

# Assessing Impacts of Improved Signal Timing as a Transportation Control Measure Using an Activity-Specific Modeling Approach

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Metropolitan areas in nonattainment for transportation-related air pollutants rely on transportation control measures (TCMs) to reduce emissions and meet clean-air goals. However, since traditional transportation-related air quality models use emission rates based on average speeds, only TCMs that either increase or decrease vehicle activity to speeds in which emissions are lower show reductions in output of air pollutants. In recent years, transportation air quality analysis has shifted to an activity-specific modeling approach that correlates emissions to vehicle operating mode. With an activity-specific approach, the emission reduction potential of a TCM can be evaluated by its ability to decrease time spent in modes in which emissions are disproportionately elevated. Signal timing improvements are attractive TCMs for traffic flow improvement. However, with traditional modeling, they may greatly decrease extremes in modal activity yet not show significant emission reduction if only moderate changes in average speed are realized. The benefits of using activity-specific modeling for evaluation of improved signal coordination as a TCM are described. A brief overview of the development of an activity-specific carbon monoxide emission rate model is provided, data collection for on-road vehicle activity estimates is briefly outlined, and a comparison of traditional emission modeling versus activity-specific modeling is provided to estimate the air quality benefits from improved coordination at a study intersection. Results for the study intersection indicate that more significant reductions in carbon monoxide emissions are realized using an activity-specific approach than with traditional methods.

The Clean Air Act Amendments require metropolitan areas—classified as severe or extreme for ozone or serious, severe, or extreme for carbon monoxide (CO)—to adopt transportation control measures (TCMs), to the extent they are necessary, to achieve attainment of air quality standards (1). TCMs are strategies intended both to reduce the total number of vehicle miles traveled and to make that travel more efficient (2). Transportation control measures are required to help reduce the amount of pollution released by the transportation sector to improve air quality and meet federal requirements.

Although various definitions exist for TCMs, a general description is that they are actions designed to change travel demand or vehicle operating characteristics to reduce motor vehicle emissions, energy consumption, and congestion. TCMs include transportation

supply improvement strategies and transportation demand management strategies. Transportation supply improvement strategies either change the physical infrastructure or implement actions for more efficient use of existing facilities to improve traffic flow and decrease stop-and-go movement. Supply improvement strategies take the form of bottleneck relief, construction improvements, improved signal timing, ramp metering, applications of intelligent transportation system technology, and alterations to land use patterns. Demand management measures attempt to change driver behavior to reduce the frequency and length of automobile trips. Demand management measures include, but are not limited to, no-drive days, employer-based trip reduction programs, parking management, park-and-ride programs, work schedule changes, transit fare subsidies, ride sharing, and public awareness programs (3).

Transportation supply improvement strategies have centered on improving flow through capital improvements or operational changes. Enhanced flow leads to improved average speeds and decreased idle time. In terms of air quality benefits, the rationale behind improving flow or decreasing idling has been the traditional relationship between vehicle activity and the rate at which emissions are produced. Historically, the MOBILE or EMFAC series of motor-vehicle emission rate models estimate emissions as a function of average speed. Emission rates vary greatly across different speed ranges, as shown in Figure 1 for CO in grams per kilometer. As shown, MOBILE5a CO emission rates are highest in the lower speed ranges and then reach their lowest rates in the middle speed ranges from 48 to 80 km/h (30 to 50 mph). Emission rates increase again after 89 km/h (55 mph). Locations on the emission curve where the slope is the steepest also indicate areas where emission rates are the most sensitive to changes in speeds (4). As shown in Figure 1, an increase in average speed from approximately 5 to 15 km/h reduces the emission rate from 80 to 25 g/km whereas a change in speed from 65 to 75 km/h only decreases emissions by little more than 1 g/km. Logically, areas on the chart where emission rates are the most sensitive to changes in average speed are also locations where errors in estimating average speed have the greatest impact to overestimate or underestimate emissions. This indicates that inaccurate estimations of average speeds for certain speed ranges may have a large impact on the validity of emission reduction estimates used in TCMs with a speed-dependent modeling approach. Concurrently, in areas of the speed-emission factor curve where the slope is flatter, even a large increase or decrease in average speed may only marginally impact emission rates. For CO, an increase from 50 to 90 km/h (31 to 56 mph) only reduces emissions by 3 g/km.

