HOT SPOT ANALYSIS OF REAL WORLD VEHICLE EMISSIONS BASED UPON A PORTABLE ON-BOARD MEASUREMENT SYSTEM

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ABSTRACT

The purpose of this study is to investigate hot spots along roadways where high values of emissions are observed based upon real-world, on-road vehicle emissions measurements. A portable instrument, the OEM-2100^{TM} manufactured by Clean Air Technologies International, Inc., was used to measure on-road tailpipe emissions of carbon monoxide (CO), nitric oxide (NO), hydrocarbons (HC), and carbon dioxide (CO_2) on approximately a second-by-second basis during actual driving. Engine parameters such as vehicle speed, engine rpm, engine coolant temperature, manifold absolute pressure (MAP), percent of wide open throttle, and open loop/closed loop flag were also recorded using the OEM-2100^{TM}. This paper presents examples of the data collected and illustrates the results obtained from analysis of on-road measurements. A key insight is that hot spots can be determined by spatial analysis of real-world on-road vehicle emissions data. In some cases it was observed that ratio of emissions estimates at hot spots to average emissions observed during free-flow was as high as seven as in the case of CO emissions for one of the study corridors. This ratio was as high as five for NO and three for HC emissions. Some air toxics can be estimated as a percentage of HC emissions, therefore the spatial distribution of HC emissions is helpful to support exposure assessments. The relations between hot spots and possible explanatory variables are investigated. The on-road emissions measurement and analysis methods demonstrated in this work enable collection of real-world representative data that can be used to assist in design and management of traffic facilities, as well as for air quality monitoring, modeling, and planning purposes.

Keywords: On-road data collection, vehicle emissions, spatial analysis, hotspots

INTRODUCTION

The purpose of this study is to investigate hotspots along roadways where high values of emissions are observed based upon real-world, on-road vehicle emissions measurements. Accurately identifying hotspots due to vehicle emissions can improve exposure assessment studies since vehicle emissions are known to be a major contributor to air pollution. In the United States in 1999, the transportation sector, including on-road and non-road vehicles, was estimated by the U.S. Environmental Protection Agency to contribute 47 percent of hydrocarbon (HC) emissions, 55 percent of nitrogen oxides (NO_x) emissions, 77 percent of carbon monoxide (CO) emissions, and 25 percent of particulate matter (PM) emissions.[1] The contribution of on-road motor vehicle emissions to local emission inventories, such as in urban areas, may be higher than the national average values. It should be noted that vehicle emissions estimates are obtained by using the MOBILE emission factor model and are subject to uncertainties inherent in this model.[2-3]

Transportation and air quality managers at the state level have the task of developing and evaluating Transportation Control Measurements (TCMs) and other types of Transportation Improvement Plans (TIPs). One of the objectives of TCMs and TIPs is to improve air quality. The benefits of many TCMs and TIPs accrue at the "micro" level, such as individual signalized intersections, traffic control devices, roadway facility improvements (e.g., ramps, roundabouts), improved incident response and management, and others. It is important to identify hotspots along routes in order to evaluate the air quality benefits of such projects. Alternatively, in order to evaluate air quality benefits of alternative routing schemes, one must evaluate changes in emissions associated with substituting one route for another between the same origin and destination. Finally, in order to assess the larger scale benefits of regional management strategies, there must be good, representative, and real-world data regarding on-road emissions for a variety of facility types and control devices. All these different scales of projects require analyzing spatial distribution of emissions and identification of possible hotspots.

The data required to accurately assessment of the air quality benefits of TCMs and/or TIPs must be real-world on-road data and must also be of sufficient temporal and spatial resolution to enable identification and evaluation of hotspots, measurement of the change in emissions as a result of specific, local TCMs (e.g., improved traffic signal coordination and timing) and yet be amenable to the development of datasets to assess regional emissions trends. However, existing highway vehicle emission factor models, such as the Mobile6 or EMFAC7 series of models, are based upon assumed standardized driving cycles, and can not be used for evaluation of the "micro" scale impact of TCMs or of many aspects of TIPs, or for estimation of microscale emissions hotspots.

This paper focuses upon a methodology for hotspots determination along roadways by utilizing on-road emissions data. In particular, the main objectives of this paper are to: (1) describe the on-board emission measurement system used in this study; (2) discuss the experimental design conducted for on-road data collection; (3) discuss data reduction and analysis; and (4) present spatial analysis of emissions and vehicle data for an example data collection route.

COMPARISON OF INSTRUMENTED VEHICLES WITH OTHER MEASUREMENT METHODS

There are currently three major types of vehicle measurement methods that are in use, with most activity focused on the first two: (1) dynamometer tests; (2) remote sensing; and (3) instrumented vehicles.

