

CARBON MONOXIDE IMPACTS OF AUTOMATIC VEHICLE IDENTIFICATION APPLIED TO VEHICLE TOLLING OPERATIONS

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INTRODUCTION

Intelligent transportation technologies (ITT's) are being promoted as a means of reducing congestion delay, improving transportation safety, and also as a means of making vehicle travel "...more energy efficient and environmentally benign (USDOT, 1990)." In theory, IVHS technologies will increase the efficiency and capacity of the existing highway and roadway systems to reduce congestion (Saxton and Bridges, 1991; Conroy, 1990; Shladover, 1991; Shladover, 1989). We are not confident, however, that vehicular emissions will be reduced by the full range of proposed ITT's.

The transportation-air quality community has in the past lacked the appropriate tools in which to predict the effects of microscopic changes to vehicular activity induced by ITT's. The currently used emissions models, EMFAC in California, and MOBILE in the remainder of the US, are unable to provide the resolution needed to quantify the effects of these changes. Research at UC Davis is focusing on estimation of a statistical 'modal' model capable of simulating the emissions impacts from individual vehicles under various operating scenarios. The emissions model, currently a significantly modified version of the mathematical algorithms employed in the CALINE 4 Line Source Dispersion Model developed by Paul Benson and others at Caltrans (Benson, 1989), predicts emissions based upon individual vehicle speed-time profiles and laboratory measured emission rates. The model, therefore, can quantify vehicular emissions under various ITT scenarios.

This paper examines the carbon monoxide (CO) emission impacts of one such applied ITT, namely Automatic Vehicle Identification (AVI) used to implement automatic tolling. AVI used in lieu of conventional toll booths has previously been identified as an ITT that is likely to offer air quality benefits (Washington, Guensler, & Sperling, 1993a). By allowing vehicles to be tolled either through a windshield displayed debit card, or by some other mechanism, vehicles could forgo the deceleration, stop-delay, and ensuing acceleration that results from an encounter with a conventional tolling station. The results presented here are preliminary, and represent the beginning stages of an ongoing research effort. More substantial and complete results will be provided as they become available.

BACKGROUND

The six basic ITT "technology bundles" (Jack Faucett Associates, 1993) include: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Commercial Vehicle Operations (CVO), and Advanced Public and Transportation Systems (APTS). Each of these technology bundles is designed to achieve the same general goal; improve the efficiency of the transportation system through the application of communications and computational technologies. However, the efficiency objectives targeted by each technology bundle are distinctly different, and will have different potential effects upon the parameters that effect vehicle emissions (Washington, Guensler, Sperling, 1993a).

Previous research has concluded that one of the most likely technology bundles to improve air quality is Advanced Traffic Management Systems (Washington, Guensler, Sperling, 1993b). As the name implies, ATMS employ computer control technologies to 'optimize' or smooth traffic flows on a transportation network. Examples of ATMS technologies are real-time traffic signal network optimization, real-time ramp metering, and automatic vehicle tolling via automatic vehicle identification technologies (AVI). These computer controlled systems are

designed to reduce congestion levels; minimize system-wide delay levels, and generally smooth vehicular flows. ATMS technology bundles also include various signal actuation bundles, incident detection, rapid accident response, and integrated traffic management.

Automatic toll collection, the topic of this paper, aims to smooth traffic flows by implementing advanced communications technologies between roadway and vehicles. If conventional tolling operations performed on bridges or tolled turnpikes were replaced with automatic and transparent vehicle identification and debiting, for example, then toll plaza delays experienced by motorists could be eliminated. The elimination of these activities would further result in fewer decelerations, idling, and acceleration events prevalent under conventional tolling operations. These 'modal' activities, representing high load and power conditions, have been shown to contribute significantly to the production of emissions from motor vehicles (LeBlanc, et al., 1994; CARB, 1991; Benson, 1989; Groblicki, 1990; Calspan Corp., 1973a; Calspan Corp., 1973b; Kunselman, et al., 1974). In fact, one sharp acceleration may cause as much pollution as does the entire remaining trip (Carlock, 1992). This suggests that a small percentage of a vehicle's activity may account for a large share of its emissions (LeBlanc, et al., 1994). In addition, longer enrichment events are more highly correlated with large emission excursions than are shorter events (LeBlanc, et al., 1994), and furthermore, deceleration events are capable of producing significant emissions (Darlington, et al., 1992). In contrast to cold start emissions that occur over a period of minutes, acceleration and deceleration related emissions occur over a period of a few seconds.

