IVHS TECHNOLOGIES AND MOTOR VEHICLE EMISSIONS

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INTRODUCTION

Advanced transportation technologies can range widely in their scope, from some of the simpler systems that provide drivers with real-time congestion conditions along their travel routes, to the tremendously complex systems that may eventually provide fully automated vehicle control. Advanced technologies applied to motor vehicles and the infrastructure are generally known as Intelligent Vehicle Highway System (IVHS) technologies. Combinations of these advanced technologies, known as "technology bundles," are being promoted as a means of reducing congestion delay, and also as a means of making vehicle travel "...more energy efficient and environmentally benign." [1]

In theory, IVHS technologies will increase the efficiency and capacity of the existing highway system to reduce congestion[2,3,4,5] and as traffic congestion is reduced and traffic flows are smoothed, significant air quality benefits are expected to accrue. On the other hand, increased travel efficiency and reduced trip times may increase trip generation, change travel destinations, increase single occupant vehicle use, and change travel routes. Hence, if IVHS systems lead to increases in the number of trips and vehicle miles traveled, the emissions associated with increased travel may negate some or all of the expected efficiency-related air quality benefits achieved from smoother traffic flows.

The six basic IVHS "technology bundles"[6] include: Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Commercial Vehicle Operations (CVO), 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 technology. 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.

In an earlier paper, some of the general relationships important in determining the potential impacts of IVHS systems were explored.[7] Problems were noted in the capabilities of existing models to estimate IVHS emissions impacts. This paper further explores the emissions implications of deploying IVHS "technology bundles"[6, 8] by examining potential effects upon important emission-producing vehicle activities and those parameters that affect emission rates.

Given the vehicle activity and emission rate modeling shortfalls that currently exist, evaluating the air quality impacts of IVHS impacts with today's modeling tools will be highly uncertain and impossible to determine in a definitive manner. What is possible, and what we do next in this paper, is to: 1) identify the important emission relationships, 2) discuss the general framework used to compare emission impacts, and 3) examine the general relationships between the characteristics of IVHS technology bundles and how these characteristics are likely to positively or negatively impact vehicle emissions.

MOTOR VEHICLE EMISSIONS

Motor vehicles account for the lion's share of air pollutant emissions in urban areas, typically more than 50% of volatile organic compound (VOC) and oxides of nitrogen (NOx) emissions, both of which are precursors to ozone formation, and more than 80% of carbon monoxide (CO) emissions. Of course, estimated transportation contributions of these pollutants vary from area to area.

Motor vehicle emissions are estimated by quantifying emission-producing vehicle activities and coupling these activities with activity-specific emission rates. For example, vehicle miles of travel and engine idling are activities known to produce emissions, and gram/mile and gram/hour emission rates can be developed for specific vehicle activities under various operating and environmental conditions.

Emission-Producing Vehicle Activities

Motor vehicles pollute, whether they are running or parked in a driveway. For the purposes of estimating emissions, the action being performed by the vehicle (or inaction) at the time the emissions occur is an emission-producing vehicle activity. Table 1 contains the general vehicle activities known to produce vehicle emissions that are often included in the emission inventory modeling process, and the type of emissions that are produced. These activities include: vehicle miles traveled, engine starts, engine shut-downs, idling, exposure to temperature fluctuation, refuelling and modal operations.

Table 1
Emission-Producing Vehicle Activities and Emissions that are Produced

Emission-Producing Vehicle Activity	Type of Emissions Produced
Vehicle Miles Traveled	• Running Exhaust (CO, VOC, NOx, PM_{10}, SOx) • Running Evaporative Emissions (VOC)
Cold Engine Starts	• Elevated Running Exhaust Emissions (CO, VOC, NOx, PM_{10}, SOx)
Warm or Hot Engine Starts	• Elevated Running Exhaust Emissions (CO, VOC, NOx, PM_{10}, SOx)
Engine "Hot Soaks" (shut-downs)	• Evaporative Emissions (VOC)
Engine Idling	• Running Exhaust Emissions (CO, VOC, NOx, PM_{10}, SOx) • Elevated Evaporative Emissions (VOC)
Exposure to Diurnal and Multi-Day Diurnal Temperature Fluctuation	• Evaporative Emissions (VOC)
Vehicle Refueling	• Evaporative Emissions (VOC)
Modal Behavior (e.g. High Power Demand, Heavy Engine Loads, or Engine Motoring)	• Elevated Running Exhaust Emissions (CO, VOC, NOx, PM_{10}, SOx)

CO = Carbon Monoxide; VOC = Volatile Organic Compounds; NOx = Oxides of Nitrogen; PM_{10} = Fine Particulate Matter (less than 10 microns in diameter); SOx = Oxides of Sulfur

Source: (9)

The elevated emissions of CO, NOx, PM_{10}, and SOx, noted in Table 1 generally result from engine conditions that exacerbate incomplete combustion and from catalytic converter temperatures too low to facilitate efficient control of exhaust gas emissions.[10-14] Two modeling approaches can be used to address elevated emission rates: 1) the cause can be modeled as a discrete emission-producing activity (e.g., an engine start), and the emissions treated as a discrete "puff;" or 2) the emission rate for the parent activity (e.g., the running exhaust emissions that are elevated by the cold start) can be adjusted upward when the conditions that cause elevated emission rates are noted. The CARB emission rate model treats the elevated engine start emissions as a single "puff" (i.e., separate from running exhaust) and multiply a cold start emission rate by the number of engine starts. The USEPA emission rate model increases the calculated running exhaust emission rate for vehicles operating in cold start mode.