Dynamometer testing is a method where emissions from vehicles are measured under laboratory conditions during a driving cycle that simulates vehicle road operation.[2] A driving cycle is composed of a unique profile of stops, starts, constant speed cruises, accelerations and decelerations and is typically characterized by an overall time-weighted average speed.[4] Dynamometer tests are often used in regulatory procedures to check compliance of new vehicles with emission standards or to inspect in-use vehicles. The data obtained from driving cycles are also used to develop emission estimation models, such as EMFAC7F, MOBILE6, Georgia Tech's MEASURE, and UC Riverside's modal emissions models.[5-7] Dynamometer testing with standardized driving cycles is not a preferred method for evaluating real-world emissions hotspots. This is because dynamometer tests must be done with an assumed speed profile in a laboratory setting. In contrast, to identify hotspots requires measurement of actual speed profiles during on-road vehicle operation and also requires simultaneous measurement of emissions.

Remote sensing devices uses infrared (IR) and, in some cases, ultraviolet (UV) spectroscopy to measure the concentrations of pollutants in exhaust emissions as the vehicle passes a sensor on the roadway. Applications of remote sensing in mobile emissions include: monitoring of emissions to evaluate the overall effectiveness of inspection and maintenance programs; identification of high emitting vehicles for inspection or enforcement purposes; and development of emission factors.[8-11] While remote sensing is capable of measuring real-world, on-road emissions, it is limited in applicability for identifying hotspots because hotspots may occur at locations where remote sensing cannot be deployed. For example, if a hotspot occurs close to an intersection, vehicles may be moving too slowly or may be spaced too closely together to allow sufficient time for sampling the exhaust plume of each vehicle. Remote sensing is difficult to use to measure emissions where there are multiple lanes of significant traffic flow, such as on primary arterials or freeways.

On-board emissions measurement is widely recognized as a desirable approach for quantifying emissions from vehicles since data are collected under real-world conditions at any location traveled by the vehicle.[12-18] Variability in vehicle emissions as a result of variation in facility (roadway) characteristics, vehicle location, vehicle operation, driver, or other factors can be represented and analyzed more reliably than with the other methods. On-board emissions measurement method is the most suitable method for hotspot analysis since it provides sufficient temporal and spatial resolution to detect changes in vehicle emissions. Details regarding on-board emissions measurement and comparison with other measurement techniques are given in elsewhere. [15-18]

PROJECT OBJECTIVES

The results presented in this paper are part of a study conducted at North Carolina State University for a project, 99-8, sponsored by the North Carolina Department of Transportation via the Center for Transportation and the Environment. The project, titled "Emissions Reduction through Better Traffic Management: An Empirical Evaluation Based upon On-Road Measurements", focused on evaluating strategies aimed at preventing motor vehicle air pollutant emissions through better traffic management. The project started in April of 1999 and continued through December of 2001. One of the key findings of this study is that feasibility of using on-board emissions measurements to collect real-world on-road tailpipe emissions data for CO, NO, and HC was established. Measured emission rates (on a gram per second basis) were found to be highest during the acceleration driving mode. Another key finding is that measured emissions tend to increase with traffic congestion since there are more acceleration events. Signal improvements such as coordination and retiming were found to be associated with lower emissions on one of the data collection sites. The study established a methodology for determining hotspots along roadways.

INSTRUMENTATION

The instrument used for on-board data collection was the OEM-2100™ manufactured by Clean Air Technologies International, Inc. The system is comprised of a five-gas analyzer, an engine diagnostic scanner, and an on-board computer.

The five-gas analyzer measures the volume percentage of CO, CO_2, HC, NO_x, and O_2 in the vehicle exhaust. Simultaneously, the engine scanner is connected to the On-Board Diagnostics (OBD) link of the vehicle from which engine and vehicle data are downloaded during vehicle operation.

The OEM provides a data stream of second-by-second engine and exhaust gas data. Eight OBD parameters are stored by the OEM-2100™ in a data file. These parameters are: manifold absolute pressure; vehicle speed; engine speed (RPM); intake air temperature; coolant temperature; intake mass air flow (available only on some vehicles); percent of wide open throttle; and open/closed loop flag. The OEM-2100™ computer synchronizes the incoming emissions and engine data.