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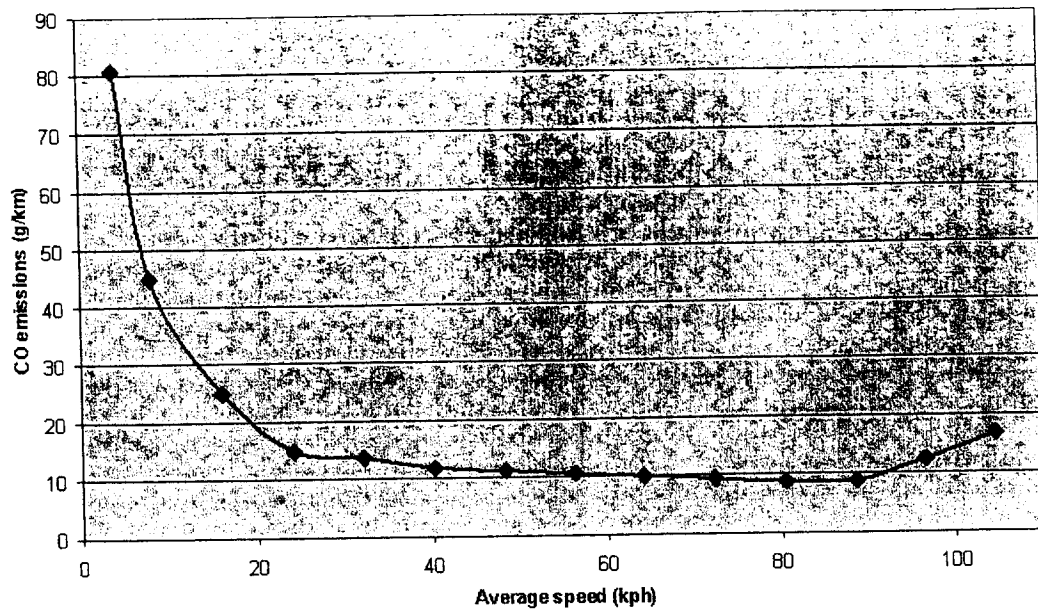


FIGURE 1 MOBILE5a carbon monoxide emissions by average speed.

Because the traditional emission-vehicle activity relationship is highly speed dependent, only TCMs that improve flow, leading to increases or decreases in average speed to ranges in which emissions are lower, result in predicted air quality improvements.

Current research projects have suggested more direct links between the operating mode of the vehicle—which is a function of the speed and corresponding acceleration and other engine loading factors, such as air-conditioning use and roadway grade—and emission rates. A number of studies have suggested that actual vehicle emissions are quite different from what is estimated by models employing an average-speed methodology (5–9). Emission-producing activity is particularly dependent on high engine loading (10). Increases in emissions of several magnitudes have been reported with hard accelerations and other loading events (6, 8, 10–12). Consequently, transportation-related air quality analysis has focused on developing emission rates and vehicle activity estimates that are more representative of real-world driving.

As transportation-related emission modeling begins to evolve to a more modal or activity-specific approach, it is expected that evaluation of TCMs also will move in that direction. Modal or activity-specific modeling of TCM impacts involves identifying vehicle activity that is disproportionately responsible for high emissions and then focusing strategies on reduction of this activity. When TCMs reduce the frequency of these important high-engine-load events, the associated high emissions are significantly reduced. From an air quality perspective, TCM strategies that reduce the frequency of these critical emission-producing activities are preferable to those that only improve traffic flow. Moving to a modal approach may assist in providing methodologies that can directly evaluate impacts of different strategies.

### INTERSECTION TIMING AS A TCM

Widespread implementation of improved signal timing plans gained popularity during the energy crises of the 1970s, when signal timing

became a popular means of decreasing fuel consumption. Strong reported the benefits from improved intersection signal timing for four cities in California to be a savings of 31 967 L (8,445 gal) of fuel annually (13). An annual travel time savings of 11,403 h per intersection also was presented. Deakin et al. also discussed the advantage of signal timing in California and reported an average first-year reduction in fuel use of 8.6 percent for retimed signals (14). The National Signal Timing Optimization Project conducted in 1980 by the Federal Highway Administration showed an average annual decrease of 15,470 vehicle hours of delay, 455,921 fewer stops per intersection, and a savings of 39 781 L (10,524 gal) of fuel for the 11 cities across the United States that participated (15). Even though results of improved timing plans often are evaluated as savings in units of fuel per year without an estimation of the corresponding emission reduction benefits, it is expected that any strategy that decreases fuel consumption will logically decrease emissions as well.