High power and load conditions, such as rapid acceleration or high speed activities, also produce significant emissions,[15-20] and may be considered discrete emission-producing activities. Recent laboratory testing indicates that high acceleration rates contribute significantly to instantaneous emission rates, and that one sharp acceleration may cause as much pollution as does the entire remaining trip.[21] In addition, unloaded vehicle deceleration events appear to be capable of producing significant emissions.[22]

Figure 1 presents a second-by-second emission trace for a utility vehicle operating under a part of the Federal Test Procedure (FTP). The figure illustrates that hydrocarbon and oxides of nitrogen "emission puffs" occur, and are likely associated with either the high rates of acceleration or deceleration (time delay associated with analytical equipment response for these data was not available, so associating the specific modal event with the resulting emission puffs was not possible). Surprisingly, operation of the same vehicle on a relatively stable high-speed portion of the Highway Fuel Economy Test also showed some variability in emission rates (albeit smaller "puffs") that may be associated with accelerations and decelerations, even though the rates of acceleration and deceleration at these speeds were low.

Like engine starts, acceleration and deceleration activities can be treated as discrete events and modeled as emission puffs, provided that emission rates for these activities (as well as any potential factors that may influence the magnitude of the puff) can be determined. In contrast to cold start emissions that occur over a period of minutes, acceleration and deceleration related emissions occur over a period of seconds. Specific modal activities that produce elevated emission rates are not currently modeled in the emission inventory process, and are likely to be a partial cause contributing to emission inventory underestimation. Research in the area of modal emission rates is ongoing.

Assessment of IVHS technology bundle impacts will hinge upon accurate assessment of changes in vehicle activity estimates. The most detailed vehicle activity data currently used in emission inventory and modeling work are outputs from transportation demand models, such as the Urban Transportation Planning System (UTPS) generation of models. UTPS-type models are generally described by a four step process: 1) estimating trip production and attraction within small geographic zones, based upon land use and socioeconomic data; 2) assigning the generated trips from zone to zone, based upon gravity-type models; 3) assigning zone-zone trips to specific travel modes, based upon discrete choice analysis using socioeconomic and transport characteristic data (e.g., regression, logit, or probit analysis); and 4) assigning the vehicle trips to specific links on a network model, using flow and capacity characteristics and an iterative delay minimization process. Thus, trips generated, VMT, and vehicle speeds can be estimated. The current accuracy of existing travel demand models, assessment of the state of the practice for these models, and development of methods to improve these models are currently being debated today,[23-25] and state of the practice guidelines are being developed for implementation.[26]

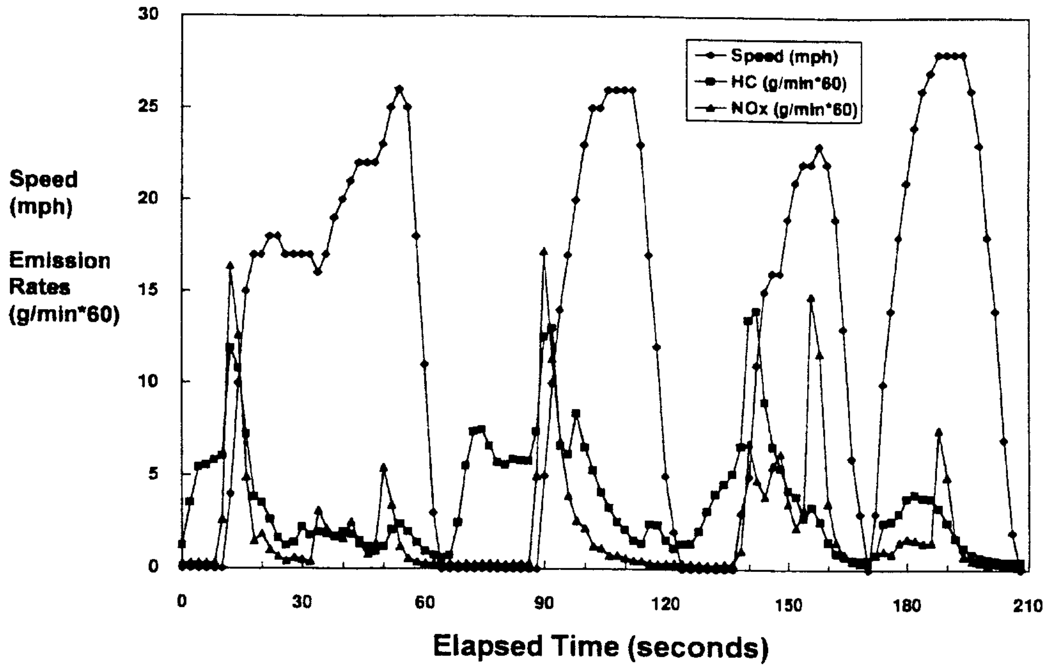
Additional discussions of the demand-side modeling problems will be reserved for another forum.