The precision and accuracy of the OEM-2100™ was tested by the New York Department of Environmental Conservation (DEC) and at the U.S. EPA's National Fuels and Vehicle Emissions Laboratory in Ann Arbor, Michigan.[19] Three light-duty gasoline vehicles (1997 Oldsmobile sedan, 1998 Plymouth Breeze and 1997 Chevy Blazer) were tested by NYDEC using the I/M 240 and NYCC driving cycles. Two light-duty vehicles, a Mercury Grand Marquis and a Dodge full size pickup truck, were tested by EPA using the FTP, US06, NYCC, and FWY-HI driving cycles at Ann Arbor. The emissions were measured simultaneously by the dynamometer equipment and by the OEM-2100™. OEM-2100™ has good precision, as reflected in R^2 values compared to the dynamometer of 0.90 to 0.99. The standard error was less than ten percent of mean emissions for all of the pollutants except comparison of OEM-2100™ hydrocarbon measurements with Flame Ionization Detector (FID) measurements, which had a standard error of 24 percent of mean emissions.

The OEM-2100™ is calibrated on a routine basis using a calibration gas. For this purpose, a calibration gas that has a composition of 4.03 percent CO, 12 percent CO_2, 1,190 ppm HC (as C_3H_8), and 2,026 ppm NO was used. In the calibration process, the calibration gas is measured by the OEM-2100™. If the measured values differ significantly from the known true values, then the OEM-2100™ is calibrated with respect to the calibration gas. The calibration process has been repeated approximately every 3 months. It has been found that the difference between the actual and measured values, before recalibration, for NO ranges between –5 percent and +4 percent. For CO, this range is –6 and +2 percent. For HC, the range is –7 and – 0.7 percent. For CO_2, the range is –3 and +7 percent. Therefore, the instruments have been shown to be stable and hold calibration reasonably well. After calibrating the equipment, it was found that the difference between the actual value and the measured value ranged between: –1.5 percent and -0.2 percent for CO; –2.2 and 0.3 percent for HC; –0.8 and +0.2 percent for CO_2; –3 and +0.6 percent for NO. In general, there is very good agreement between the instrument's measurements and the true composition of the calibration gas.

Routinely during data collection and operation of the instrument, the instrument automatically zeros itself on a periodic basis. Zeroing is done by making measurements on ambient air, which is taken to be a reference gas. The main challenge in zeroing is to sample ambient air that is believed to be free of significant levels of CO, HC, and NO. The O_2 and CO_2 levels are assumed to be at typical average ambient values of 21 volume percent and 0.03 volume percent respectively. The CO_2 level in the exhaust is typically approximately 15 volume percent and it is not important for the instrument to be sensitive to ambient CO_2 levels. Zeroing is a means of preventing drift in the measurements. Details regarding the instrumentation can be found elsewhere.[16]

Field data collection activities include the use of the OEM-2100™ as well as supplemental equipment. Road grade was measured with digital level on the study corridors at one-tenth mile increments. The data were encoded into a database and synchronized with the engine and emissions data obtained from the OEM. Key characteristics of the study corridors, such as roadway geometry (e.g., number of lanes), speed limits, and traffic control device locations (e.g., traffic signals) were recorded. A laptop computer was used to record temperature and humidity, and information regarding each vehicle tested such as year, make, model, VIN, engine size, and other characteristics. Events during trips were also recorded using a laptop computer, including the time at which the vehicle crossed the centerline of key intersections or entered queues.

EXPERIMENTAL DESIGN

The data used in this paper were collected on two arterials in Cary, North Carolina between the summer of 2000 and the winter of 2000. A total of 622 one-way runs representing 75 hours and 1,500 vehicle miles of travel were conducted involving two drivers and two vehicles. These vehicles were: two different 1999 Ford Taurus sedan and two different 1996 Oldsmobile Cutlass. Details on experimental design can be found elsewhere.[16]

PROCESSING AND ANALYSIS

A substantial effort was devoted during the study to the development of data reduction and screening protocols in order to obtain an accurate database. Data collected from the OEM, from the laptop computer used in the field, and from other sources (e.g., measurement of road grade) were integrated into single combined vehicle emissions and traffic data file. The data were screened for errors that would impact the quality of the data. Errors that were encountered during data collection and methods for correction is explained elsewhere. [16-17]

EXPLORATORY ANALYSIS OF DATA

The final combined database contains datasets for second-by-second vehicle activity and emissions. The temporal profile of vehicle activity and emissions provides important insights regarding potential factors that can explain variation in vehicle emissions and, in particular, explain high emissions events or "hot spots". A high emission event may be any event that produces high emissions. In contrast, a "hot spot" would be a location at which emissions tend to be high because of the influence of roadway, traffic control, or other traffic characteristics at that location.

