

Emission Impacts of
Intelligent Vehicle Highway Systems

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Abstract

This paper identifies the IVHS technology bundles most likely to result in air quality benefits. The assessment is preliminary, as current state of the practice emission modeling is not sufficient for quantitatively assessing the effects of flow smoothing - an effect common among IVHS technologies. This analysis concludes that the most beneficial application of IVHS will be to those technologies aimed at improving non-recurrent congestion events. These include rapid accident response systems, off-peak electronic toll collection, and variable message signs. Peak period application of IVHS technologies such as automation, electronic toll collection, and traffic signal management will provide very uncertain and perhaps even negligible air quality benefits. The assessment reported in this paper does not take into account the implementation of simultaneous technologies such as electric vehicles and market strategies which could potentially improve the current outlook. In addition, it is assumed that no significant long term changes in mode choice, fleet characteristics, or travel behavior will occur with the application of IVHS technologies. We do recognize, however, that carefully planned and implemented IVHS systems can be designed to affect such changes in driver behavior, typically in concert with demand management strategies. Our analysis suggests that realistic solutions to air quality problems will likely be solved with a mix of IVHS technologies and other transportation measures such as congestion pricing, preferential treatment of shared modes, and the development of alternatively fueled IVHS fleets (i.e. automation with electric vehicles).

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Introduction

Advanced transportation technologies range from simple systems that provide drivers with real-time travel information, to complex systems that provide automated vehicle control. Advanced technologies applied to motor vehicles and infrastructure are generally known as Intelligent Vehicle Highway System (IVHS) technologies. Combinations of these advanced technologies, known as "technology bundles," are being promoted for reducing congestion delay, improving transportation system safety, and making vehicle travel "...more energy efficient and environmentally benign" (U.S. Department of Transportation, 1990).

IVHS technologies can be classified into six basic IVHS technology bundles (Jack Faucet Associates, 1993): 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), and Emergency Vehicle Services (EVS). Each of these technology bundles is designed to achieve a similar goal; improve the efficiency of the transportation system through the application of communications technologies. However, the efficiency objectives targeted by each technology bundle are distinctly different, and will have different potential effects upon vehicle emissions.

In theory, IVHS technologies will increase the efficiency and capacity of the existing highway system resulting in reduced congestion (Saxton, 1991; Conroy, 1990; Shladover 1991; Shladover 1989). The reduced congestion will result in 'smoothed' traffic flows, which in turn are expected to provide air quality benefits.

This desirable chain of events that leads to lowered emissions, however, may not occur as expected. First, increased travel efficiency and reduced trip times may increase trip generation, change travel destinations, increase single occupant vehicle use, and change travel routes. Furthermore, depending on the time of day, IVHS may simply shift the spatial location of congestion on a network when demand significantly exceeds capacity, resulting in marginal or non-existent air quality benefits. Consider, for example, an IVHS infrastructure that relieves congestion on downtown freeway segments and results in the creation of congestion on freeway off ramps and local arterials when the traffic flows leave the automated network. Hence, we must be careful to consider the full ramifications of IVHS technologies, taking into account behavioral changes, transportation supply characteristics, and temporal fluctuations in the transportation system. Most importantly, the IVHS infrastructure to be developed must be analyzed as a complete system, not in component pieces.

In earlier papers, we noted problems with the capabilities of existing models to estimate IVHS emissions impacts (Sperling, Guensler, Page, and Washington, 1992) and identified specific emission-related cause-effect relationships likely to be affected by IVHS implementation (Guensler, Sperling, and Washington, 1993). Considering that vehicle activity and emission rate modeling shortfalls currently exist, evaluating

the air quality impacts of IVHS impacts with today's modeling tools is highly uncertain, and impossible to determine in a definitive manner. What can be done and is done in this paper, however, is identify and discuss IVHS technologies that will likely result in the improvement of air quality.

This paper first summarizes the current state of the practice in vehicle emission estimation. Then, emission producing vehicle activities are identified. Next, considering emission modeling shortcomings and activities that cause emissions, travel characteristics most likely to be affected by IVHS are identified. Finally, IVHS technology bundles most likely to improve air quality are identified and discussed, with recommendations for further research provided.

