VEHICLE EMISSIONS AND TRAFFIC MEASURES: EXPLORATORY ANALYSIS OF FIELD OBSERVATIONS AT SIGNALIZED ARTERIALS

Nagui M. Rouphail, Ph.D.
Professor, Civil Engineering
North Carolina State University
rouphail@eos.ncsu.edu

H. Christopher Frey, Ph.D.
Associate Professor, Civil Engineering
North Carolina State University
frey@eos.ncsu.edu

James D. Colyar
Graduate Student, Civil Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908
Tel: (919) 515-6456
jdcolyar@eos.ncsu.edu

Alper Unal
Graduate Student, Civil Engineering
North Carolina State University
Campus Box 7908
Raleigh, NC 27695-7908
Tel: (919) 515-4232
aunal@eos.ncsu.edu

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ABSTRACT

Understanding the relation between vehicle emissions and traffic control measures is an important step toward reducing the potential for global warming, smog, ozone depletion, and respiratory illness. Traffic analysts, through improved roadway design and traffic control, have the ability to reduce vehicle emissions. However, current vehicle emissions models do not allow traffic analysts to easily and accurately predict vehicle emissions based on commonly used traffic measures.

The primary purpose of this exploratory research is to study the effects of traffic flow on real-world vehicle emissions. The rates of vehicle emissions are evaluated during each “mode” of travel: acceleration, deceleration, cruise, and idle. Then, the relationship between vehicle emissions and a commonly used traffic measure, control delay, is investigated.

Data for this research were collected in real-time through the use of a portable, On-board Emission Measurement unit (OEM 2100^{TM}). The OEM 2100 allows real-time, field data collection of second-by-second measurement of tailpipe emissions (i.e., CO, HC, and NO) and engine operations (i.e., speed and engine rpm). This is the first research project deploying the OEM 2100 and differs from the majority of past emissions research in focusing on the collection of real-world, on-road data from instrumented vehicles.

A key result from this study is that vehicle emissions were found to be highest during the acceleration mode and lowest during the idling mode. Also, vehicle emissions were found to be approximately twice as much during control delay than when not in delay. This is because acceleration events often occur within control delay events.

KEYWORDS: Vehicle Emissions, Emissions Model, Control Delay, Signalized Arterial

INTRODUCTION

The emission of vehicle pollutants into the atmosphere is an increasingly important health issue that affects nearly everyone. For example, hydrocarbons (HC) and nitric oxides (NO) are the primary gases needed in the formation of ozone, which can cause lung tissue damage and respiratory illness (1). Also, high amounts of carbon monoxide (CO) at ground level can lead to carbon monoxide poisoning and can impair visual perception, manual dexterity, and exercise capacity. Vehicle emissions account for approximately one-half of total HC emissions, one-half of total NO emissions, and two-thirds of total CO emissions (1). Thus, a direct link can be seen between vehicle emissions and societal health.

The primary purpose of this study is to investigate the effects of traffic flow quality on vehicle emissions. Specifically, this paper investigates the relationship between vehicle emissions and a commonly used traffic measure, control delay. The benefit of this research is that it may allow traffic analysts to predict vehicle emissions based on a Highway Capacity Manual (HCM) style analysis (2) and, thus, make vehicle emissions prediction much more accessible to traffic analysts.

The methodology of the study is unique because it features an on-road vehicle data measurement device that allows simultaneous field measurements of both vehicle speed and emissions on a wide variety of light duty vehicles, in contrast to laboratory dynamometer measurements found in the literature (3, 4, 5, 6). This research project is the first to use this portable on-road emissions measurement device, the OEM 2100.

This paper is organized into the following sections:

- literature review of traffic models and predictions of vehicle emission;
- methodology used to collect and reduce field data with the OEM 2100;

- classification of vehicle emissions data by driving mode;
- classification of vehicle emissions data by delay event; and
- future work planned with the OEM 2100.

LITERATURE REVIEW

A literature review was performed of commonly used traffic models and their use of vehicle emission models. Perhaps the most widely known vehicle emission model is MOBILE5, developed by Environmental Protection Agency (EPA). The MOBILE5 model was developed based on laboratory dynamometer driving tests (3). The model predicts carbon monoxide (CO), hydrocarbons (HC), and nitric oxide (NO) emissions as a function of a number of factors, with vehicle speed and vehicle-miles-traveled (VMT) constituting the only traffic measures.

However, most traffic operations software packages do not use the MOBILE5 model. A number of microscopic traffic models predict vehicle emissions from look-up tables on a second-by-second basis as a function of vehicle type, speed, and acceleration. CORSIM, a microscopic model, uses unpublished vehicle emission rates from dynamometer testing as the basis of its emissions model (7). The program determines the total emissions on each link by applying the default emission rates (based on speed and acceleration) to each vehicle for each second the vehicle travels on the given link. Another microscopic model, INTEGRATION, computes the fuel consumption for each vehicle on a second-by-second basis as a function of speed and acceleration. It then estimates vehicle emissions on a second-by-second basis as a function of the fuel consumption, ambient air temperature, and the extent to which a particular vehicle’s catalytic converter has already been warmed up during an earlier portion of the trip (8).

SYNCHRO, a macroscopic traffic model, contains a simplified emissions model (9). SYNCHRO predicts vehicle emissions by first predicting fuel consumption, which is calculated as a function of vehicle-miles, total delay in veh-hr/hr, and total stops in stops per hour. Then, the fuel consumption is multiplied by an adjustment factor (differs depending on the type of emissions) to estimate vehicle emissions.

Other macroscopic traffic models, such as Transyt-7F (10), Passer II-90 (11), HCS (12), and SIGNAL97 (13), do not include emission predictors. Because these are widely used traffic models, it is difficult for traffic analysts to estimate vehicle emissions in many cases.