To illustrate the type of data that were collected and the insights they provided, an example of an individual one-way vehicle trip for a 1999 Ford Taurus on August 29, 2000 is presented. Figure 1 shows vehicle speed versus elapsed time of the trip. The figure is labeled with the location of the vehicle at specific times. The trip took place on Chapel Hill Road. The trip began south of

Morrisville Parkway and ended a short distance north of Airport Boulevard. There is notation in the figure indicating when the vehicle crossed the center of the intersection, such as at Aviation Parkway. The travel time on the corridor was approximately 14 minutes. The instantaneous speed ranged from zero to approximately 45 mph, and the average speed was 10 mph. The longest waiting times occurred in the queue at the intersection with Morrisville Parkway.

An example of an emission trace for a pollutant is shown in Figure 2 for CO. The CO emission rate exceeded 0.02 grams per second only six times during the trip, and emissions exceeded 0.2 grams per second only one time. The largest peak in the emission rate occurred at the same time as the acceleration from zero to approximately 40 mph as the vehicle cleared the intersection with Aviation Parkway. In fact, most of the peaks in CO emission rate tend to coincide with accelerations. The CO emission rate remained below 0.02 grams per second for the first ten minutes of the trip, corresponding to a period of stop-and-go travel with speeds ranging from zero to less than 20 mph. These data suggest that the CO emission rates during idling or crawling are comparatively low compared to CO emissions during acceleration.

Analysis conducted during this study revealed that emissions during the acceleration mode are significantly higher than emissions during idle or deceleration modes.[16-17] An important insight is that high emissions may not necessarily be associated with heavily congested traffic flow, as is often assumed. Instead, high emissions may occur at a specific location because of the influence of traffic control and traffic regulations (e.g., speed limit) at a specific site.

In general, the time traces for all four measured pollutants, including HC, NO, and CO_2 (not shown here but documented in elsewhere.[16]) indicate that there is a relatively large contribution to total emissions from short-term events that occur within the trip. These short-term events cause hotspots that might have emissions significantly higher than rest of the trip. This implies that efforts to reduce on-road emissions should be aimed at understanding and mitigating these hotspots. In particular, it may not be necessary to reduce vehicle miles traveled in order to reduce emissions; instead, it may be necessary to prevent hotspots.

SPATIAL ANALYSIS

Real world vehicle emissions are influenced by a variety of factors. Some of these factors are specific to driver/vehicle combinations, while others are associated with roadway geometry, traffic signalization and other traffic control measures, incidents, and ambient conditions. The factors associated with driver/vehicle combinations, such as differences in driver behavior and vehicle type, lead to variability in emissions when comparing on-road vehicles with each other at any given location. Factors associated with the roadway itself can lead to localized differences in emissions. For example, high road grades tend to produce more emissions because vehicles must operate with higher engine power demand in order to climb the grade. Poorly timed and coordinated signals can lead to higher emissions if they require a high frequency of stops and, consequently, a large number of accelerations.

In order to analyze emissions data spatially vehicle position data is required. Vehicle position was determined based upon recording of time stamps when the vehicle passed key landmarks (e.g., the center of each signalized intersection) and by use of the speed trace obtained from the engine scanner to estimate vehicle position between landmarks. The distance of each roadway segment between landmarks was estimated based upon an average of differences in vehicle

Figure 1. Vehicle speed versus elapsed time of the trip.

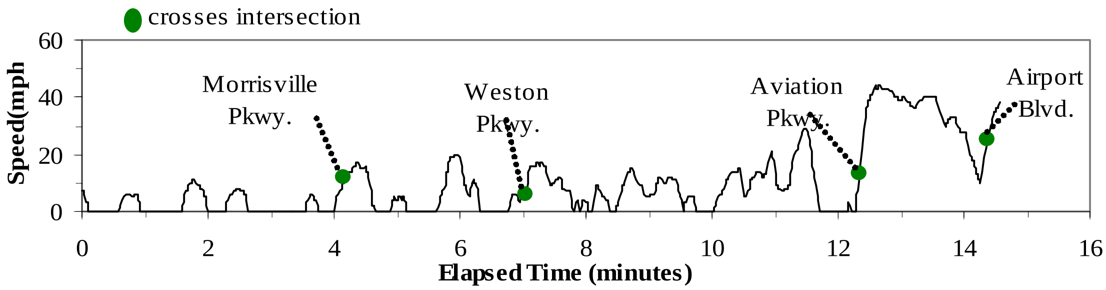
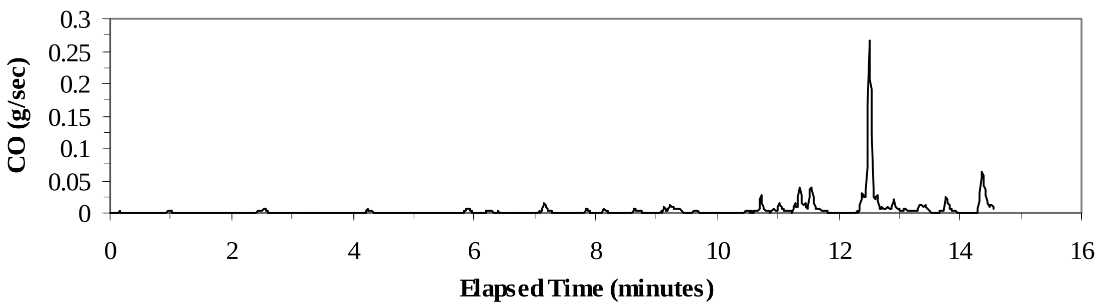