Using a preliminary 'modal' model that accounts for relative contributions of CO emissions from acceleration, deceleration, cruise, and idle events, we assess the impacts of automatic tolling using AVI. The goal is to quantify the expected CO emission differences between a toll-plaza and AVI scenario. In addition, the expected variation in these benefits is approximated given current limitations of the vehicle emissions data. The results provided represent preliminary research findings, and will be supplemented with further findings when they become available.

DESCRIPTION OF THE MODAL MODEL

The preliminary 'modal' model employed in these analyses is a derivative of the CALINE Line Source Dispersion Model that has been developed over many years by the California Department of Transportation (Benson, 1989). The model is different from the CALINE model in several very important respects. First, individual vehicle 'FTP BAG 2' (Washington, Guensler, and Sperling 1994) emission rates are used in the model, rather than an 'approximated' average values applied to the vehicle fleet. Second, individual idle emission rates are used in the model, rather than 'approximated' average values applied to the vehicle fleet. Finally, the 'dispersion' portion of the CALINE model is not employed, but rather, only the algorithms used to determine the emissions inventory are used. These differences result in a statistical model that can explain approximately 70% of the variation in emissions for individual vehicles tested on 14 different emission testing cycles. This is in comparison to both the current EMFAC and CALINE models, while employing fleet average FTP Bag 2 and idle emission rate values, explain about 13% and 2% of the variation in emissions for individual vehicles respectively (Washington, Guensler, and Sperling, 1994).

The latest version of the CALINE4 model is similar to the Colorado Department of Highways (CDOH) model released in 1980. The data used to estimate model coefficients were derived from 37 discrete modes driven by 1020 light-duty vehicles ranging from 1957 model year to 1971 model year. In both the Caltrans and CDOH model development efforts, a strong relation was noted between modal emissions and the average acceleration speed product (AS) for the particular acceleration mode. Consequently, AS is one of the explanatory variables used in the CALINE4 model (Benson, 1989).

The CALINE4 model is descriptive and not deterministic. This means that the model is estimated using observed emissions and vehicle behavior, rather than using more causal variables such as fuel volatility, cylinder size, mechanical efficiency losses, etc. The model employed in this research effort is identical to the functional form contained in CALINE model, except for the significant and important differences noted earlier (and described below).

The modified CALINE model can be written as:

$$TE_{ik} = EI_{ik} + EA_{ik} + EC_{ik} + ED_{ik} \text{ where;}$$

TE_{ik} = Total CO emission estimate for vehicle i on cycle k in grams.

EI_{ik} = CO emissions from idle events for vehicle i on cycle k in grams,

EA_{ik} = CO emissions from acceleration events for vehicle i on cycle k in grams,

EC_{ik} = CO emissions from cruise events for vehicle i on cycle k in grams,

ED_{ik} = CO emissions from deceleration events for vehicle i on cycle k in grams.

The emission contributions from modal events are defined as:

$$EI_{ik} = (IR_{[grams/sec]}) * (t_{i[secs]}), \text{ where;}$$

IR is the measured individual vehicle idle emission rate,

t_i is time in the idle operating mode.

$$EA_{ik} = [(FTP_{B2}[_{grams/min}]) * (C1) * EXP(C2 * AS)] * t_{a[secs]} * I_{[min]} / 60_{[sec]}, \text{ where;}$$

FTP_{B2} is measured emission rate on FTP Bag2 for individual vehicles,

Coefficients C1 = 0.75 and C2 = 0.0454 for acceleration condition 1,

Coefficients C1 = 0.027 and C2 = 0.098 for acceleration condition 2,

AS is the acceleration speed product based upon average speed and average acceleration rate of the accel mode,

Acceleration condition 1 is for vehicles starting at rest and accelerating up to 45 mph,

Acceleration condition 2 is for vehicles starting at 15 mph or greater and accelerating up to 60 mph,

t_a is the time in the acceleration mode.

$$EC_{ik} = (FTP_{B2}[_{grams/min}]) * [(0.494 + 0.000227 * S_{[mph]}^2)] * (t_{c[secs]} * I_{[min]} / 60_{[sec]}), \text{ where;}$$

FTP_{B2} is measured emission rate on FTP Bag2 for individual vehicles,

t_c is the time in the cruise event.

$$ED_{ik} = (IR_{[grams/sec]}) * (t_{d[secs]}), \text{ where,}$$

IR is the measured individual vehicle idle emission rate,

t_d is time in the deceleration operating mode.