Perhaps the most comprehensive vehicle emissions research is currently being performed at the University of California at Riverside as part of the National Cooperative Highway Research Project (NCHRP) 25-11 (16). This project is developing a modal emissions model that will reflect Light-Duty Vehicle (LDV) emissions produced as a function of the vehicle's operating mode. The model, which is based on laboratory dynamometer testing, will use a total of 47 parameters to estimate vehicle tailpipe emissions, of which 16 are readily available and 31 need to be calibrated under laboratory conditions. This model will be eventually integrated with the under-development TRANSIMS transportation simulation model.

The recently developed MEASURE model predicts vehicle emissions as a function of engine power, kinetic energy, speed, and acceleration (5). This model is different than MOBILE5 from a traffic parameter standpoint in that it uses both speed and acceleration as model inputs, rather than just speed.

A mesoscopic emission model was recently developed based on average speed and number of stops (6). This model was developed based on the collection of on-board engine parameter and dynamometer vehicle emissions measurement. The dynamometer data were separated into deceleration, acceleration, and cruise driving modes. The model uses a generalized speed trace to predict emissions associated with each stop.

The intent of the mesoscopic model is similar to our project in that it is aimed at giving traffic analysts a practical approach to estimating vehicle emissions by using commonly used traffic parameters, such as control delay or intersection stops. However, the approach of our research is unique in that it is based upon real-world, on-road engine and emissions data collected simultaneously under actual driving conditions.

DATA COLLECTION METHODOLOGY

This project features the deployment of a portable, on-road vehicle data measurement device (OEM 2100) to collect vehicle emissions and engine data as the vehicle is driven under real-world conditions. The specific data collected include second-by-second data streams for vehicle operation and vehicle emissions. Vehicle operation data obtained include vehicle speed (mph), engine rpm, engine coolant temperature, intake air temperature, manifold absolute pressure (MAP), percent of wide open throttle, open/closed loop flag, and other engine parameters depending on the specific vehicle.

The emissions data obtained include CO, NO, HC, CO_2, and O_2. Some parameters such as fuel consumption are not directly measured by the OEM 2100 but are calculated using the methodology developed by Vojtisek-Lom and Cobb (15).

The OEM 2100 is a portable instrument that can be installed in approximately 15 minutes in a light duty vehicle. It has three connections with the vehicle: a power cable typically connected to the cigarette lighter or power port, an engine data link connected to the On-Board

Diagnostic (OBD) link, and an emissions sampling probe inserted into the tailpipe. The connections are fully reversible and do not require any modification to the vehicle.

The OEM 2100 is designed to measure engine data and emissions from gasoline-fuel vehicles equipped with an OBD interface. The OEM 2100 has the capability to work with OBD interfaces of 1990 to 1995 model year vehicles, as well as with the standardized OBD-II interface of 1996 and newer model year vehicles. The equipment vendor is currently developing a similar instrument to measure on-road gases and particulate matter emissions of heavy-duty diesel vehicles.

The consistency of the OEM 2100 and dynamometer measurements has been tested at the New York Department of Environmental Conservation (DEC) laboratory and at the EPA National Fuels and Vehicle Emissions Laboratory in Ann Arbor, Michigan (16). Various standard driving cycles were compared, including the NYCC, FTP, US-606, and I/M 240 cycles. The results show high correlation between the OEM 2100 and laboratory dynamometer tests for CO_2, CO, NO, and HC gases (R^2 values ranging from 0.90 to 0.99).

Figure 1 illustrates the placement of the OEM 2100 instrument on a seat inside the vehicle. Figure 2 illustrates the emission sampling probe and hose, which are routed into the vehicle and to the instrument. Figure 3 illustrates the vehicle fully equipped with the OEM 2100 and ready for on-road testing.

During late 1999 and early 2000, a field study was conducted to obtain simultaneous emissions and traffic data at two major arterials in Research Triangle Park, North Carolina. Data were collected over the course of 20 weekdays on NC 54 and Miami Boulevard. Table 1 shows the traffic characteristics of the two arterials.

FIGURE 1 OEM 2100 installed in a 1998 Toyota Camry.

FIGURE 2 Sampling probe routed from vehicle tailpipe into vehicle, secured by clamps.

FIGURE 3 Vehicle fully equipped with OEM 2100 and ready for testing.

TABLE 1 Traffic Characteristics of Test Arterials

Characteristic	**Miami Blvd.**	**NC 54**
Speed Limit (mph)	45	45 mainly, short segments of 35 and 50
# Traffic Signals	13	8
Corridor Length (mi.)	5.9	3.8
Signal Density (signals/mi.)	2.2	2.1
Free Flow Speed (mph) [a]	45-50	40-45
Arterial Level of Service [b]	C – AM/PM Peaks B – Noon Peak	B – AM/Noon Peaks C – PM Peak

a. See 'Estimation of Control Delay' section for discussion of free flow speed estimation.
b. Based on HCM Table 11-1 (2).

Four different vehicle types were used during data collection: a 1996 Oldsmobile Cutlass sedan, 1998 Plymouth Breeze sedan, 1999 Ford Taurus sedan, and Ford Club Wagon 15-passenger van. A total of 400 one-way runs were made on the two arterials. These data equate to approximately 72 hours of on-road measurements, during which time data was recorded each second. A total of 2,000 vehicle-miles were traveled during the data collection.

The main purpose of the experiment was to study the effect of signal coordination on vehicle emissions by comparing data collected before and after signal coordination plans were implemented. Because this is a first-of-a-kind pilot study, a first step was to collect sufficient data to characterize variability between runs in aiding later determinations of the minimum number of runs needed to obtain statistically significant comparisons. The number of runs and number of vehicles used is highly dependent on the purpose of the study. Studies that address other objectives would be designed differently. For example, a study aimed at characterizing fleet average emissions would involve more vehicles but fewer runs per vehicles.

Timestamps were recorded using a laptop computer for each significant traffic event, including stopping at a signalized intersection, passing through the center of a signalized intersection, and stopping or slowing significantly at a mid-block location due to a turning vehicle or incident. These timestamps were used to develop estimates of traffic measures, as discussed in the next section.