Figure 2. Vehicle CO emissions versus elapsed time of the trip.



odometer readings. The measurement of segment lengths by odometer readings was typically done for four runs using the Chevrolet Venture minivan, and then these runs were averaged.

The segment distance between intersections was estimated from the speed data by integrating speed between the time that the vehicle crossed the first intersection and the time that the vehicle crossed the second intersection. The segment distance estimated by integration of the speed trace data may be different than that estimated from an average of vehicle odometer readings. The former method is referred to here as the "speed data" method and the latter as the "odometer" method. The odometer method is taken as a reference. Therefore, for each segment between intersections, the distance traveled between the intersections was estimated by the speed data method but was corrected based upon the odometer method.

To evaluate the data spatially, the second-by-second speed and emissions data for each run were first grouped into bins of one-tenth of a mile. Thus, there would be 26 bins for a 2.6-mile corridor. The second-by-second data within each bin were then averaged to determine the average speed or vehicle emissions for each bin.

The runs were separated into different data sets by vehicle make and model, peak period, and direction of travel. For example, one data set represented all runs with a 1999 Ford Taurus made during the AM peak in the northbound direction. These divisions were made to isolate auxiliary variables so that spatial data is analyzed in a more controlled manner. As explained in Frey *et al.*,[16] statistical analysis, such as Analysis of Variance (ANOVA), found that vehicle make and model, peak period and direction of travel are all variables that have a significant impact on vehicle emissions.

In this paper, an example for spatial analysis is presented for 1999 Ford Taurus. Similar results were obtained for other vehicles, a different 1999 Ford Taurus sedan and two different 1996 Oldsmobile Cutlass sedans. Figure 3 shows a graphical output of the spatial analysis of speed for runs with the Ford Taurus during the AM peak on the Walnut Street corridor. Figures 4 to 6 show the spatial distribution of emissions for the same runs. The data shown in these graphs are averages of 24 runs. 95 percent confidence intervals for each data point are also shown in each figure.

As seen in Figure 3, average speed is more than 35 mph for the part of the trip between the 4^{th} and 7^{th} traffic signals, which are located at a cumulative trip distance of 0.7 to 1.6 miles. Between these traffic signals approximately free-flow conditions occur for traffic.

There was a decrease in average speed from 30 mph to 15 mph at approximately the 0.1-mile mark of the trip because of the first traffic signal. There are also significant drops in average speed for traffic signals number eight and nine. These findings indicate that signals 1, 8, and 9 caused stops and delay.

Figure 3 and Figure 4 provide insight into the basic relationship between vehicle speed and emissions. The spikes in average CO emissions occurred for the most part when vehicles accelerate from low to high speeds. For example, in Figure 4, the peak average CO emissions occurred at the 1.9-mile point which corresponded to an acceleration event, from approximately 9 mph to 32 mph. The second largest average CO peak occurred at approximately the 0.3-mile point. At this point the speed trace suggest that there was cruising at a speed of 32 mph. Average CO emissions are less than 1 g/sec for most of the trip, between 0.4 and 1.8 miles. For a very small part of the trip, at the 1.9-mile point, the average CO emissions were more than 3 g/sec. Average CO emissions at this point were more than seven times higher than the average CO emissions that occurred for the portions of the trip where free-flow conditions occurred. This indicates that the 1.9-mile point was a hotspot for this trip in terms of CO emissions. Figure 5 presents the average NO emissions profile for the same roadway section. As seen in Figure 5, the peak average NO emissions occurred at the 1.9-mile point, similar to CO emissions. Average NO emissions for this part of the trip were approximately four times higher than the part of the trip where free-flow conditions occurred between 0.4 and 1.6 miles. Therefore, the 1.9-mile point was also a hotspot for NO emissions.