The modified CALINE model is used in conjunction with summed emissions from steady-state modal events for a vehicle on any cycle. For example, a given speed-time trace is parsed into discrete modal events of idle, cruise, acceleration, and deceleration. The emissions from these events are then summed over the cycle to obtain the total emission estimate.

EXPERIMENTAL DESIGN

To estimate the difference in CO emissions between a vehicle encountering a conventional toll plaza, and the 'no delay' experience by automatic vehicle identification tolling operations, the modified CALINE model is employed. To perform these comparisons, a toll plaza is first simulated on a typical transportation link. The link could be a typical tolled bridge entrance, or could be the entrance to a tolled freeway. The toll plaza design follows that described by Lin (1994), representing a Gate type 'C' operating at level of service A. Under these conditions, the average vehicle experiences about 6 seconds of delay waiting for previously queued vehicles (Lin, 1994). Since the emissions estimates from vehicles encountering toll plazas are done on a per-vehicle basis, and because level of service A is assumed in these initial analyses, the traffic volume is not important (congestion delay induced by toll plazas and high traffic volumes will be covered in subsequent analyses).

To simulate vehicular activity under the two different scenarios, speed-time profiles were developed for four different vehicle trajectories. Table 1 displays some characteristics of these speed-time profiles. Two speed-time profiles were developed for vehicles entering a toll plaza, one for drivers exhibiting 'aggressive' driving behavior and one for drivers exhibiting 'normal' driving behavior. All vehicles were assumed to begin and end their speed-time trajectory at a speed of 60 mph (other speeds will be covered in subsequent analyses). Aggressive driving

Table 1. Characteristics of Assumed Vehicle Speed-Time Profiles Under both Toll-Plaza and AVI Scenarios

Cycle Description	Maximum Acceleration Rate (mph/sec)	Length of Cycle (seconds)	Distance of Cycle (miles)	Deceleration Time in seconds (60mph to 0mph)	Acceleration Time in seconds (60mph to 0mph)
Toll Plaza, 'Aggressive' Driving	4.5	37	0.249	14	15
Toll Plaza, 'Normal' Driving	2.0	66	0.517	30	30
AVI, 'Aggressive' Driving	1.0	15, 31	0.249, 0.517	n/a	n/a
AVI, 'Normal' Driving	0.5	15, 31	0.249, 0.517	n/a	n/a

includes acceleration and deceleration rates of about 4.5 mph/sec, while normal driving includes acceleration and deceleration rates of 2 mph/sec. These rates agree with current car following and instrumented vehicle research that has substantiated acceleration and deceleration rates as high as 6 mph/sec (Cicero-Fernandez, et. al., 1993).

Two more speed-time profiles were developed for the non-toll plaza scenario. Again, one for drivers exhibiting 'aggressive' driving behavior and one for drivers exhibiting 'normal' driving behavior. In the former case, aggressive drivers 'floated' around their 60 mph target speed by 3 mph with 1 mph/sec maximum acceleration and deceleration rates. 'Non-aggressive' drivers were assumed to 'float' around their 60 mph target speed by 1 mph with 0.5 mph/sec maximum acceleration and deceleration rates. Both of these cycles were 'length corrected' so cross-comparisons could be made between all categories of driving.

A BASIC computer program was used to 'parse' cycles into discrete modes of acceleration, deceleration, cruise, and idle (see Washington, Guensler, and Sperling, 1994). The program is also used to apply the modified CALINE algorithms to estimate the CO emissions estimates from generated speed-time profiles.

All of the vehicles contained in the current Speed Correction Factor Data Base (see Guensler, 1994) were used to estimate CO emissions from a 'fleet' of vehicles passing through the toll plaza and AVI scenarios. After several outlying test results were discarded, 436 remaining vehicles were used to approximate the vehicle fleet. The appropriateness of the vehicle fleet represented will be treated in subsequent analyses.