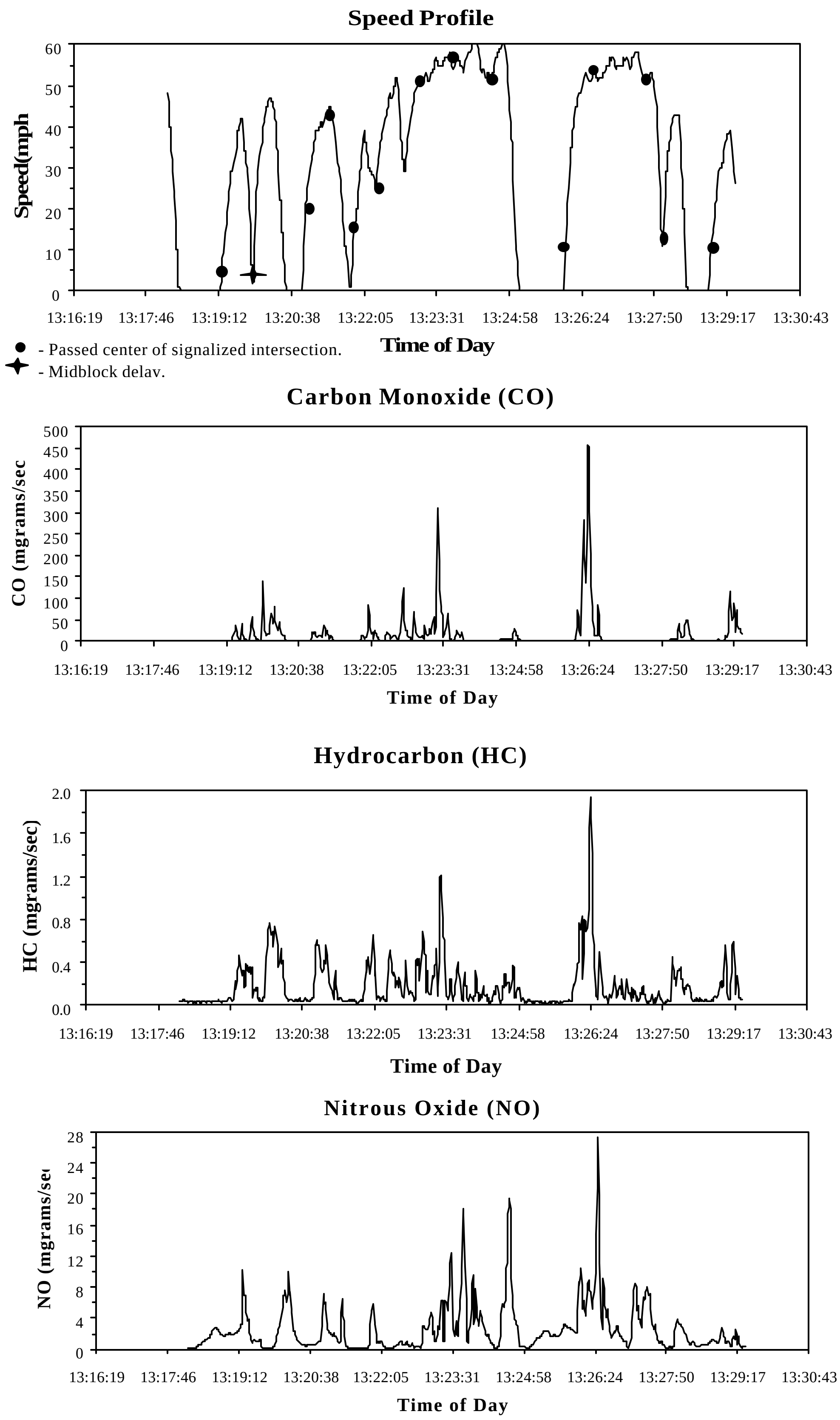
A more detailed description of the data collection methodology is provided by Frey, *et. al.* (17).

DATA REDUCTION

The data collected by the OEM 2100 are summarized in a tab-delimited format, then converted to spreadsheet format for ease of data analysis. The traffic event information, which comprised recording timestamps for each major traffic event, was collected with a laptop computer and stored in spreadsheet format as well. The OEM 2100 and traffic event files were merged for each one-way corridor run using a macro which synchronized the traffic event timestamps to the OEM clock time. This single file was then examined by discarding invalid data associated with equipment failures. The final result of the data reduction process was a single, error-free file for each one-way corridor run containing the second-by-second emission, engine diagnostic, and traffic event information.

Speed and Emission Profiles

As described previously, the OEM 2100 measures both vehicle engine and tailpipe emissions on a second-by-second basis. This allows a direct association between instantaneous speed and vehicle emissions. Figure 4 depicts an example profile of the speed, CO, HC, and NO of a floating car run on Miami Boulevard. The run shown in Figure 4 was made with a 1996 Oldsmobile Cutlass sedan.


Speed Profile

Carbon Monoxide (CO)

Hydrocarbon (HC)

Nitrous Oxide (NO)

Vehicle: 1996 Oldsmobile Cutlass

FIGURE 4 Example Speed and Vehicle Emission Profile on Miami Boulevard.

There are a number of insights that can be gained from Figure 4. First, the vehicle emissions are composed primarily of short episodes of high emissions. A qualitative observation from this is that emissions are not directly proportional to vehicle-miles traveled. The high spikes in emissions occur concurrently with steep accelerations (e.g. at time 13:26:24). However, a steep acceleration does not always translate to a high spike in emissions (e.g. at time 13:20:38). Another insight is that vehicle emissions are very low while the vehicle is stopped (idle mode). Thus, a qualitative observation is that transportation improvement projects aimed at reducing the number of accelerations can lead to substantial air quality benefits, whereas projects aimed at just reducing idling time would yield relatively small air quality benefits.