Improved signal timing has long been proposed as a way to improve traffic operation and reduce fuel consumption and emissions (14). It not only reduces stops and delays leading to increased operational efficiency of streets but offers other benefits, including

- Reduced travel time,
- Increased safety, and
- Reduced emergency-vehicle response time (16).

Traffic signalization is a common traffic management technique used in the United States. Traffic signalization improvements may include

- Timing plan improvements,
- Signal coordination and interconnection, or
- Signal removal (2).

Although the benefits of improved signal timing for reduced fuel consumption are well documented, the effectiveness of signal retiming as a TCM has not been as clear-cut. Air quality benefits of

signal timing improvements and other TCMs previously have been evaluated based on speed-dependent emission rate models, such as MOBILE. As discussed previously, with average-speed emission-rate models, TCMs demonstrate air quality improvements only if average speeds are improved to ranges in which emission production is deemed more efficient. Figure 1 shows that CO emission rates in MOBILE5a are a function of speed and only show emission reduction when average speeds move from either lower- or upper-speed ranges to the more efficient mid-speed ranges. No modal activity is accounted for. Consequently, the only measurable benefits resulting from improved signal timing for current modeling methodologies are reducing congestion (improving flow) and reducing the extent of vehicle idling leading to improved average speeds. Additionally, as discussed previously, if changes in average speed occur in flat areas of the speed/emission rate curve, even a significant change in average speeds may show no measurable air quality benefits.

Historically it has been difficult to demonstrate TCM benefits of improved signal timing with existing transportation-related air quality models since improvements in average speeds may only be marginally different between an existing and improved timing plan. As a result, the benefits and cost-effectiveness of capital outlay for retiming projects may not make sense for the limited improvements in air quality projected based on a speed-dependent modeling approach.

Because of the importance of meeting Clean Air Act goals and the role TCMs play in assisting a metropolitan area in meeting those goals, an improved methodology for evaluating the impacts of TCM or intelligent transportation system alternatives is necessary to fully capitalize on the benefits of those strategies. Since emissions have been shown to be activity specific, it is important to find methods that have the ability to estimate the effect of traffic flow improvements on trip emissions in terms of changes in speed or acceleration profiles (16).

The application of modal-based or activity-specific emissions modeling is expected to show that improved signal timing leading to fewer extremes in modal activity may have a pronounced impact on emissions. Intersections are locations of intense modal activity, and in many urban areas, a significant amount of traffic occurs on signal-controlled roadways. At signal-controlled intersections, a large percentage of extremes in modal activity occurs within a relatively short distance of the signalized intersection depending on queue length. Vehicles decelerate to a stop, idle, and then accelerate from rest. Even for vehicles not stopped or slowed by the signal, a large number of interactions with other vehicles leads to "rough" traffic flow. If an activity-specific approach indicates that improved timing leads to less vehicle activity in modes with elevated emissions, signal timing as a TCM could become a much more important strategy.

## MEASURE

In order to approach mobile source emission modeling using an activity-specific modal approach, various research efforts are under way around the United States. At the Georgia Institute of Technology, a modal methodology based in a geographic information system is in progress. The Mobile Emission Assessment System for Urban and Regional Evaluation (MEASURE) is a research model originally developed by researchers at Georgia Tech in cooperation with the Environmental Protection Agency (EPA). The model takes in mesoscopic data (road segment and census block) about vehicle activity and technology, then outputs estimated, gridded, mobile exhaust emissions. It employs modal emission rates developed in-house

as well as MOBILE base emission rates. It relies on modal vehicle activity measures—starts, idle, cruise, acceleration, and deceleration. Vehicle technology characteristics (model year, engine size, etc.) and operating conditions (road grade, traffic flow, etc.) also were developed at a large scale (small zones and road segments).

The scope of MEASURE currently is being expanded to include microscale air quality estimates of at least the three main mobile source pollutants—hydrocarbons (HC), nitrogen oxides ( $\text{NO}_x$ ), and carbon monoxide (CO). As designed, MEASURE will be able to read spatial databases and estimates of modal activity and then provide facility-level estimates as well as gridded estimates of the various pollutants. This model could feasibly replace the standard MOBILE sequence or, at least, provide a wrapper for preprocessing, running, and postprocessing the models. From a research perspective, MEASURE will be able to make comparisons of standard speed correction factor approaches versus activity-specific approaches, since both types will be embedded. From a practical perspective, it would provide planners and engineers a tool kit to generate regulatory-level reporting as well as provide a flexible means of gaming various TCMs. Both of these capabilities make MEASURE an attractive tool for the research discussed in this paper. The most important factor, however, is the modal emission rates generated during model development. These emission rates provide the ability to explore the emission impacts of changes in vehicle activity such as changes in specific acceleration ranges.