Activity Specific Emission Rates

The motor vehicle emission rates associated with each of the emission-producing vehicle activities (i.e., grams of emissions per unit of emission-producing vehicle activity) are functions of vehicle parameters, fuel parameters, vehicle

Figure 1

1990 Caravan - FTP Segment
Hot Stabilized Mode
Second-by-Second Speed and Emission Data



operating conditions, and the vehicle operating environment. Table 2 illustrates some of the important variables that can be taken into consideration in developing emission rate estimates:

Table 2
Vehicle Parameters, Fuel Parameters, Vehicle Operating Conditions, and Environmental Conditions Known to Affect Motor Vehicle Emission Rates

Vehicle Parameters:	Fuel Parameters:
• Vehicle class {weight, engine size, HP, etc.]*	• Fuel type
• Model year	• Oxygen content
• Accrued vehicle mileage	• Fuel volatility
• Fuel delivery (e.g. carbureted or fuel injected)	• Sulfur content (SOx precursor)
• Emission control system	• Benzene content
• Onboard computer control system	• Olefin and aromatic content
• Control system tampering	• Lead and metals content
• Inspection and maintenance history	• Trace sulfur effects on catalyst efficiency*

Vehicle Operating Conditions:	Vehicle Operating Environment:
• Cold or hot start mode (unless treated separately)	• Altitude
• Average vehicle speed	• Humidity
• Modal activities that cause enrichment*	• Ambient temperature
• Load (e.g. A/C, heavy loads, or towing)	• Diurnal temperature sweep
• Influence of driver behavior*	• Road grade*

* These components are not explicitly included in the USEPA and CARB emission rate models

Source: (9)

The Emission Inventory Process

The on-road motor vehicle emission modeling process consists of: 1) quantifying emission-producing vehicle activities through a travel demand model or other means of estimation, 2) providing data on vehicle, fuel, operating, and environmental characteristics to the computer model, 3) running the emission rate model to predict activity-specific emission rates for the given vehicle, fuel, operating, and environmental characteristics, 4) multiplying each activity estimate by its appropriate activity-specific emission rate, and 5) summing the estimated emissions for all activities.

Ideally, these emissions estimates must be temporally and spatially resolved for the purposes of air quality modeling. Developing an accurate emission inventory for motor vehicles is tremendously complex. As with most modeling approaches, various modeling assumptions and data aggregation techniques have been developed to simplify the emission inventory preparation and minimize labor and data requirements. However, these simplifications often tend to yield uncertain emissions estimates.

The procedure for evaluating the potential air quality impacts of any proposed transportation strategy involves developing a baseline emission inventory, a future baseline (i.e., no action) emission inventory, and a future scenario emission inventory. To assess the emissions impacts, we compare the future scenario emission inventory to the future baseline emission inventory. To assess the potential impacts of IVHS technology bundles on the future emission inventory, we must understand the impacts that these bundles will have upon vehicle activity and the conditions that affect emission rates from each activity. Many of the IVHS technology bundles have the potential to change the amount of vehicle activity that will occur. All of the IVHS technology bundles also have the potential to affect both the vehicle and environmental characteristics that impact the magnitude of activity-specific emission rates.

POTENTIAL IVHS IMPACTS ON EMISSION-PRODUCING VEHICLE ACTIVITIES

In our previous work, we discussed potential changes in tripmaking activity in terms of the land use and travel demand modeling framework.[7] That is, we discussed potential changes in land use configuration, trip generation, mode choice, trip distribution, and route selection that could potentially result from the implementation of IVHS scenarios. In this section, we discuss the potential IVHS impacts within a different framework; potential changes in emission-producing vehicle activity.

Vehicle Miles Traveled

The implementation of some information-related IVHS technologies will be designed to reduce vehicle miles of travel, by providing better information about route selection and helping motorists from becoming lost. Alternatively, some IVHS technologies, by providing better information, may increase vehicle miles of travel as the motorist attempts to reduce total travel time by selecting uncongested routes. Also, improved access to parking and cost information may reduce cruising activity.[27]

If the effective speed on new AVCS systems were twice the speed on the existing congested system, people might choose to live up to twice as far from their workplaces without having to spend more time traveling.[28] Plus, if travel speeds increase and congestion and travel times decrease, it is likely that average trip lengths will increase as attractive destinations, once inconvenient, become viable.[29] For example, consumers may explore comparable services in new areas. Better access to parking availability and cost information may change shopping and other destinations. Also, potential diversion from higher-occupancy modes, such as buses and carpools, to single-occupant vehicles, may yield an increase in VMT. If, on the other hand, successful APTS technologies are implemented, VMT may decrease as diversions from single occupant vehicles to alternative modes of transportation occur.