VEHICLE EMISSIONS BY DRIVING MODE

Methodology

The raw emissions data were subsequently analyzed by four modes of travel: acceleration, deceleration, idle, and cruise. A simplified decision tree was used to categorize the second-by-second data into the four modes using speed and acceleration as the decision thresholds. A detailed description of the decision tree is described in Frey, *et. al.* (17).

Results

The vehicle emissions by driving mode are summarized in Figure 5. The emission rates shown are for a 1996 Oldsmobile Cutlass sedan measured over 48 runs and a 1999 Ford Taurus sedan measured over 23 runs. All runs were completed on the Miami Boulevard arterial.

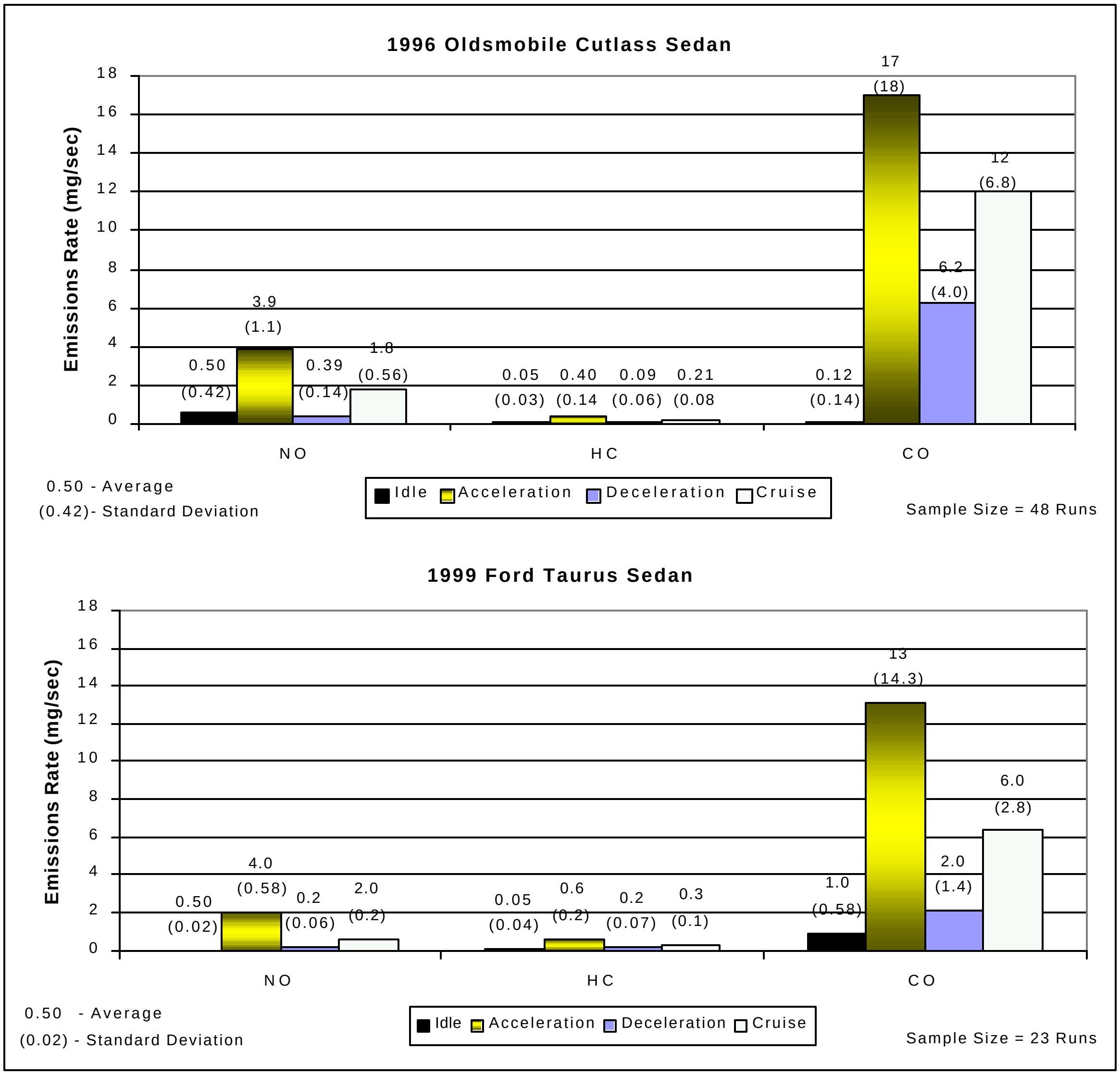


FIGURE 5 Vehicle Emissions by Driving Mode.

As shown in Figure 5, the highest emissions rate was produced during acceleration. This confirms the earlier observation in Figure 4 that the highest spikes in emissions occur during acceleration events. The cruise mode experienced the next highest emissions rate. As observed earlier in Figure 4, idling had the lowest emissions rate. The standard deviation is relatively large for the majority of the emission rates. This is due to the variability in vehicle emissions and the presence of other factors effecting emissions, such as engine condition, driver aggressiveness, and weather conditions.

The deceleration CO emission rate for the Oldsmobile is comparatively high given that most late model vehicles have a deceleration fuel cut. However, the deceleration CO emission rate for the Taurus, and for the other vehicles tested, is proportionately lower and more in-line with expectations. The relatively high deceleration CO rate for the Oldsmobile may indicate an engine maintenance problem.

VEHICLE EMISSIONS BY DELAY EVENT

It is important to understand what causes the variations in vehicle emissions, especially which factors are responsible for episodes of high vehicle emissions. However, it is equally important to relate vehicle emissions to traffic measures commonly used by traffic analysts so they can make informed choices of how roadway design and traffic control measures affect vehicle emissions.

Traffic analysts do not typically have access to field data on the four driving modes to represent traffic conditions. However, measures such as intersection control delay are commonly measured (or can be predicted), and as such they could possibly act as surrogate measures to driving mode. For this reason, the relationship between vehicle emissions and control delay was investigated. Using delay and non-delay emission rates could be used concurrently with a Highway Capacity Manual (HCM) arterial level-of-service analysis. The HCM arterial analysis procedure estimates the amount of time in control delay and the total arterial travel time, which could be applied to the delay and non-delay emission rates (2).