For effective modeling, MEASURE requires two fundamental input variables: accurate vehicle activity profiles and technology group-specific emission rates. Both also are necessary to evaluate air quality impacts of TCMs.

## MEASURE Emission Rates

Part of the MEASURE model research has been to create new emission rates that are more representative of real-world modal activity. Emission rates are being developed for HC,  $\text{NO}_x$ , and CO. The production of carbon monoxide at signalized intersections is of particular concern because of the immediate health effects from CO. Therefore, CO usually is analyzed on a microscale, whereas HC and  $\text{NO}_x$  most often are analyzed on a regional scale. Because of its localized effects and the fact that the transportation sector is primarily responsible for up to 90 percent of the CO produced in urban areas (4), for the purposes of discussing signal timing improvements as a TCM, this paper will focus on carbon monoxide. A brief overview of development of the CO emission rate model for MEASURE is presented. For a more detailed discussion on the statistical analysis, see Fomunung (17).

The CO model was developed by analyzing a data set of more than 13,000 hot-stabilized laboratory treadmill tests on 19 driving cycles (specific speed versus time testing conditions) and 114 variables describing vehicle, engine, and test-cycle characteristics. The data set represents almost two decades of in-use driving tests conducted by EPA and the California Air Resources Board and compiled by EPA's Office of Mobile Sources for use in developing the MOBILE model.

The emission rate model for CO, presented here, was estimated with a response variable as the logarithm of the emission rate ratio for carbon monoxide. The ratio is the vehicle emission rate (in grams per second) driven on a given cycle (or across a speed/acceleration matrix) divided by that vehicle's emission rate while driving on the federal test procedure (FTP) Bag2. The MEASURE aggregate modal model predicts the ratio of grams-per-second emission rates for each

vehicle technology group. The following sequence of equations shows the method of calculating the predicted emission rate for CO in units of either grams per second or grams per mile:

$$\Psi_{CO}(g/s) = \Psi_{CO}(g/mi) * S/t \quad (1)$$

$$\Psi_{CO_{Bag2}}(g/s) = \Psi_{CO_{Bag2}}(g/mi) * 3.91/866 \quad (2)$$

$$R_{CO}(\text{rate ratio}) = P_{CO}(g/s)/\Psi_{CO_{Bag2}}(g/s) \quad (3)$$

where

$\Psi_{CO}$  = measured or observed CO,

$P_{CO}$  = predicted CO,

$\Psi_{CO_{Bag2}}$  = FTP Bag2 rate of CO for a given vehicle,

$S$  = driving cycle distance in miles,

$t$  = cycle duration in seconds,

3.91 = hot-stabilized FTP Bag2 subcycle distance in miles, and

866 = FTP Bag2 subcycle duration in seconds.

On a vehicle-by-vehicle basis, this implies that after calculating  $R_{CO}$  from the response variable, the predicted rate in grams per second can be obtained by

$$P_{CO}(g/s) = R_{CO} * \Psi_{CO_{Bag2}} \quad (4)$$

Note that Equation 4 is similar in form to the embedded algorithm in MOBILE, which gives emission rates as the base emission rate (BER) multiplied by correction factors. BER is akin to  $\Psi_{CO_{Bag2}}$ ;  $R_{CO}$  is a composite representation of several variables and can be thought of as speed, load, and technology correction factors.

Equation 4 can be converted easily to grams per mile by using

$$P_{CO}(g/mi) = R_{CO} * \Psi_{CO_{Bag2}} * 1/AVGSPD \quad (5)$$

where AVGSPD is the average speed of the speed-acceleration profile of the driving schedule.