Historically, the construction of the limited-access interstate highway system and implementation of fiscal policies and subsidies have tended to favor the development of rural lands for suburban uses. These policies have resulted in sprawling growth patterns surrounding urban areas. Similarly, development of a new high speed limited access IVHS infrastructure may promote continued sprawling development patterns, decreasing the efficiency of services and increasing other externalities associated with sprawl. However, closer analysis may reveal that actual impacts will be a function of the infrastructure that is developed. In fact, it may be possible (although perhaps politically unfeasible) to use IVHS systems to direct population growth and changes in land use. Rational comprehensive planning initiatives may reduce sprawl and increase infill in desired locations by providing IVHS access only in those areas. The IVHS system, however, must be designed and implemented from the top down with this goal in mind for this to occur.

Trip Ends - Cold, Hot, or Warm Engine Starts, and Engine "Hot Soaks"

If capacity and travel speeds increase and congestion and travel times decrease, additional vehicle trips may be undertaken.[29] Thus, IVHS technologies may increase the total number of trips generated and change the number of trips made in cold, hot, or warm engine mode (and increasing the number of engine shut-downs associated with the end of each trip). Fully automated traffic lanes are anticipated to increase freeway flow capacities from today's 2000-2200 vehicles per lane per hour to as much as 3600-7200 vehicles per lane per hour, with the possibility of vehicles operating at speeds of 60 mph or more. On the other hand, ATIS technologies may increase the efficiency of tripmaking if increased access to information yields increased trip chaining, perhaps replacing some cold start trips with hot start trips. "How much change in the number of trips generated" is the first question. "Will these trips be made in cold or hot mode" is the second question. The impacts upon trip generation are by no means certain.

One important behavioral question arises in regard to additional tripmaking behavior given decreased travel time. Perhaps location decisions will be altered as people opt to live further from work. Also, businesses may be more willing to move to remote locations that become more readily accessible through IVHS congestion relief. In either case sprawl may be encouraged. Those individuals who do not relocate will experienced decreased daily travel time. While some will substitute non-travel activities, some may undertake new travel activities during the time was previously consumed in driving. The relationship between travel time budgets, disposable income, and travel behavior must be refined.

Engine Idling

IVHS technologies are very likely to decrease the amount of idling time likely to be experienced by motor vehicles in the future baseline scenario. Advanced traffic management systems are likely to reduce vehicle wait times at intersections, a major cause of idle emissions. Access to more and better information will likely result in less time caught in queues and motoring in search of parking spots. Finally, advanced vehicle control systems have the potential so significantly reduce the amount of congestion currently experienced by vehicles, thereby reducing time spent at idle.

Exposure to Diurnal and Multi-Day Diurnal Temperature Fluctuation

Diurnal evaporative emissions result from the expansion of fuel and increased vapor pressure in the fuel tank caused by ambient warming. Diurnal emissions are controlled to a great extent (when evaporative control canisters are functioning properly), but some diurnal emissions still occur. The existence of the vehicle and its fuel tank are the activity that causes the emissions. Emissions associated with diurnal temperature variation are not likely to be significantly impacted by IVHS technologies, unless there is a major change in the number or fuel characteristics of vehicles in the fleet. Hence, if IVHS vehicles become niche vehicles and are purchased as additional household vehicles, diurnal emissions might increase.

Multi-day diurnal emissions are important because, if a vehicle sits idle for more than one or two days, the evaporative control canister becomes saturated and emission control efficiency drops significantly. Hence, if IVHS technology bundles cause vehicles to remain unused for multiple days, multi-day diurnal emissions from the non-IVHS fleet may increase.

Vehicle Refueling

Emissions from vehicle refueling will be a function of the number of additional fleet vehicles associated with the IVHS system, the type of fuel they employ their fuel efficiency, the size of the fuel tanks, and any additional refueling emission control systems used with the new-technology vehicles. In comparing a future case scenario, one would want to examine the number of non-IVHS vehicles that the IVHS vehicles would replace; hence, while there are emission increases associated with new IVHS vehicles, there are also emission reductions associated with displaced vehicles in then future fleet.

Vehicle efficiency is often considered "the forgotten emission control strategy." Improvements in fleet fuel efficiency generally lead to reductions in emissions because fuel tanks are downsized, fueling is less frequent, and smaller fuel-efficient vehicles generally emit less per mile than their larger counterparts.[30] Changes in vehicle efficiency expected to result from IVHS will clearly be reflected in reductions in refueling emissions.

Modal Activity (e.g., High Power Demand, Heavy Engine Loads, or Engine Motoring)

All of the IVHS technologies discussed in this paper are designed to reduce congestion. Congestion relief is likely to reduce the number of significant acceleration and deceleration events that cause elevated emission rates. Hence the likelihood that modal emission-producing activities will be undertaken is significantly reduced, especially when the computerized vehicle technologies can be readily programmed to avoid undertaking enrichment activities. For example, intelligent vehicles can be pre-programmed for onramp acceleration rates that do not yield excess emissions.

Better tools are needed to assess the impacts of changes in modal operations, because traffic flow tradeoffs resulting from IVHS and other transportation improvement strategies are complex. Consider for example the effect on driving conditions of "improving" one part of the highway system: doing so may push congestion elsewhere, and in a complex non-linear manner. For example, ramp metering reduces congestion on the freeway upstream of the onramp but also causes congestion on the freeway onramp itself, congestion that can spill over onto other roadways. In an ongoing study at UC Davis using travel demand models for the Sacramento region, Johnston and Page found that on a systemwide level, automation of freeways appear to result in significantly reduced vehicle-hours of delay on the freeways, but these reductions are coupled with large congestion increases on the onramps, arterials, and collectors that feed into the freeway system.[31] Changes in the modal components of emission contributions are very likely to be significant.