Methodology

Field control delay was estimated through the use of the second-by-second speed data and the timestamps recorded as a vehicle passes through the center of a signalized intersection. Control delay, as defined in the HCM (2), is the difference in time it takes a vehicle to reach cruising speed at a distance downstream of an intersection (after slowing down and stopping at the intersection) and the time taken had the vehicle maintained its cruising speed through the intersection. Figure 6 illustrates the concept of control delay on a time-distance graph.

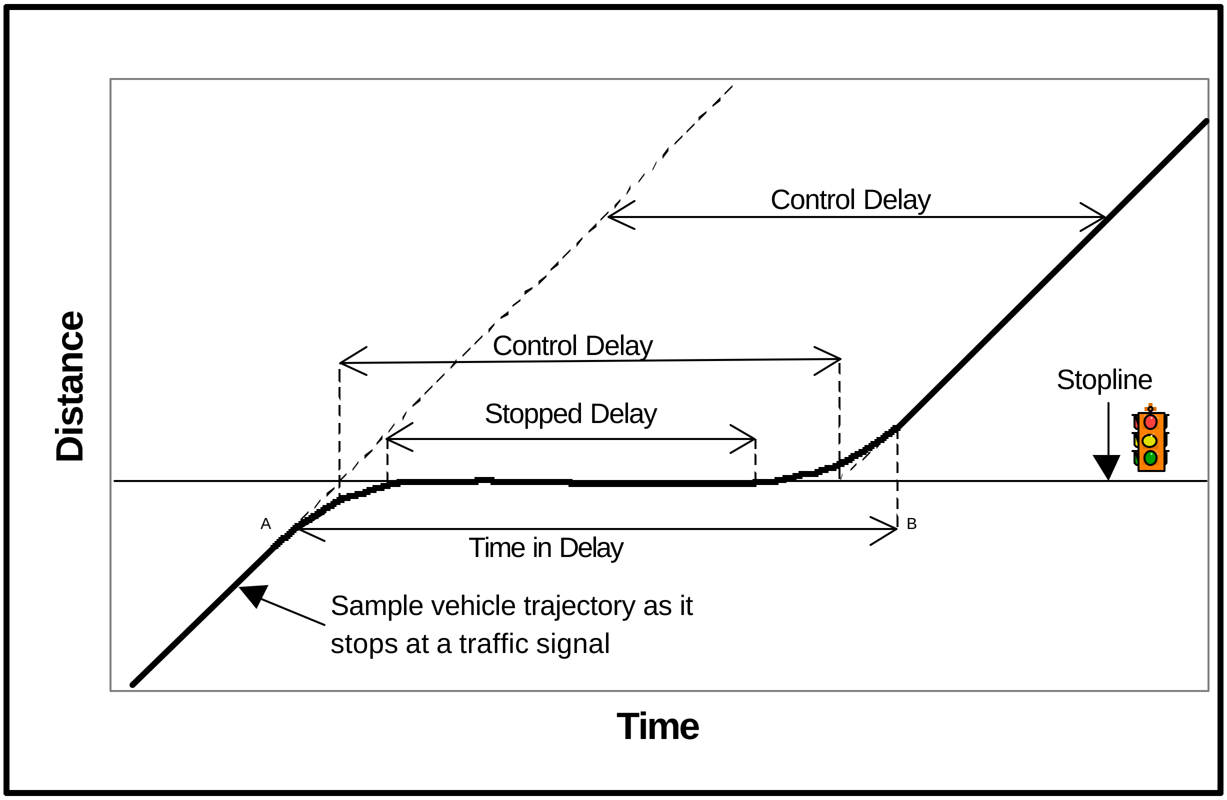


FIGURE 6 Illustration of Delay Types at Signalized Intersection – Single Vehicle Trajectory.

Another type of delay shown in Figure 6 is *Time in Delay*, which is the time from when a vehicle first starts to slow down until the vehicle reaches cruise speed again. The Time in Delay is always larger than the control delay. The third type of delay shown in Figure 6 is *Stopped Delay*, which is the vehicle idling time.

