the start of the event to zero when cruise speed is achieved. The CALINE4 algorithm was developed for the average acceleration rate over the entire event. If a maximum acceleration rate is used, gross overpredictions will result.

Receptor Location

The choice of receptor location is extremely critical for intersection air quality analysis. The concentration of idle and acceleration emissions in the small area of an intersection can, under the right conditions, create high pollutant concentrations nearby. The shorter the distance between the pollutant source and the receptor, the less atmospheric dispersion will be able to lower these concentrations. Since the public has access next to and through most intersections via sidewalks and crosswalks, short-term exposures to drivers and pedestrians will be high. comparisons at these locations under worst case conditions against the 1 and 8-hour National Ambient Air Quality Standard for CO are likely to show exceedances now and in the future for many major intersections.

This makes it difficult, if not impossible, for CO nonattainment areas to demonstrate conformity for both regional plans and individual projects. Taken to extreme, if the public is deemed to have access to the immediate vicinity of a tailpipe, then conformity can never be demonstrated until 100% of America's cars and trucks are electric!

The issue of receptor location for intersection modeling should be recognized for what it is: a policy determination, not a technical issue. CALINE4 and other models are perfectly capable of predicting concentrations on roadways as well as next to them. The question becomes, what accessible locations at an intersection can the public be expected to remain at for continuous periods of 1 to 8 hours during worst-case meteorological conditions (i.e. wintertime early morning or evening). The U.S. Environmental Protection Agency's (EPA) current guidance is to locate receptors no closer than 3 m from curbside and 10 m from the cross street.[9] While this appears reasonable for the 1-hour standard, some question its use for a non-work related 8-hour exposure.

As more and more critical and costly decisions hinge on the results of intersection CO "Hot Spot" analysis, EPA's guidance on receptor location may come under closer scrutiny. The willingness of the public to pay the price for clean air at the corner of every major intersection will be the determining factor in whether this guidance is retained or modified.

SPECIAL APPLICATIONS

CALINE4 is able to handle many nonstandard intersection modeling applications. A brief description of how to handle the three most common nonstandard applications follows.

Signed Intersections

The CALINE4 intersection link option can be used to model intersection links controlled by a stop sign as well as signalized intersections. The user simply treats the link as an overcapacity condition in which n_d equals the number of vehicles queued at the sign and n_c equals one (i.e. only one vehicle clears the intersection per cycle). To determine t_1, divide 3600 seconds by vph_o. This gives the length of each cycle. Since the CALINE4 emissions are computed on a per cycle basis and are later apportioned by vph_i or vph_o (depending on whether the segment in question is before or after the stopline) the overall hourly emissions will be accounted for and placed in their proper location. With an assigned value of zero for t_2, the model will automatically account for the continuous idle emissions of the permanent queue, tapering those emissions to zero only over the last vehicle position. The model assumes this position will be occupied, on average, 50 percent of the time.

"T" or "Y" Intersections

Occasionally, one is asked to model an intersection that is comprised of non-collinear legs. The most typical examples of this are "T" and "Y" intersections. These can be handled by the CALINE4 intersection link option by employing a "phantom" leg. The "phantom" is created by assigning a zero value to either vph_i or vph_o. The model must think it is seeing a complete intersection link, but all computed contributions from the "phantom" leg either before or after the stopline will be negated by the zero value. As many links as are needed (and as many "phantom" legs) may be superimposed at the angles dictated by the geometry of the intersection.

Street Canyon Intersections

In very densely built-up central business districts, intersections may be bounded by buildings on all sides. These conditions hamper effective dispersion and lead to high concentrations of CO and other pollutants at ground level. The few models that have explicitly treated this street canyon condition attempt to model the recirculatory effects that can occur in a crosswind condition at mid-block.

In CALINE4, a canyon option can be employed in conjunction with the intersection link option to create an intersection street canyon model. This approach does not include a recirculation element, but instead assumes a parallel wind flow along one of the intersecting streets and a crosswind for the other. For the street (i.e. two links) on which the parallel wind flow is assumed, horizontal boundaries parallel to the links can be established to contain all emission within the "canyon" width. Care is needed to make sure that the horizontal boundaries are coincident for the two links. Contributions from the cross-street are added by modeling those two links under crosswind conditions.

Enhanced vertical dispersion modeled through CALINE4's heat flux algorithm partially offsets the restrictive effects of the canyon boundaries. Still, the canyon option yields higher modeled concentrations than equivalent runs without the option.

CONCLUSIONS

Few, if any, of the available microscale air quality models have the flexibility of CALINE4 to model both freeways and intersections. Most utilize the older CALINE3 dispersion algorithms. These make no provision for vehicle-induced heat flux or wind direction variability, both important factors in the dispersion process. Most other models are unable to deal with overcapacity conditions, signed intersections, "T" or "Y" intersections or street canyons. As pointed out here, CALINE4 can model these special applications by combining options and astutely assigning input variables.

Not all issues are as easily solved, however. The current EPA guidance for receptor location, especially with respect to the 8-hour CO standard, deserves reexamination. A better definition, legal or otherwise, of what comprises a transient exposure versus a chronic exposure is needed.

On the technical front, improvements are certainly still needed in the model. Integrating CALINE4 with a default traffic algorithm equivalent to the "back-of-the-envelope" procedure described in this paper would be helpful. Also, an updating of the modal emissions component of the intersection link option with data from newer, electronically fuel-injected cars is needed. Fortunately, work is progressing in this direction at both California Air Resources Board's El Monte Laboratory and EPA Ann Arbor. As soon as a newer modal model is made available, it will be installed in CALINE4.

DISCLAIMER

The views expressed in this paper are solely those of the author and do not necessarily represent the views of the California Department of Transportation.

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