Figure 6 presents the average HC emissions profile. Peak HC emissions occur for the 0.1 and 1.8-mile points of the trip, slightly different from CO and NO emissions. Average HC emissions at these points were approximately three times higher than the part of the trip where there was a free-flow condition for traffic. These results indicate that the 0.1 and 1.8-mile points were hotspots for HC emissions.

Factors Affecting Hotspots

In order to understand the factors affecting the occurrence of hotspots, an analysis was conducted to investigate the effects of possible explanatory variables. A number of potential explanatory factors were investigated, including roadway grade, proximity to a traffic signal, and the likelihood of whether the vehicle producing the emissions spike was at the front of the queue while waiting at a traffic signal.

Figure 3. Spatial Distribution of Speed Based upon Averages of 24 vehicle runs

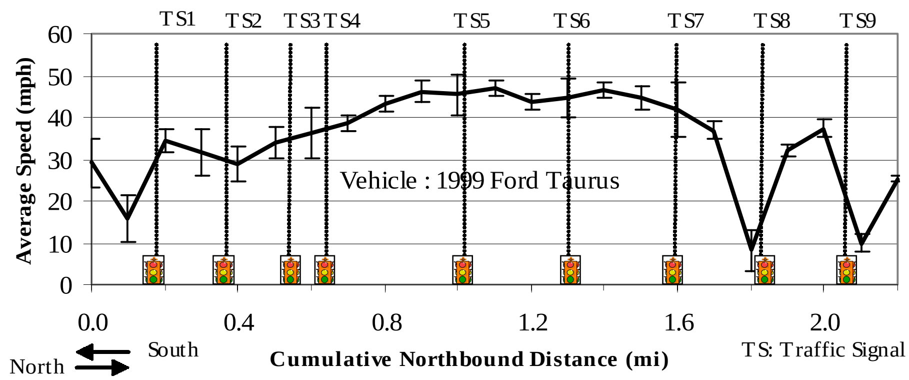


Figure 4. Spatial Distribution of CO Emissions Based upon Averages of 24 vehicle runs

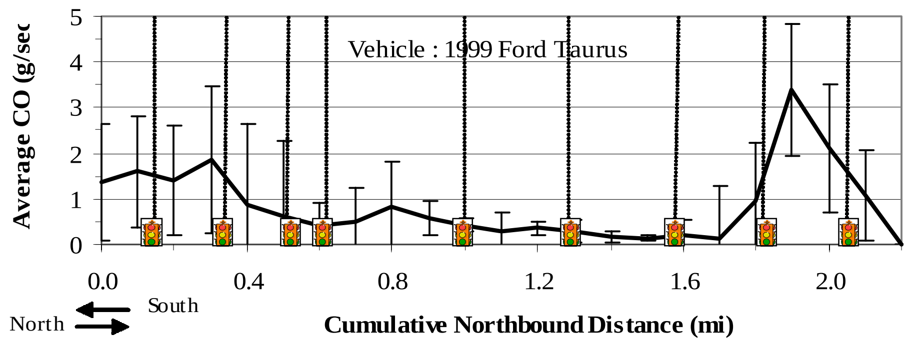


Figure 5. Spatial Distribution of NO Emissions Based upon Averages of 24 vehicle runs

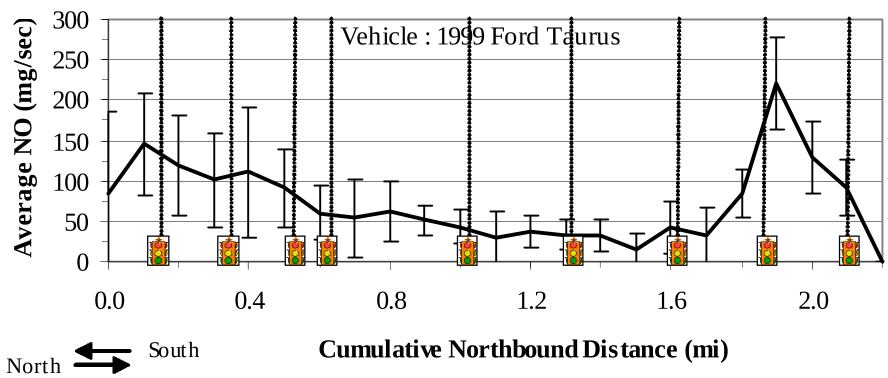


Figure 6. Spatial Distribution of HC Emissions Based upon Averages of 24 vehicle runs