Since the modal model can predict CO emission contributions from acceleration and deceleration events, the resulting emissions predictions reflect the effect of microscopic traffic flow adjustments under the two different scenarios. The results of the modeling runs can be seen in Table 2. The model predicts that 'aggressively' driven vehicles will emit about 52 fewer grams of CO with AVI (on average) than with a toll-plaza. The median difference is about 11 grams of CO, which suggests that the distribution of CO emissions from this fleet of vehicles is non-normal and heavily skewed by influential 'dirty' vehicles. The standard deviation under the same scenario, about 123 grams, illustrates the extreme influence of these high emitting vehicles.

Table 2. Carbon Monoxide Emission Prediction Differences Between Toll Plaza and AVI Scenarios

Driving Behavior with Toll-Plaza	Driving Behavior with AVI	Mean Carbon Monoxide Difference (grams / vehicle)	Median Carbon Monoxide Difference (grams / vehicle)	Standard Deviation in Carbon Monoxide Difference (grams)
Aggressive	Normal	53.68	11.04	127.10
Aggressive	Aggressive	51.67	10.59	122.66
Normal	Normal	12.17	2.97	27.85
Normal	Aggressive	8.03	1.87	18.52

The table also illustrates that ‘normal’ driving behavior, i.e. vehicle activity incorporating moderate acceleration and deceleration rates, results in much smaller CO emission rate differences. These findings agree with current literature that has identified high emission rates with extreme modal activity.

DISCUSSION

These findings suggest that a large reduction in CO emissions can be realized through the application of an Intelligent Transportation Technology (ITT). This limited scenario, the replacement of conventional toll plazas on a freeway link with automatic vehicle identification technologies to debit passing vehicles, has been previously identified as an application of ITT’s with likely benefits to air quality. If we could implement this scenario for 6 months on a freeway segment, for example, with an average daily traffic volume of 15,000 vehicles per lane, in approximate numbers we could expect a reduction in CO emissions from about 33 to 140 metric tons per lane. The uncertainty in these estimates, however, need to be addressed.

Although it is a significant improvement over currently employed models in terms of individual emissions estimations, the statistical model employed here still needs improvement and refinement. This research is currently underway at UC Davis.

The representativeness of the vehicles contained in the Speed Correction Factor data set are not likely to be representative of the current vehicle fleet (Guensler, 1994). There are several methods in which to approach this deficiency. Subsequent analyses will incorporate a random sampling scheme, which will provide a means to mimic actual sampling from the real-world population of vehicles (from an emissions standpoint). Furthermore, we need to test new vehicles and sample the existing fleet to determine which fleet characteristics are truly ‘representative’.

The impact of high-emitting vehicles and aggressive driving behavior is extremely important in these analyses. Subsequent analyses will address this effect, and will try to quantify the influence these vehicles and activities have on estimated emissions.

We need to look at many different implementation scenarios. Different approach speeds need to be considered, as well as different levels of congestion. In the above analyses, congestion is assumed not to exist, but practical experience shows that toll plazas are generally bottle-necks during peak periods, and we need to consider these congestion effects on emission estimates. We will address some of these issues in subsequent analyses.

Finally, we need to address the behavioral changes that might be induced by application of ITT's. For example, previous peak-period congestion induced by toll-plazas, now eliminated by application of automatic tolling using AVI, might make the travel route more attractive to motorists. If this short-term increase in peak period level of service attracts 'new' motorists to the facility, then the projected emissions reductions may be partially or fully offset by increased traffic and congestion.

BIBLIOGRAPHY

Benson, Paul (1989). "CALINE 4 - A Dispersion Model For Predicting Air Pollutant Concentrations Near Roadways". State of California Department of Transportation, Division of New Technology and Research. Revised June 1989.

Calspan Corporation (1973a). "A Study of Emissions from Light-Duty Vehicles in Six Cities; Buffalo, NY"; Prepared for the Environmental Protection Agency (Document #APTD-1497), Office of Mobile Source Air Pollution Control; Ann Arbor, MI; March 1973.

Calspan Corporation (1973b). "Automobile Exhaust Emission Surveillance (PB-220 775); Buffalo, NY"; Prepared for the Environmental Protection Agency (Document #APTD-1544), Office of Mobile Source Air Pollution Control; Ann Arbor, MI; May 1973.