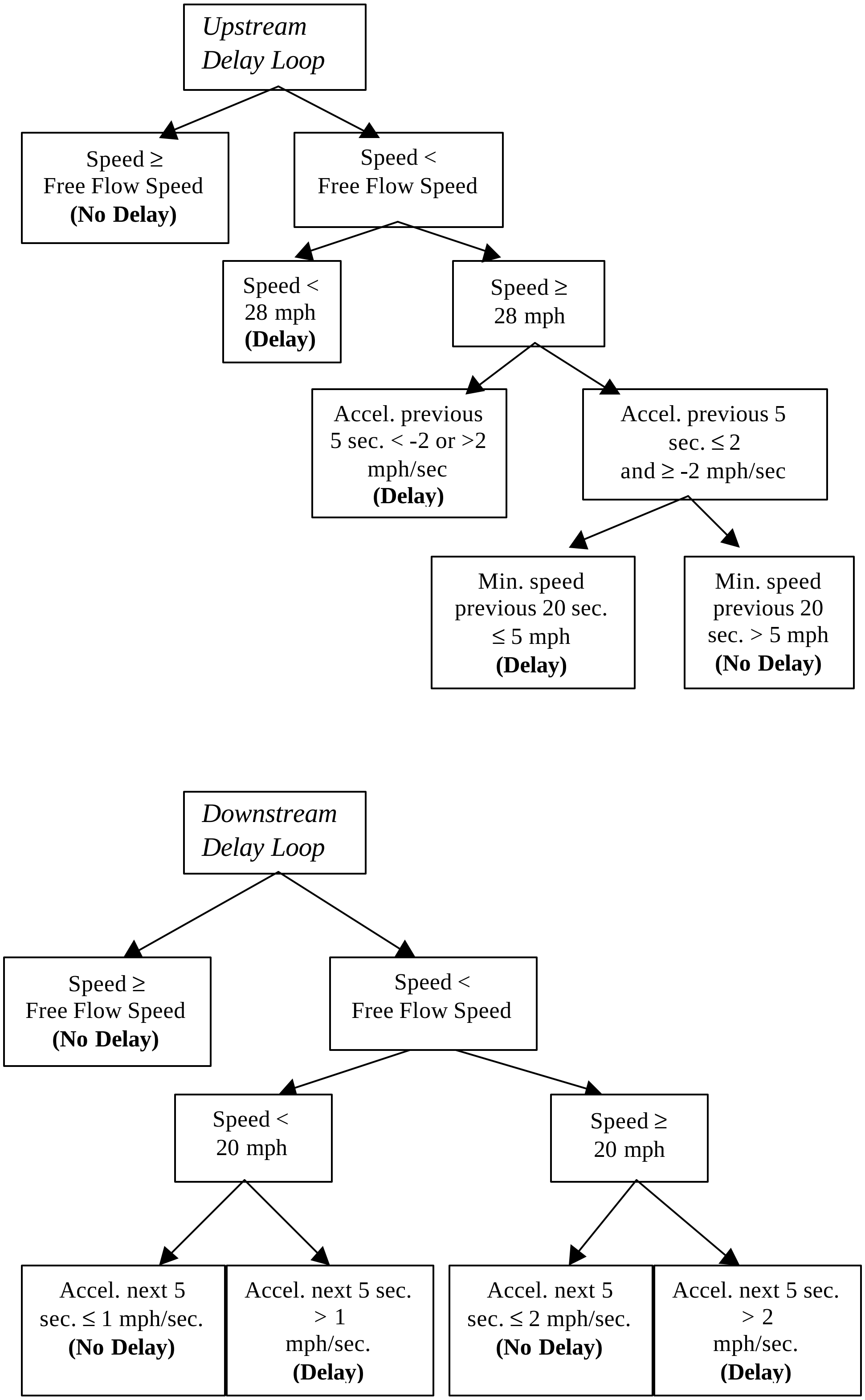
The control delay at a signalized intersection was estimated through a three-step process:

1) estimate Time in Delay using a decision tree for determining when a vehicle enters and exits a delay event (time A to B in Figure 6),
2) estimate stopped delay by summing all seconds when a vehicle is traveling at less than or equal to three mph immediately upstream of the signalized intersection, and
3) estimate control delay as a function of Time in Delay and stopped delay (see Eq. 1 later).

The first step is to estimate the times when a vehicle enters and exits a delay event using a decision tree. The program begins by searching through the second-by-second speed trace for the timestamp when the vehicle passes through the center of an intersection. The program then runs through a decision tree both upstream and downstream of the center of intersection to determine when the vehicle entered and exited the delay event.

The basic premise of the decision tree is to check in each second whether the vehicle is experiencing delay. If a 'delay' decision is produced, then the decision tree determines that the second being tested is in delay and continues checking the next upstream or downstream second(s) until if finds the time where the vehicle is no longer in delay. A schematic diagram of the two decision trees is shown in Figure 7.

A number of speed and acceleration parameters are used in the decision tree. For example, the upstream loop places all speeds less than 28 mph in delay and thus loops to the next



Note: ‘Delay’ means the second being tested is experiencing delay and the program loops to the next second. ‘No Delay’ means the second being tested is not experiencing delay and thus exits the loop.

FIGURE 7 Time in Delay Decision Tree.

second. This parameter was calibrated via a sensitivity analysis. Sensitivity tests were also performed on the other parameters in the decision tree.

The free flow speed was estimated using runs completed during the noon peak. Free flow speed is defined in the HCM as the average speed during low volume conditions outside the influence area of traffic signals (2). Speeds above 40 mph were estimated to be outside the influence of traffic signals (the speed limit is predominantly 45 mph on the test arterials) and were thus used as the sample range for free flow speeds. The average speed when vehicles were traveling above 40 mph was calculated from the second-by-second speed traces for each run. The resultant speed was then increased slightly to account for some travel under acceleration and deceleration modes (as opposed to cruise mode, where free flow speed should technically be measured). This adjusted speed was used as the free flow speed for the decision tree.

The next step in the estimation of control delay was calculation of stopped delay. A speed of three mph or lower was used to indicate a stopped condition. This threshold was needed to ensure that low speeds recorded while a vehicle was creeping forward during a stopped queue were classified as stopped delay. The three-mph threshold was chosen based on investigation of the second-by-second speed data while vehicles were creeping within a queue.

Once the Time in Delay and Stopped Delay were determined, the Control Delay was then estimated using the following equation (see Figure 6):

$$\text{Control Delay} = \frac{(\text{Time in Delay} + \text{Stopped Delay})}{2} \qquad (1)$$

This equation assumes that the average speed during the acceleration and deceleration modes is one-half of the free flow speed. This is a reasonably accurate assumption based on investigation of the second-by-second speed data.

Figure 8 illustrates the three-step process used to calculate intersection control delay. In the example, the control delay was estimated to be 24 seconds for the northbound through movement at the Miami Boulevard/I-40 WB Ramp intersection.

Results

The emissions rate (in milligrams per second) during a delay event was estimated by summing the vehicle emissions during Time in Delay and dividing by the Control Delay. Emissions during Time in Delay (in grams) was used as the numerator in the delay emissions rate to ensure that the emissions during the entire deceleration and acceleration periods were included in the delay emissions rate. The Control Delay (in seconds) was used as the denominator of the emissions rate so these rates can be applied by traffic analysts who can estimate control delay but not Time in Delay. The same procedure was performed for the period outside the delay events to get an emissions rate when the vehicle is not in delay.