The CO model is presented in both an estimation form and a prediction form. The estimation form is the following regression equation:

$$\begin{aligned} \text{Log } R_{CO} = & 0.0809 + 0.002 * \text{AVGSPD} + 0.0461 * \text{ACC.3} \\ & + 0.0165 * \text{IPS.60} - 0.0283 * \text{ips45sar2} \\ & + 0.3778 * \text{ips90tran1} - 0.0055 * \text{tran3idle} \\ & + 0.1345 * \text{tran5mi1} + 0.3966 * \text{finj3sar3} \\ & - 0.0887 * \text{cat3tran1} - 0.2636 * \text{sar3tran4} \\ & - 0.481 * \text{flagco} \end{aligned} \quad (6)$$

where

AVGSPD = average speed of the driving cycle in miles per hour;

ACC.3 = proportion of the driving cycle on acceleration greater than 4.8 km/h/s (3 mph/s);

IPS.X = proportion of the driving cycle on inertial power surrogate (IPS) (speed × acceleration) greater than X (km/h)<sup>2</sup>/s [thus IPS.60 implies IPS greater than 155 (km/h)<sup>2</sup>/s or 60 (mph)<sup>2</sup>/s];

ips45sar2 = interaction between IPS.45 [IPS ≥ 116 (km/h)<sup>2</sup>/s or 45 (mph)<sup>2</sup>/s] and a vehicle with no air injection;

ips90tran1 = interaction variable for a vehicle with automatic transmission on IPS.90 [IPS ≥ 233 (km/h)<sup>2</sup>/s or 90 (mph)<sup>2</sup>/s];

cat3idle = interaction variable for a three-speed manual transmission at idle;

tran5mi1 = interaction variable for a five-speed manual transmission vehicle with mileage ≤ 40 233 km (25,000 mi);

finj3sar3 = interaction variable for a vehicle that has throttle-body fuel injection and pump air injection;

cat3tran1 = interaction variable for a vehicle with automatic transmission and track warrant control;

sar3tran4 = interaction variable for a vehicle with four-speed manual transmission and pump air injection; and

flagco = flag used to tag a high-emitting vehicle under CO emissions.

The prediction format is a more intuitive presentation for prediction purposes and is given by

$$\begin{aligned} P_{CO}(g/s) = & 1.205 * \text{FTP Bag2} * \text{antilog}(0.0809 + 0.002 \\ & * \text{AVGSPD} + 0.0461 * \text{ACC.3} + 0.0165 * \text{IPS.60} \\ & - 0.0283 * \text{ips45sar2} + 0.3778 * \text{ips90tr1} - 0.0055 \\ & * \text{tran3idle} + 0.1345 * \text{tran51} + 0.3966 * \text{finj3sar3} \\ & - 0.0887 * \text{cat3tran1} - 0.2636 * \text{sar3tran4} \\ & - 0.481 * \text{flagco}) \end{aligned} \quad (7)$$

## Technology Class Definition

The objective is to be able to define mutually exclusive and collectively exhaustive rules for each technology class. Four different emission control technology types were investigated during model development. These are the fuel injection type (FINJ), catalytic converter type (CAT), transmission speed type (TRAN), and supplemental air injection type (SAR). There are four categories each of FINJ, CAT, and SAR and five categories of TRAN. To these were added four bins of mileage representing the odometer reading of a vehicle, to serve as surrogates for deterioration rates of these emission control components (9).

A matrix of 2,560 cells is formed from the four technology types plus vehicle mileage and two groups representing high emitter status resulting in mutually exclusive and collectively exhaustive groups of vehicles by type. Then with the use of Equations 3 and 7, and modal variables from any arbitrary driving cycle, a predicted rate ratio was computed for each rule. Several rules were found to have the same predicted rate, which were grouped and assigned an aggregate definition referred to as "technology class." A total of 44 such technology classes were defined out of 2,560 technology rules.

## Emission Rates

The next step was prediction of CO emission rates. Since the predicted ratios for each technology class are different, it follows that a reasonable method of predicting emissions should proceed on a technology-class basis. To predict emissions for each technology class, one at a time, Equation 5 is modified into the form

$$P_{CO}(g/mi) = R_{CO} * P\Psi_{CO/Bag2} * 1/AVGSPD \quad (8)$$

where  $P\Psi_{CO_j, Bag2}$  now is defined as the average of the base emission rate (FTP Bag2), in grams per second, of CO for technology class  $j$ . Note, again, that in this form the term  $R_{CO_j}/AVGSPD$  in Equation 8 represents a cycle correction factor for each technology class.  $R_{CO_j}$  is the predicted rate ratio of CO for technology class  $j$ . The values for  $P\Psi_{CO_j, Bag2}$  are obtained from the FTP Bag2 measurements in the original sample data set, which was used to estimate Equation 6, whereas values for  $R_{CO_j}$  depend on the modal variables inputted in the model.