CARB (1991), California Air Resources Board; Modal Acceleration Testing; Mailout No. 91-12; Mobile Source Division; El Monte, CA; March 20, 1991.

Carlock, Mark (1992). "Overview of Exhaust Emission Factor Models". In: Proceedings, Transportation Modeling: Tips and Trip Ups; Air and Waste Management Association; Pittsburgh, PA; March 1992.

Cicero-Fernandez, Pablo, Jeffrey Long (1993). "Modal Acceleration Testing on Current Technology Vehicles". Presented at the specialty conference: The Emission Inventory, Perception and Reality. Pasadena, CA. October 1993.

Conroy, Patrick J; Transportation's Technology Future: Prospects for Energy and Air Quality Benefits; TR News; Transportation Research Board; Washington, D.C.; May June 1990.

Darlington, Thomas L., Patricia E Korsog, and Robert Strassburger; Real World and Engine Operation: Results of the MVMA/AIAM Instrumented Vehicle Pilot Study; Proceedings of the 85th Annual Meeting of the Air and Waste Management Association; AWMA; Pittsburgh, PA; June 1992.

Guensler, Randall (1994). "Vehicle Emission Rates and Average Operating Speeds". Dissertation, Department of Civil & Environmental Engineering, University of California at Davis, Davis, CA. 95616.

Groblicki, Peter J.; Presentation at the California Air Resources Board Public Meeting on the Emission Inventory Process; General Motors Research Laboratories; Warren, MI; November 5, 1990.

Jack Faucett Associates; Information Package Prepared for the Video-Conference on the Effect of IVHS Technologies on Air Quality; Bethesda, MD; March 8, 1993. The specific IVHS technologies listed in the Faucett report are presented for each technology bundle in this paper, with a few minor additions.

Kunselman, P., H.T. McAdams, C.J. Domke, and M.E. Williams; Automobile Exhaust Emission Modal Analysis Model; Calspan Corporation; Buffalo, NY; Prepared for the Environmental Protection Agency (Document 460/3-74-005), Office of Mobile Source Air Pollution Control; Ann Arbor, MI; January 1974.

LeBlanc, David C., Michael D. Meyer, F. Michael Saunders, James A. Mulholland (1994). "Carbon Monoxide Emissions From Road Driving: Evidence of Emissions Due to Power Enrichment". Presented at the 73rd Transportation Research Board Annual Meeting, January 9 - 13, 1994, Washington D.C.

Lin, Feng-Bor (1994). "Level of Service Analysis of Toll-Plazas on Freeway Main Lines". *Journal of Transportation Engineering*, Vol. 120, No. 2. Mar./Apr. 1994.

Saxton, Lyle G., and G. Sadler Bridges; Intelligent Vehicle-Highway Systems; A Vision and A Plan (1991). *TR News*; 152, January-February 1991.

Shladover, Steven E.; Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production (PATH Technical Memorandum 91-4); Institute of Transportation Studies, University of California, Berkeley; Berkeley, CA; August, 1991.

Shladover, Steven E.; Roadway Automation Technology - Research Needs; Paper 880208, Presented at the 68th Annual Meeting of the Transportation Research Board; Washington, D.C.; January 1989.

U.S. Department of Transportation; National Transportation Strategic Planning Study (1990). Washington, D.C.; March 1990.

Washington, Simon, Randall Guensler, and Daniel Sperling (1993a). "Air-Quality Impacts of Intelligent Vehicle-Highway Systems". *Transportation Planning and Air Quality II*. Paul Benson, ed. American Society of Civil Engineers. Forthcoming.

Washington, Simon, Randall Guensler, and Daniel Sperling (1993b). "Assessing the Emission Impacts of IVHS in an Uncertain Future". Proceedings of the World Car 2001 Conference, Riverside CA. The Center for Environmental Research & Technology, University of California Riverside.

Washington, Simon, Randall Guensler, and Daniel Sperling (1994). "Modeling IVHS Emission Impacts, Volume I: Assessment of the CALINE 4 Line Source Dispersion Model". Interim Draft Report, Feb. 2, 1994. Institute of Transportation Studies, University of California at Davis. Davis, CA 95616.