Unfortunately, modal emission rates and relationships for both the current and future vehicle fleet are relatively unknown at this time, and potential emission tradeoffs associated with changing vehicle flow parameters cannot be evaluated without further analysis of existing and future data. As additional second-by-second emission profiles become available for modern vehicles that are likely candidates for IVHS incorporation, these tradeoffs will become more clear (at least for those vehicles for which data become available). However, it is likely that the projected emission effects that result from specific modal operations will play a very important role in determining which vehicles will ultimately be selected for IVHS incorporation. Individual vehicle emission behavior and final IVHS vehicle fleet profiles are inextricably linked.

POTENTIAL IVHS IMPACTS ON VEHICLE AND FUEL PARAMETERS

In this section, the potential impacts of IVHS on the variables that affect the magnitude of activity-specific emission rates are discussed.

Vehicle Class, Model Year, Fuel Type and Fuel Characteristics, Fuel Delivery Systems, Emission Control Systems, and Onboard Computer Control Systems

The parameters described by this section (vehicle class, model year, fuel type and fuel characteristics, fuel delivery systems, emission control systems, and onboard computer control systems) are all directly dependent upon the composition of the vehicle fleet. Unless IVHS technologies necessarily requires changes in the vehicle characteristics (e.g., fuel type, vehicle size, etc.,) there are no impacts of concern for emission rates from individual vehicles. Existing regulatory programs must be considered, such as the California Low Emissions Vehicle and Clean Fuels Program which requires significantly cleaner new vehicles and mandated percentages of electric vehicles. If IVHS technologies, such as APTS, lead to significant changes in mode share, these parameters become important. One of the real challenges with modeling future IVHS scenarios will be predicting if there will be a significant change in composition of the future vehicle fleet.

Fleet turnover rates may also be affected by IVHS technologies. If newer vehicles, complete with IVHS instrumentation are purchased, a larger supply of used vehicles may enter the market for a time and encourage fleet turnover. On the other hand, a significant increase in average new vehicle prices may play a mitigating role by encouraging the retention of older non-IVHS vehicles in the fleet for longer periods of time. Given these to competing factors, the ultimate effect is currently unknown.

Accrued Vehicle Mileage and Inspection and Maintenance History/Tampering

Vehicle emission rates increase as emission control systems degrade over time. The rate of degradation is generally a function of accrued vehicle mileage, maintenance history, and whether the control systems have been tampered with. Will changes in driving characteristics under IVHS affect emission control degradation rates? For the most part, the difference between an IVHS scenario and non-IVHS scenario appears negligible in terms of the effects of accrued vehicle mileage. Vehicle control requirements (allowed degradation rates) continue to evolve over time. Plus, with the current applications of onboard computer technologies, even in the absence of IVHS, there is no reason to believe that tampering rates will change significantly. On the other hand, a shift to an electric vehicle IVHS infrastructure would have significant implications.

POTENTIAL IVHS IMPACTS ON VEHICLE OPERATING CONDITIONS

In the case of comprehensive improvements in capacity and level of service, vehicle activity and congestion may be reduced and/or redistributed both temporally and geographically. Changes in number of trips, by time of day, and the physical conditions (i.e., vehicle flow conditions) under which the vehicle is operated may change as a result of IVHS.

Cold and Hot Start Modes

Discussed earlier, as a discrete emission-producing activity.

Average Speed and Modal Contributions

Carbon monoxide and hydrocarbon emissions from motor vehicles are noted to decrease as average vehicle speeds increase between zero and forty-five mph (although NOx emission increase as speed increases). At average speeds in excess of 60 mph, the CARB indicated that emission rates of all pollutants rise dramatically.[32-34] There is a high degree of uncertainty associated with the VOC and CO speed-emission relationships[35] for modern fuel-injected vehicles at low speeds (important for establishing future emission baselines under congested scenarios) and at high speeds (important for estimating emissions under IVHS scenarios).

Vehicle speed profiles on the road vary greatly. Two trips may have the same average speed, but very different speed profiles and emissions (e.g., one trip may be traveled at a smooth speed, and another traveled part of the time in stop-and-go congestion and part of the time at high freeway speeds). Expressed more formally, two vehicle trips with the same "average speed" can be composed of significantly different modal characteristics (stops, starts, acceleration rates, time at idle, etc.).

If speed profiles could be smoothed, by reducing stop-and-go driving conditions and increasing free flow speeds, significant emission reduction and fuel economy benefits may be achieved. By eliminating acceleration and deceleration components of a vehicle trip, inertial energy losses are minimized, and emissions associated with these modes of activity are avoided. The quantitative effects of modal components, as discussed earlier, are fairly uncertain at this time and current models use average operating speeds as the explanatory factor for changes in emission rates.