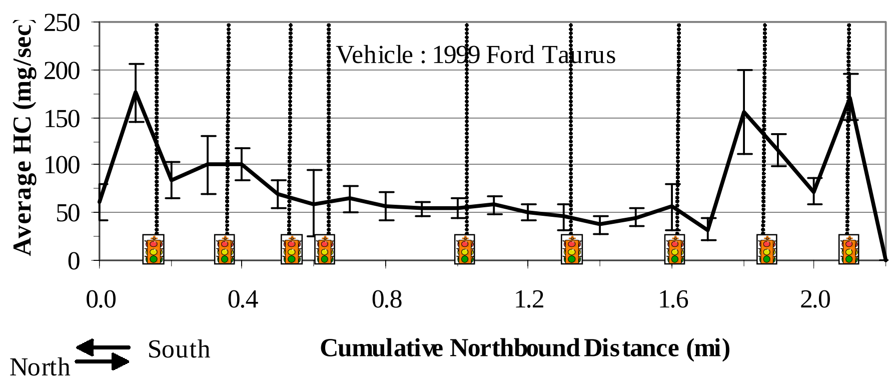
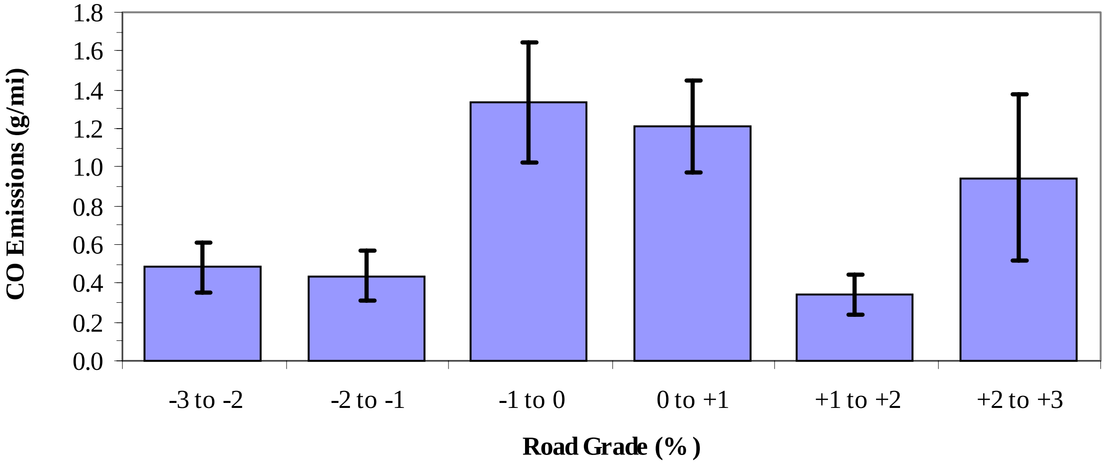


Figure 7. Relation between Roadway Grade and Average CO Emissions of 24 vehicle runs on Walnut Street



In order to identify the relation between roadway grade and emissions, emissions were grouped into bins using one percent intervals of roadway grade. For this analysis, the same data that were used in the previous section were utilized. For example, average CO emissions were estimated for roadway grade between 2 and 3 percent. Figure 7 presents result of this analysis. 95 percent confidence intervals on the mean are also shown in Figure 7. The highest CO emissions occurred for the roadway grade bins, -1 to 0 percent and 0 to +1 percent. The average emissions in those two bins are not statistically significantly different from the average emissions in the roadway grade bin of +2 to +3 percent, as illustrated by overlap of the 95 percent confidence intervals. Average CO emissions for other roadway grade bins are lower. There is no clear trend of CO emissions with respect to roadway grade in this case. Most likely, the range of road grade observed in this study was not enough to produce large differences in emissions and other factors varied at the same time to mask such differences. Similar results were obtained for HC emissions. For NO emissions a moderate influence of roadway grade was observed.[16]

Research for the in-development MEASURE model has found that vehicles at the front of a queue produce higher emissions than vehicles further back in a queue because they are not following a vehicle and can thus accelerate more quickly and travel at a higher speed.[7] In order to test this hypothesis, data collected on Walnut Street with both 1996 Oldsmobile Cutlass, and 1999 Ford Taurus were utilized. Runs were ranked with respect to total CO emissions for each vehicle, direction and peak time category. Then runs where total emissions are more than 99th percentile of the trips were selected. In most of the cases, runs which were selected with respect to CO had also very high emissions for NO and HC. A total of 16 runs were identified out of 622 runs. In each of these runs, hotspots were present, but their locations were not the same with each other. Of these 16 runs, 14 occurred adjacent to a traffic signal. The queue position during a run was estimated by comparing the times when the vehicle passed the center of the intersection and the time when the green phase began. However, timestamps for the beginning of the green phase were not recorded in all cases. Of the 14 emission spikes that occurred adjacent to an intersection, seven of them had timestamps where the green phase was recorded during the run. Of these seven runs, the test vehicle was within the first three vehicles in the queue, which was determined looking at the time stamps and speed profile, at the intersection where significantly high emissions spike occurred. Thus, this limited data set suggests that there may be some correlation between an emissions spike occurring when a vehicle is at the beginning of the queue at a traffic signal.