Figure 9 displays the emissions rate by delay event. These data represent 178 corridor runs on Miami Boulevard and 140 runs on NC 54, for a total of over 50 hours. As shown in Figure 9, the emissions rates are approximately twice as high during delay than the rates outside delay. The delay events are essentially a weighted average of the deceleration, idling, and acceleration modes. The non-delay events are composed primarily of the cruise mode. As shown previously, the acceleration mode has a much higher emissions rate than the other driving modes, which is the driving force behind the high emission rate during delay.

Steps in Estimating Control Delay

1. Estimate Time in Delay.
2. Estimate Stopped Delay.
3. Estimate Control Delay as a function of Time in Delay and Stopped Delay.

Spreadsheet Output of Second-by-Second Data

Time of Day	Center of Intersection	Speed (mph)	Accel. (mph/s)
8:27:42		35	2
8:27:43		36	1
8:27:44		38	2
8:27:45		39	1
8:27:46		37	-2
8:27:47		35	-2
8:27:48		35	0
8:27:49		34	-1
8:27:50		33	-1
8:27:51		30	-3
8:27:52		28	-2
8:27:53		25	-3
8:27:54		22	-3
8:27:55		19	-3
8:27:56		17	-2
8:27:57		11	-6
8:27:58		11	0
8:27:59		3	-8
8:28:00		3	0
8:28:01		1	-2
8:28:02		0	-1
8:28:03		0	0
8:28:04		0	0
8:28:05		1	1
8:28:06		1	0
8:28:07		1	0
8:28:08		1	0
8:28:09		1	0
8:28:10		3	2
8:28:11		3	0
8:28:12		10	7
8:28:13		11	1
8:28:14		16	5
8:28:15	Miami Blvd/I-40 WB Ramp	18	2
8:28:16		21	3
8:28:17		24	3
8:28:18		27	3
8:28:19		28	1
8:28:20		30	2
8:28:21		32	2
8:28:22		32	0
8:28:23		33	1
8:28:24		33	0
8:28:25		33	0
8:28:26		32	-1
8:28:27		32	0

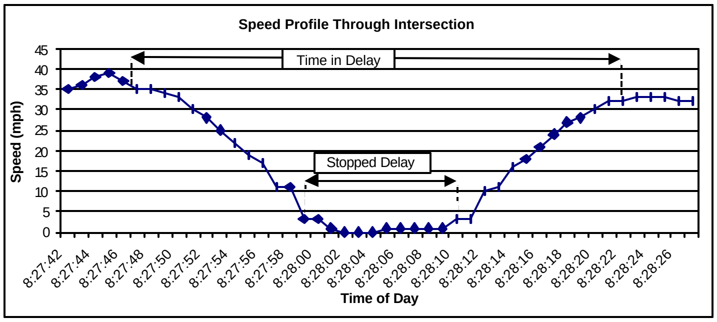
Step 1b: Use 'Upstream Delay Loop' to determine when vehicle enters delay. For this example, the loop determines upstream delay starts at 35 mph.

Step 2: Estimate stopped delay as time when speed is less than or equal to 3 mph. *SD = 13 sec.*

Step 1a: Find time when vehicle passes center of intersection.

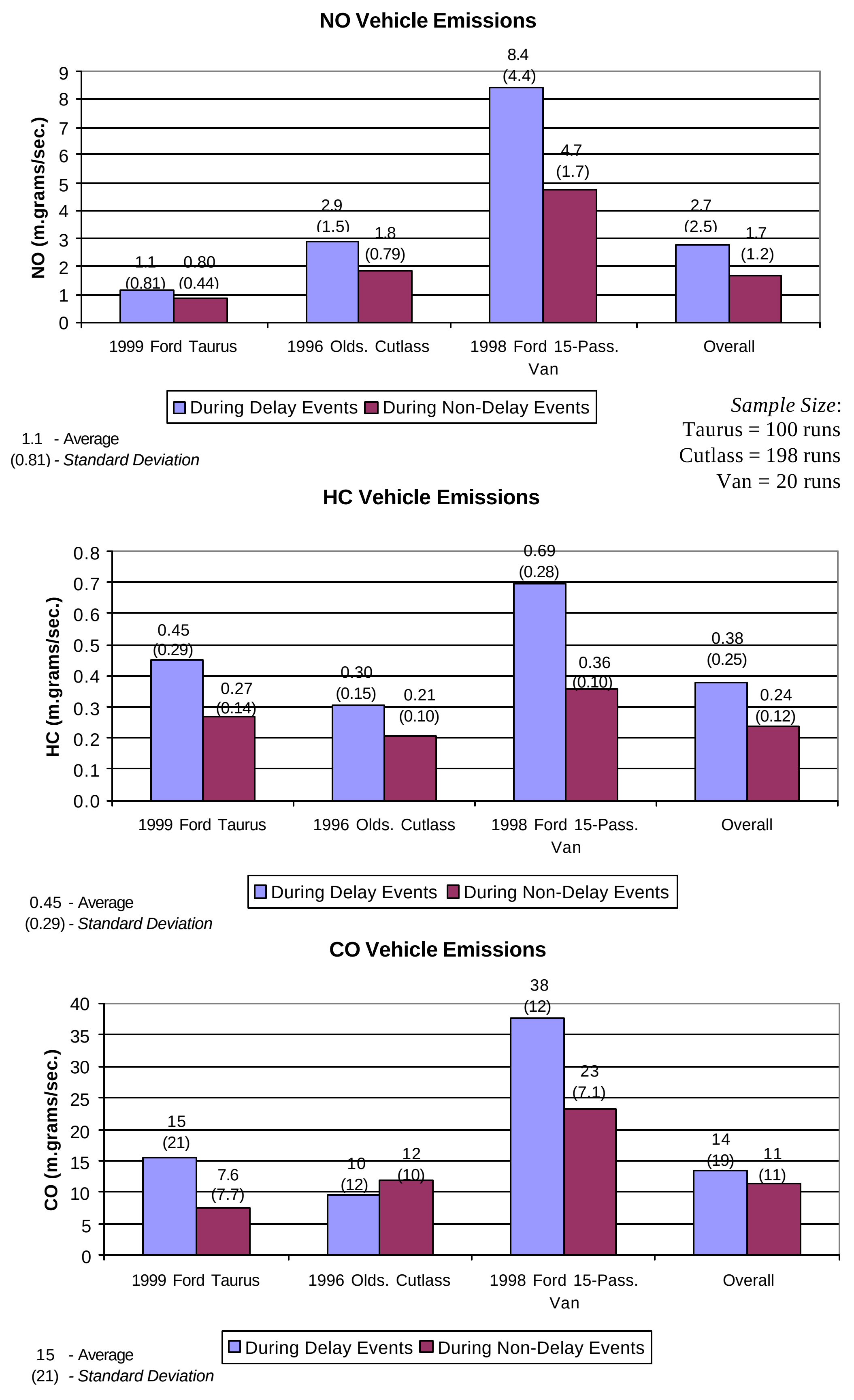
Step 1c: Use 'Downstream Delay Loop' to determine when vehicle exits delay. For this example, the loop determines downstream delay stops at 32 mph. *TD = 35 sec.*