### Significant Predictor Variables for CO

The carbon monoxide model indicates that there are three predictor variables that relate to specific modes of vehicle operation and apply to all technology groups in the fleet. Other variables contain an activity-specific component but apply to a particular technology group. The three fleetwide modal variables for carbon monoxide are the average speed, the percent of vehicle activity in which acceleration exceeds 4.8 km/h/s or 3.0 mph/s, and the product of instantaneous speed and acceleration termed IPS greater than or equal to 155 (km/h)<sup>2</sup>/s or 60 (mph)<sup>2</sup>/s (*IPS.60*). In particular, high-load events (hard accelerations and the product of acceleration and speed) contribute to elevated CO output.

Three other variables are related to both the vehicle's modal activity and a specific characteristic of the fleet. The percent of time spent idling is significant for three-way catalyst-equipped vehicles (*cat3idle*). IPS is significant for vehicles with automatic transmissions when an IPS is greater than or equal to 233 (km/h)<sup>2</sup>/s or 90 (mph)<sup>2</sup>/s (*ips90tr1*). For vehicles with no excess air injection, an IPS greater than or equal to 116 (km/h)<sup>2</sup>/s or 45 (mph)<sup>2</sup>/s (*ips45sar2*) is a relevant variable.

To determine the emissions at an intersection with the modal emissions model, the technology group must be determined and then the vehicle speed/acceleration profiles estimated. Once the fleet distribution is known for an intersection, changes in operational characteristics will only affect the vehicle activity side so that impacts can be measured by the changes in relevant modal activity. These modal variables then are used in Equation 6 to get predicted ratios. A look-up table is used to obtain the corresponding FTP Bag2 emission rate. Together, they can be used in Equation 7 to obtain emission rates, which then are fed into MEASURE.

### INTERSECTION VEHICLE ACTIVITY

Activity-specific modeling requires two primary components: mode-specific emission rates and accurate estimates of on-road vehicle activity. Currently few models exist that accurately represent the range of activity that vehicles undergo as part of normal driving operation on signalized roadways. Simulation models are coming on-line that output vehicle activity profiles to address deficiencies in the ability to represent on-road activity. However, their ability to accurately model actual vehicle activity is unproved (18, 19). In order to develop a method to predict on-road vehicle activity profiles as input to MEASURE, activity profiles were collected at a wide variety of signalized intersections in the Atlanta, Georgia, metropolitan area. Data were collected at various intersections with differing geometric and operational conditions. Modal activity was collected at studied intersections for deceleration to the point of queue at the signal, acceleration away from the point of queue, and cruise activity of vehicles proceeding without being stopped by the signal. These speed/acceleration profiles

were collected so that more accurate information regarding intersection modal activity could be provided as input to MEASURE. Individual activity profiles were collected, in the field, using handheld laser range-finding (LRF) devices. These laser guns are capable of measuring the distance to an object at a high sampling frequency (238.4 distance measurements per second) with a manufacturer's accuracy specification of 15 cm (6 in.) (root mean squared) over 762 m (2,500 ft). The laser range finders collect a data stream of straight-line distances from the LRF to the vehicle. This data stream then is processed to calculate instantaneous speed, acceleration, and distance from the intersection stop line.

As discussed earlier, high-load events [accelerations  $\geq 4.8$  km/h/s and the product of acceleration and speed,  $IPS \geq 155$  (km/h)<sup>2</sup>/s] contribute to elevated CO output. Figure 2 shows a profile of fractions of vehicle activity by queue position spent in each of the two indicated modes from the CO emission rate model plus the percent of activity in the "extreme" edge of modal activity ( $\geq 9.7$  km/h/s or 6.0 mph/s). Presented are the results for 11 intersections with the following geometric and operational characteristics:

- Grade from -2 to +1 percent,
- Level of service from A to F,
- On-road per lane volumes from 195 to 924, and
- An a.m. or p.m. peak period.

Data are shown for all activity from the point of initial queuing to a point 76 m (250 ft) downstream. For "thru" vehicles, the data are for activity from the stop line for a distance of 76 m downstream.

As demonstrated in Figure 2, modal activity varies greatly by queue position. As shown, the first vehicle in the queue experiences, by far, the greatest percent of modal activity in the high-load categories with 53 percent of the total instantaneous activity equal to or exceeding 4.8 km/h, 6 percent of the activity equal to or exceeding 9.7 km/h/s, and 43 percent of activity with an IPS greater than or equal to 155 (km/h)<sup>2</sup>/s. Higher queue positions and "thru" vehicles (those not stopped by the signal) experience the least amount of modal activity with only 5 percent of activity in the 4.8 km/h/s category, less than 1 percent of activity in the 9.7 km/h/s range, and 10 percent in the  $IPS \geq 155$  category. These numbers indicate that strategies, which reduce the number of vehicles caught in queue by a traffic signal, may significantly affect the amount of emission-producing activity that occurs at a signalized intersection.