DISCUSSIONS

The analysis conducted in this study clearly indicated that data collected using an on-board instrument for CO, NO, and HC emissions can reveal locations where hotspots occur. Although air toxics emissions were not measured in this study, it has been observed by other researchers that, emission rates of some air toxics can be estimated as a fraction of total hydrocarbon emissions.[20] Therefore, with knowledge of the spatial distribution of tailpipe hydrocarbon emissions, it is possible to make an estimate of the spatial distribution of tailpipe air toxics emissions in some cases. Although there are uncertainties associated with this approach, the analysis of Bammi suggests that approximately half of the variability in emissions of selected air toxics is explained by variability in the total hydrocarbon emission rate.[20] Therefore, the use of hydrocarbon hotspots data as surrogate for air toxics emissions hotspots may be useful. The measurement of on-road hotspots is important to the development of realistic and accurate spatially and temporally distributed emissions estimate for use in exposure and risk assessment.

CONCLUSIONS

This paper has successfully demonstrated a method determining hotspots along roadways with the use of on-board measurement of on-road tailpipe emissions for gasoline-fueled light duty vehicles. The method was applied to an example case study to illustrate the types of insights obtained from real-world emissions data.

Compared to other measurement methods, such as dynamometer testing and remote sensing, on-board emissions measurement provides detailed data that can be used to identify real-world microscale events that significantly impact overall emissions. For example, the case study for spatial distribution demonstrated that emissions associated with a single signalized intersection contributed substantially to total emissions for a particular corridor.

The type of data provided by on-board emissions measurement cannot be replicated or accounted for in the current generation of the highway vehicle emission factor models recommended for use by the U.S. Environmental Protection Agency. Both the Mobile5 and Mobile6 models are based upon average emissions for specified driving cycles. Therefore, these models cannot be used to estimate the effects of microscale events on emissions. Any traffic simulation models based upon output from the Mobile models will have the same inherent limitations of these models, which includes an inability to evaluate the effect of microscale events on emissions. In contrast, in this work, an empirical approach to measurement of microscale events was employed. No modeling was involved.

The emissions during a trip are typically dominated by a few microscale events during the trip. For example, just a few seconds of hard acceleration can produce a substantial portion of total emissions for an entire trip. Therefore, the appropriate measurement method to use to identify hotspots within a route will be a method that enables approximately continuous measurement of emissions along the entire route. It is not possible to know where a hotspot is without first understanding the spatial profile of emissions along a route and without identifying those locations that produce higher emissions than other locations. This study successfully presented ways to identify hotspots by the use of on-board data. In the examples presented in this paper, it was observed that peak emissions tend to occur at locations where acceleration events occur. Average emissions in hotspot locations were found to be as much as seven times higher than the average emissions at locations where free-flow traffic conditions occur. A preliminary effort was made to determine if other factors, such as road grade and the vehicle position in the queue, contributed to the observed hotspots. Road grade was not found to be a significant influence in the case of CO or HC, and may have moderately influenced NO. Limited data suggest that the highest acceleration may be associated with the first few vehicles in the queue. Future studies should more thoroughly explore these possible explanatory variables, as well as others, such as fuel type, ambient temperature, and catalyst temperature.

This paper provides empirical insight regarding factors contributing to hotspots on signalized primary arterial roadways. This information is important with respect to accurate spatial estimation of emissions to support exposure and risk assessments for small geographic scales. Although this study focused primarily upon the role of signalized intersections in creating hotspots, the study design can be adapted to collect real-world data for other hypothesized hotspots, such as at freeway acceleration ramps, merges after toll booths, and others. Moreover, although the data collected were only for CO, NO, and HC, other work suggests that HC emission may be a useful surrogate from which to estimate emissions of some air toxics. Therefore, the type of data collected in this study could be used to support emissions and exposure assessments for a variety of pollutants. The study addresses tailpipe emissions. Evaporation emissions are not measured by the on-board system. Therefore, supplemental data regarding evaporative emissions are needed.

The findings from the example case study are specific to the conditions of the case study, including the specific vehicles used and the conditions under which they were operated. It is important not to extrapolate these findings without additional data and verification. Thus, the findings from the case study are suggestive of insights that are likely to be obtained from other work, but they not definitive without data for additional vehicles, roadways, and drivers.

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