Speed and acceleration profiles are expected to change as a result of the use of automated controls. Advanced traffic management systems are designed to increase average vehicle speeds through the reduction in stop delays, a clear benefit that will reduce emissions. Advanced traveler information systems also increase average operating speeds, usually by routing flows to uncongested routes. However, because individuals make route decisions designed to minimize their own travel time, the provision of perfect information may lead to higher overall congestion levels when individual decisions are made at the expense of overall system efficiency; nevertheless, it may be possible to reduce total travel times by designing efficient information systems that provide information selectively.[36]

A comprehensive advanced vehicle control system infrastructure will likely relieve congestion along existing freeways and expressways, as a result of computer control over separation distances and from a reduction in number of accidents. Thus, AVCS will likely reduce the magnitude of emissions allocated to these spatial locations. Reduced congestion levels will result in improved vehicle flow and better levels of service on automated segments. However, if the infrastructure creates additional traffic congestion along ramps and arterials surrounding access points, as indicated by Johnston and Page,[31] congested traffic conditions on local roads are likely to increase emissions allocated to these spatial locations. Automation may result in spatial shifts in congestion, with congestion being forced to the peripheries of the automated system and between different roadway functional classes. Spatial shifts in congestion and speed profiles are a complex modeling challenge.

Vehicle Load

Although the typical vehicle load factors that are currently modeled (air conditioning and towing) are not likely to be significantly altered by the implementation of IVHS systems unless perhaps the system cannot accommodate towing or these types of emission effects are not exhibited by the new IVHS fleet. However, as noted for modal emission-producing activities, all IVHS technologies have the potential to impact vehicle load characteristics by reducing congestion. Additional research into the effects of vehicle loads under specific operating conditions is necessary.

Driver Behavior

Laboratory emission test result differences between trained and untrained drivers have been postulated.[37] Although the emission differences are still theoretical, experienced laboratory drivers may perform smoother accelerations and decelerations on the testing cycles than would typically be exhibited by onroad drivers. Thus, laboratory drivers with different "gas pedal behavior" may achieve significantly lower emission rates for the modern low-emission vehicles operating dynamometer cycles than would untrained drivers. If this theory is proven in the laboratory, IVHS systems have the capability of using computerized controls to mimic the smoother acceleration and deceleration behaviors noted in the laboratory setting, thereby reducing emissions.

POTENTIAL IVHS IMPACTS ON ENVIRONMENTAL CONDITIONS

The number of trips by time of day are likely to change as a function of operating conditions. Trip distribution may change as a function of reduced travel time during peak periods, so that more trips can be made during peak periods. Information technologies may change , the temporal distribution of tripmaking as a function of access to information, and peak spreading may occur. The resulting change in ambient environmental conditions, based upon time-of-day, may affect vehicle emission rates.

Altitude, Humidity, and Diurnal Temperature Sweep

None of the six technology bundles should have any relative impact upon altitude, humidity, or diurnal temperature sweep. These environmental conditions for the future baseline emission inventory scenario should also exist for the future controlled emission inventory scenario.

Ambient Temperature

To the extent that an IVHS technology bundle changes the time of day of a vehicle's operation, the ambient temperature under which the trips are made will change. The change in time-of-day for trips will likely be related to the time and out-of-pocket costs of a trip as a function of time, as well as individual demand elasticities associated with tripmaking. As congestion is relieved, the times of trips may shift to some extent, but shifts of less than one hour are unlikely to be perceptible in the emission modeling process, compared to the relatively large amounts of error already associated with trip aggregation.

Road Grade

The only IVHS technology bundle that seems likely to change road grade conditions is Advanced Vehicle Control Systems (AVCS), which requires a new infrastructure. If such an infrastructure were developed, the emission rate models might be adapted based upon new data to account for emission reductions associated with gently-sloped grade-separated right-of-way. However, potential impacts cannot be evaluated with current models.

CONCLUSIONS

Accurately quantifying emission reductions resulting from changes in mobile source operating conditions using current modeling tools is extremely difficult. Changes in emission-producing vehicle activity must be estimated, and activity-specific emission rates for these changes must be known. Yet, if IVHS technologies are to be seriously considered as environmentally benign congestion management tools, the emission tradeoff between induced trips and increased VMT and reduced congestion-related vehicle emission rates need to be quantified.

The implementation of IVHS technologies has the potential to dramatically alter our transportation infrastructure, affecting land use patterns, trip generation, trip distribution, mode choice, and route selection. The implementation of IVHS technology bundles will have a mixed effect upon emissions (and energy use). Emissions increases and decreases are likely to result from changes in vehicle activity. Also, changes in vehicle emission rates are expected to result from changes in vehicle characteristics and vehicle operating conditions. Ideally, the magnitude of emission increases and decreases will be measured.

Unfortunately, at this time, for most of the land use, tripmaking, and emission rate effects, neither theoretical nor empirical evidence exists to make such a determination. Because the models do not well represent the actual cause-effect relationships at work for vehicle activity and emission rates (especially for modal activities), it is impossible to determine in a definitive manner the overall emission impact of IVHS. The likely impacts of IVHS systems on vehicle activity and the variables that affect vehicle emission rates are summarized in Table 3. Changes in environmental characteristics are not included in Table 3, because the only expected change is ambient temperature associated with shifts in tripmaking by time-of-day.