Step 3: Calculate Control Delay using the following formula:
CD = (TD + SD)/2
CD = (35 + 13)/2
CD = 24 sec.



Notes: Free flow speed was determined to be 45 mph through this intersection. TD = Time in Delay, SD = Stopped Delay, CD = Control Delay.

FIGURE 8 Example Calculation of Control Delay.



1.1 - Average
(0.81) - *Standard Deviation*

Sample Size:
Taurus = 100 runs
Cutlass = 198 runs
Van = 20 runs

0.45 - Average
(0.29) - *Standard Deviation*

15 - Average
(21) - *Standard Deviation*

FIGURE 9 Vehicle Emissions by Delay Event.

The 15-passenger van has much higher emissions than the other two light duty vehicles. The Taurus and Cutlass also have differences, with the Taurus emitting more HC, the Cutlass emitting more NO, and both emitting approximately the same amount of CO. These differences show the variability in emissions among the same vehicle class (light duty).

The standard deviations reflecting variability in emissions from one run to another are relatively high in comparison to the average emission rates. Of the three gases measured, CO had the highest relative variability, with the standard deviation often exceeding the average. This seems to indicate that CO is more dependent on other variables, such as engine condition, driver aggressiveness, and outside weather conditions, than the other the other two gases measured. Of the three vehicles tested, the 1999 Ford Van had a consistently lower standard deviation, and thus variability, than the other two vehicles tested. This could indicate that the emissions from the van are less dependent on other variables than the other two vehicles tested.

Even though the standard deviations are fairly high, there is relative certainty that the average emission rate during delay is indeed higher than the average emission rate during non-delay. For example, the standard error for HC emissions from the Taurus is 0.03 mg/sec for delay events and 0.01 mg/sec for non-delay events. This means that the lower 95 percent confidence level for the average delay emissions is 0.39 mg/sec, and the upper 95 percent confidence level for the non-delay emissions is 0.29 mg/sec. Therefore, the emissions during delay are statistically significantly higher than during non-delay, even though there is a large amount of variability among individual runs.

One could conclude from Figure 9 that designing a signal system with less control delay will lead to lower vehicle emissions. However, it is important to note that the acceleration portion, not the idle portion, comprises the majority of emissions while in control delay. There is often a trade-off between minimizing delay or stops when timing traffic signals. For example, choosing a higher cycle length will generally result in fewer stops but in increased control delay. Fewer intersection stops would lead to fewer hard acceleration events because each intersection stop has an associated acceleration from a stopped position. Thus, transportation projects that tend to minimize the number of stops would likely lead to greater air quality benefits than a project that is just concerned with control delay reduction.

PLANNED WORK

The next step of this research project is to investigate the applicability of other traffic measures as predictors for vehicle emissions. For example, intersection stops may be the best surrogate for predicting high emission events because a steep acceleration will occur after each vehicle stop. Other possible traffic surrogates include average speed, travel time, and percent time in control delay. Each of these traffic measures would be compatible with an HCM-style analysis. The biggest challenge in this work will be the variability of emissions due to non-traffic measures, such as engine condition, driver aggressiveness, and weather conditions.

As mentioned previously, the primary purpose of the data collection effort was to study the effect of signal coordination on vehicle emissions. Once the before and after study is complete, the results of this effort will be examined in detail. In addition, the large number of input parameters and flexibility of the OEM 2100 will allow investigations into a number of additional research areas, such as the effect of driver aggressiveness.

CONCLUSIONS

The primary purpose of this paper was to investigate the effects of traffic flow on vehicle emissions by evaluating the relationship between vehicle emissions and control delay. The key findings and conclusions from this paper can be summarized as follows:

- This research is unique in that it uses on-board, real-time, on-road measurement of vehicle speeds and emissions simultaneously on a wide range of light duty vehicles.
- Vehicle emissions are highest during acceleration events, particularly steep accelerations after idling. Idling, the predominant mode during control delay, produces a low emissions rate.
- Based on the driving mode analysis, transportation improvement projects aimed at reducing the number of accelerations could lead to substantial air quality benefits, whereas projects aimed at just reducing idling time would yield relatively small air quality benefits. In terms of traffic measures, transportation projects that reduce the number of intersection stops could lead to more air quality benefit than a project that attempts to minimize just control delay.
- Vehicle emissions are approximately twice as high during control delay than not in delay. This is due to the fact that the acceleration mode, which was shown to produce high emissions, occurs within the delay event. The non-delay events are primarily composed of the cruise mode, which produce fairly low emissions.
- The relationship between control delay and vehicle emissions could be incorporated into an HCM-style analysis. This would give traffic analysts the option of minimizing vehicle emissions in designing a roadway or timing a signal system. Future research will include investigating a number of traffic measures, such as number of intersection stops, average travel speed, and percent time in control delay, and their effect on vehicle emissions.

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