### IMPACTS OF USING ACTIVITY-SPECIFIC APPROACH TO EVALUATE EFFECTIVENESS OF SIGNAL TIMING AS TCM

A consensus exists that, although transportation control measures are important in meeting and maintaining air quality goals, quantitative information is not always available about which strategies work best and in which circumstances they are the most applicable (20, 21). Consequently, there is a need for a method that can more accurately assess the air quality impacts of different intelligent transportation system alternatives and TCMs in terms of both emission-reduction potential and cost-effectiveness. The use of an activity-specific approach to evaluate impacts of projects such as signal timing provides an improved method to perform such an evaluation. As discussed earlier, vehicle emissions for CO and other pollutants are highly correlated to operating mode. Intersections are locations of significant modal activity so it is expected that with

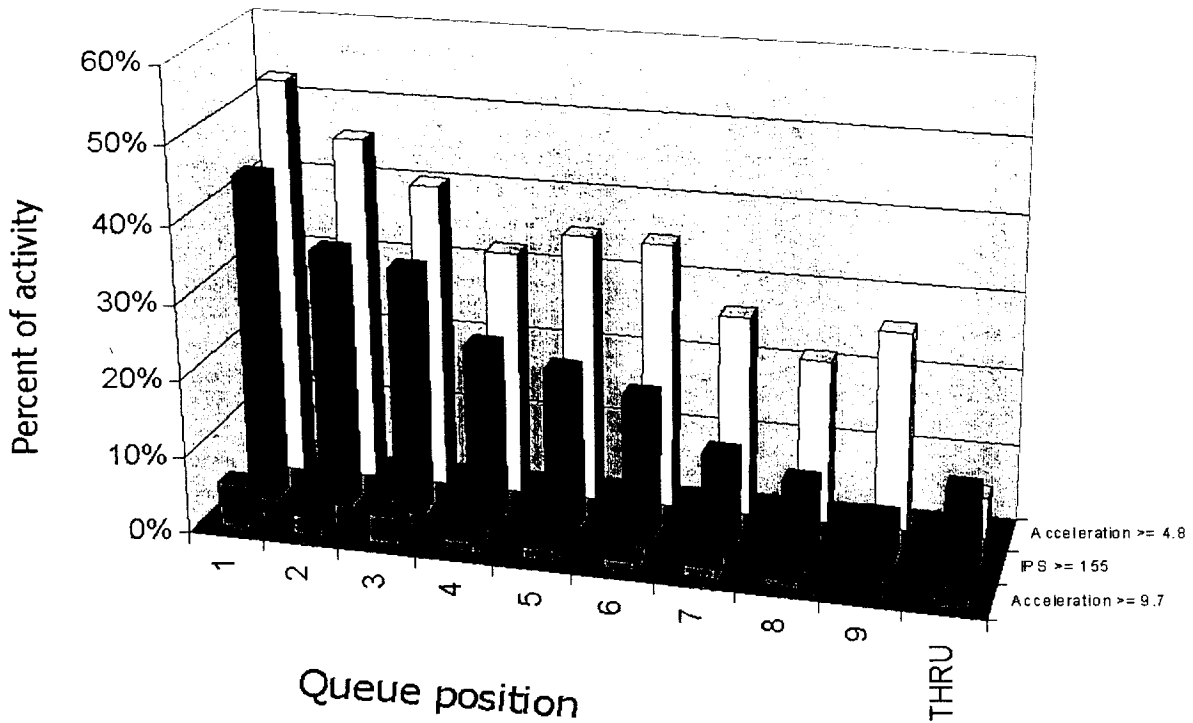


FIGURE 2 Percent of vehicle activity by mode (km/h/s or (km/h)<sup>2</sup>/s).

an activity-specific approach, a reduction in modal activity will demonstrate more significant emissions benefits than previously realized using an average-speed modeling approach.