The important items to note in Table 3 are: 1) the implementation of advanced public transportation systems is likely to provide significant emission-related benefits in all categories of vehicle activity, and variables that affect emission rates and pursuit of APTS technologies for air quality purposes appears beneficial, 2) the impacts of IVHS on tripmaking and VMT are highly uncertain, and 3) IVHS has the potential to significantly reduce emissions associated with modal activities but that these reductions cannot be quantified at this time.

Table 3
Potential Impacts of Various IVHS Technology Bundles
on Emission-Producing Vehicle Activities,
and on Variables Expected to Affect Vehicle Emission Rates

	ATMS	ATIS	AVCS	APTS	CVO[a]
Emission-Producing Activities					
Vehicle Miles Traveled	U[b]	U[b]	U[b]	↓	NC
Engine Starts and Hot Soaks	NC	↓	↑↓	↓	↓
Diurnal Evaporation	NC	NC	U	NC	NC
Vehicle Refueling	↓	↑↓	↑↓	↓	NC
Modal Behavior (and Idling)[c]	↓	↓	↓	U	↓
Vehicle Parameters					
Vehicle Class[d]	U	↑	U	↓	NC
Fleet Turnover[d]	U	U	U	U	U
Accrued Vehicle Mileage	↑↓	↑↓	↑	↓	NC
Tampering and I&M	NC	↓	↓	↓	NC
Vehicle Operating Conditions					
Average Vehicle Speed[e]	↓	↓	↓	↓	↓
Modal Activities	↓	↓	↓	↓	↓
Vehicle Load	↓	↓	↓	↓	↓
Driver Behavior	↓	↓	↓	↓	↓

a Changes in the CVO category apply almost exclusively to the goods movement sector.
b Longer trips may be made to save travel time. VMT is also affected by mode selection (e.g. increased use of shared modes may reduce overall VMT).
c IVHS technologies will be designed to reduce congestion and emission rates from modal activities. However, these reductions cannot be quantified at this time due to uncertainty in emission models
d Changes in fleet composition and fleet turnover rates must occur, compared to the future baseline condition, for IVHS systems to have an impact upon this category.
e NOx emissions may increase with average speed.

(NC) = Not Likely to Significantly Change Activity or Emission Rates
(↑) = Likely to Increase Activity or Emission Rates
(↓) = Likely to Decrease Activity or Emission Rates
(↑↓) = Likely to Partially Increase and Partially Decrease Activity or Emission Rates
(U) = Uncertain Impacts

Note that none of the observations presented in this paper actually dealt with air quality, only with emissions. A whole new set of uncertainties presents itself with respect to pollutant dispersion. For example, will the presence of high-speed vehicle platoons change the pollutant dispersion characteristics, and will drivers potentially be exposed to higher in-vehicle pollutant concentrations?[38] Furthermore, the formation of ozone occurs when hydrocarbons and oxides of nitrogen are combined in the presence of sunlight. Hence, whether the pollutants are emitted during the morning or evening periods can be of consequence to single-day ozone formation. In general, morning emissions tend to form more smog. However, the photochemical reactions occurring during a daily cycle are often exacerbated by poor airflow that traps pollutant in an airshed for multiple days. Thus, under extremely stagnant conditions, the emission of the pollutant by time of day is of lesser consequence. We are dealing with a complex system, composed of tremendously complex interactions, and we must face the fact that our predictive capabilities today are still in their infancy.

The primary goal of IVHS-related emissions research should be to identify and quantify the important cause-effect relationships at work. To achieve this goal, the effect of modal operations of vehicles on emissions must be further investigated. Future IVHS-emissions research should be designed to: 1) identify important emission related vehicle activities that will be affected by IVHS implementation for both the IVHS and non-IVHS vehicle fleets; 2) develop a modal emission modeling framework, applicable to both IVHS and non-IVHS vehicle fleets; 3) improve existing transportation demand models or develop new activity modeling approaches that incorporate simulation techniques so that modal activity outputs can be estimated; 4) develop a new modal emissions model using second-by-second emission testing data now becoming available; and 5) analyze the implications of IVHS implementation, in terms of IVHS and non-IVHS vehicle performance profiles, based upon the emission rate model outputs.

REFERENCES

1. U.S. Department of Transportation, National Transportation Strategic Planning S tudy, Washington, D.C., March 1990.

2. Saxton, Lyle G., and G. Salder Bridges, Intelligent Vehicle Highway Systems, A Vision and a Plan, *TR News*, 152, January-February 1991.

3. 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.

4. 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.

5. 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.

6. Jack Faucett Associates, Information Package Prepared for the Video-Conference on the Effect of IVHS Technologies on Air Qality, 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.

7. Sperling, Daniel, Randall Guensler, Dorriah L. Page, and Simon P. Washington, Air Quality Impacts of IVHS: an Initial Review, In: Proceedings, IVHS Policy: A Workshop on Institutional and Environmental Issues, Gifford, Horan and Sperling, Eds., The Institute of Public Policy, George Mason University; Fairfax, VA, April 1992.

8. Lawrence, Michael F., Emissions and Air Quality Impacts of IVHS Actions (Non-Technical IVHS Issue Paper for TSC), Presented at the Transportation Research Board, Meeting of the Committee on Transportation and Air Quality; Washington, D.C., Available through Jack Faucett Associates, Bethesda, MD, January 11, 1993.