Although MEASURE originally was developed for regional scale modeling, the two major components of the model—mode and technology group-specific emission rates and vehicle activity profiles—also can be used to estimate emissions on a microscale, such as comparing the results of different intersection timing plans. To demonstrate the possible benefits of an activity-specific approach for evaluation of signal timing improvements as a TCM, the differences in emission production for a coordinated and uncoordinated timing plan for the same intersection are presented.

The intersection at Marietta and Chatahochee, a four-approach intersection in Atlanta, Georgia, with a total afternoon peak-hour volume of 2,441 vehicles, was used for a case study. The east and west approaches to the intersection have two “thru” lanes and one left-turn lane each. The north and south approaches have one “thru” lane and one left-turn lane each. The intersection is operating on an 80-s cycle length. Using the existing timing plan for the study intersection and the signalized intersections upstream and downstream, a coordinated plan and an uncoordinated plan were developed and then

simulated using FHWA’s CORSIM simulation model to determine queue lengths and volumes.

Once the length of queue and volumes were calculated in CORSIM, field data (described above) were used to develop a distribution of second-by-second speed/acceleration profiles for individual vehicle traces and were used to determine fractions of activity spent in relevant operating modes for application of activity-specific emission rates. Table 1 presents statistics for the coordinated versus uncoordinated plans. Data are presented for activity that occurs 152 m (500 ft) upstream of the intersection and 152 m (500 ft) downstream. The variable for acceleration activity greater than or equal to 9.7 km/h/s was not necessary to complete calculations, but it was included to illustrate extreme ranges of modal activity. Emissions were estimated using the technology group mix from the regional vehicle fleet for the Atlanta, Georgia, area. Then the carbon monoxide model, described in Equation 7, and MOBILE5a were used to create an emission rate that was applied to the distribution of activity and yielded total CO emissions produced for each scenario. As shown in the table, the percent of activity at the intersection in which accelerations were  $\geq 9.7$  km/h/s and  $\geq 4.8$  km/h/s was reduced roughly by half for the coordinated plan, whereas the percent of activity in which IPS  $\geq$

TABLE 1 Comparison of Coordinated and Uncoordinated Signal Timing for Marietta and Chatahochee Intersection

Timing Plan	Average Speed	Activity $\geq$ 9.7 kph/s	Activity $\geq$ 4.8 kph/s	Activity $\geq$ 155 kph <sup>2</sup> /s	Total Sec. of Activity	MEASURE Emissions for Peak Hour (g)	MOBILE5a Emissions for Peak Hour (g)
Uncoordinated	47 kph	0.7%	11.4%	16.6%	96,151	5,130	2,016
Coordinated	60 kph	0.4%	5.4%	10.7%	90,645	4,680	1,878
Difference between uncoordinated and coordinated	-13 kph	0.3%	6.0%	5.9%	5,506	449	138

155 (km/h)<sup>2</sup>/s decreased roughly by a third. The coordinated plan resulted in a substantial savings of 449 g per hour of CO using the MEASURE emission rates, whereas a savings of only 138 g per hour resulted from the improved coordination using MOBILE5a. When multiplied over several hours a day over a year, the benefits of using signal coordination for this intersection are significant when analyzed using an activity-specific approach.

The results presented here are specific to the intersection studied. The actual emission benefits realized by improved timing plans or coordination will vary from scenario to scenario and will depend on increases or decreases in average speeds and fractions of time spent in operating modes in which emissions are elevated, traffic volumes, time spent idling, and the specific mix of technology groups in the fleet.

The differences between the total emissions estimated at the intersection using an activity-specific approach versus the traditional modeling approach should be noted. For both the coordinated and uncoordinated scenarios, MEASURE predicted more than double the amount of CO as MOBILE5a. This also indicates the ramifications of using an activity-specific approach in terms of overall emission modeling.

## CONCLUSIONS

Signal timing improvements, such as signal coordination, are attractive TCMs for vehicle flow improvement and subsequent emission reduction as they can be integrated within existing transportation systems without requiring extensive capital expansion. However, with traditional modeling, timing improvement may greatly decrease modal activity yet not yield relevant benefits in terms of emission reduction if only moderate changes in average speed are realized. The use of an activity-specific approach, MEASURE, to evaluate the transportation-related air quality reduction in carbon monoxide emissions from signal coordination for a study intersection was shown to be much more significant than reductions calculated with MOBILE5a.

Although results cannot be unilaterally applied to all intersections, evidence suggests that TCMs can be shown to be much more beneficial when the changes in operating mode are taken into consideration as well as average speed. As a result, TCMs, such as improved signal timing, may be more beneficial than previously realized.

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