9. This section, including the tables, is adapted from Guensler, Randall, "Vehicle Emission Rates and Average Vehicle Operating Speeds," Dissertation, submitted in partial satisfaction of the requirements for the degree of Doctor of Philosophy in Civil/Transportation Engineering, Department of Civil Engineering, University of California, Davis, CA, Forthcoming in August 1993.

10. Jacobs, Paul, Donald J. Churnich, and Mark A. Burnitzki, Motor Vehicle Emissions and their Controls, California Air Resources Board, Sacramento, CA, July 1990.

11. Heywood, John B., Internal Combustion Engine Fundamentals, McGraw-Hill Publishing Company, New York, NY, 1988.

12. Richard W. Joy, Drive Thru Windows - A Case Study, Proceedings of the Transportation Modeling Tips and Trip-Ups Conference, Air and Waste Management Association, Pittsburgh, PA, March 11-12, 1992.

13. Stone, C.R., A.J. Sorrell, T.W. Biddulph, and R.A. Marshall, Analysis of Spark-Ignition Engine Performance after Cold Start, with Thermal and Cyclic Measurements, Proceedings of the Institution of Mechanical Engineers, International Conference on Automotive Power Systems Environment and Conservation, Mechanical Engineering Publications, Ltd., Suffolk, England, September 1990.

14. Pozniak, Donald J. (1980), The Exhaust Emission and Fuel Characteristics of an Engine During Warmup, A Vehicle Study (800396), Society of Automotive Engineers, Warrandale, PA, February 1980.

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

16. Benson, Paul, CALINE4 - A Dispersion Model for Predicting Pollutant Concentrations Near Roadways (FHWA/CA/TL-84/15), State of California Department of Transportation, Division of New Technology and Research, Sacramento, CA, November 1984, Revised June 1989.

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

18. Calspan Corporation, 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.

19. Calspan Corporation, 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.

20. 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.

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

22. 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.

23. Purvis, Charles (1992), Sensivity of Transportation Model Results to Uncertainty in Input Data, Transportation Modeling Tips and Trip-Ups Proceedings, an Air and Waste Management Association Specialty Conference, Pittsburgh, PA, March 1992.

24. Ismart, Dane, Travel Demand Forecasting Limitations for Evaluating TCMs, A Paper Presented at the 84th Annual Meeting of the Air and Waste Management Association, copies available from author at the Federal Highway Administration, Washington, D.C., June 1991.

25. Transportation Research Board, Environmental Research Needs in Transportation, Transportation Research Circular, Number 389, Washington, D.C., March 1992, [pp. preface, 19-23, and 47-49].

26. Harvey, Greig, Deakin Harvey Skabardonis, Berkeley, CA.

27. Ullberg, Cyrus G., Parking Policy and Transportation Demand Management, Proceedings of the 84th Annual Meeting of the Air and Waste Management Association, Pittsburgh, PA, June 1991.

28. Varaiya, Pravin, and Shladover, Steven E., Sketch of an IVHS Systems Architecture (UCB-ITS-PRR-91-3), Institute of Transportation Studies, University of California, Berkeley, Berkeley, CA, February 2, 1991.

29. Stafford, Frank P., Social Benefits of IVHS Systems, Automated Highway/Intelligent Vehicle Systems: Technolgy and Socioeconomic Aspects, Warrendale, PA: Society of Automotive Engineers, Inc., 1990.

30. Deluchi, Mark, Quanlu Wang, and David L. Greene, Motor Vehicle Fuel Economy, the Forgotten HC Control Strategy?, ORNL-6715, Oak Ridge National Laboratory, Oak Ridge, TN, June 1992.

31. Johnston, Robert a., and Dorriah L. Page, A Preliminary Systems-Level Evaluation of Automated Urban Freeways, 2nd International Conference on Applications of Advanced Technologies in Transportation Engineering: Minneapolis, Minnesota, April 10, 1991.

32. California Air Resources Board, Methodology to Calculate Emission Factors for On-Road Motor Vehicles, Technical Support Division, Sacramento, CA, 1992.

33. California Air Resources Board, Derivation of the EMFAC7F Speed Correction Factors, Mobile Source Division, Inventory Analysis Branch, Analysis Section, El Monte, CA, July 1992.

34. However, the true cause-effect relationship is still unclear at this time, and may be associated in part with the high rate of acceleration used in the dynamometer testing cycle.

35. Guensler, Randall, Simon Washington, and Daniel Sperling, A Weighted-Disaggregate Approach to Modeling Speed Correction Factors, Institute of Transportation Studies, University of California, Davis, Davis, CA, January 1993.

36. de Palma, Andre, A Game-Theoretic Approach to the Analysis of Simple Congested Networks, *Transportation Economics*, Volume 82, Number 2, May 1992.

37. Ripberger, Ted, USEPA, Office of Air Quality Planning and Standards, Research Triangle Park, personal communication, November 1991.

38. Points raised by Paul Benson, developer of the CALINE4 dispersion model, during the video conference on IVHS and Air Quality, March 8, 1993.