Summary of Current Emission Estimation Procedure

Assessment of IVHS technology bundle impacts hinges upon accurate assessment of changes in vehicle activity estimates. To predict changes in vehicle modal activities, we need to know several things. First, we need to know the relationship between modal vehicle activities (i.e. speed, idle, acceleration, and deceleration) and emissions, and we need to know what changes in modal activities are likely to occur under various IVHS scenarios. Currently, we do not have the capability to estimate emissions from discrete modal events, because emission models employ average vehicle speeds. However, we appear to have a better notion of what types of modal activity will result under IVHS scenarios. The current state of the practice in emission inventory and estimation is described below.

The first step in the emission estimation process is to model the transportation network with a suitable model. The most detailed vehicle activity data currently available are 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 (Purvis, 1992; Ismart, 1991; Transportation Research Board, 1992), and state of the practice guidelines are being developed for implementation (Harvey, 1993). Additional discussions of the demand-side modeling problems are reserved for another forum.

The output from UTPS type models are used as inputs to emission models such as CARB's EMFAC and EPA's MOBILE. Then, 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. 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 operating conditions, and the vehicle operating environment.

So, 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 are temporally and spatially resolved for the purposes of air quality modeling. 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.

As described above, the emission estimation process involves a series of computer inputs and outputs that rely on user inputs and assumptions. The process lacks the inherent capability to quantify emission estimates of discrete modal activities, and therefore can not be relied upon to assess the current mix of IVHS technologies. A new modeling approach, one based upon modal activity of vehicles, is in the initial stages of development at UC Davis.

Identification of Emission Producing Vehicle Activities

The anticipated air quality benefits from IVHS technologies are based upon the increased efficiency offered by these systems. To understand the nature of the emission reductions, we must quantify the changes in travel behavior (e.g. trip making, VMT, modal vehicle activity, etc.) resulting from the implementation of advanced technologies. In addition, we must identify the motor vehicle activities that produce emissions. With these activities identified, we can proceed to outline a feasible IVHS system plan designed to minimize the occurrence and impact of high emission-producing vehicle activities.

Table 1 contains the general emission-producing vehicle activities that are often included in the emission inventory modeling process, and the type of emissions that are produced by each activity. The elevated emissions of CO, NO_x, PM₁₀, and SO_x, 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 (Jacobs, Churnich, and Burnitzki, 1990; Heywood, 1988; Joy, 1992; Stone, Sorrel, Biddulph, and Marshall, 1990; Pozniack, 1980).

High power and load conditions, such as rapid acceleration or high speed activities, also produce significant emissions (CARB, 1991; Benson, 1989; Groblicki, 1990; Calspan, 1973a; Calspan, 1973b; Kunselman, McAdams, Domke, and Williams, 1974), and are 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 (Carlock, 1992). In addition, unloaded vehicle deceleration events appear to be capable of producing significant emissions (Darlington, Korsog, and Strassburger, 1992).

High power and load conditions can be seen in the speed time trace shown in Figure 1. The figure shows the second-by-second emission trace for a utility vehicle operating under parts 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.

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.

Identification of Travel Characteristics Likely to be Affected by IVHS Technologies

In previous work, we discussed potential changes in trip making activity in terms of the land use and travel demand modeling framework (Guensler et. al., 1993). 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 identify the trip and travel characteristics that are likely to be affected by implementation of IVHS technologies.

Vehicle Miles of Travel

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 (Ullberg, 1991).

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 (Varaiya, Pravin, and Shladover, 1991). 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 (Stafford, 1990). For example, consumers may explore comparable services in new areas. Better access to parking availability and cost information may change shopping and other destinations. Plus, 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 infeasible) 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.

On the contrary, if IVHS systems are funded by system users via higher vehicle costs and taxes etc., and if these costs are significant, then these systems might have a reverse impact on trip length and trip generation. These higher costs may cause

people to travel shorter distances and make fewer trips, offsetting the increased level of service and capacity improvements brought about by IVHS technologies.

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 (Stafford, 1990). 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 trip making 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 trip making 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 experience decreased daily travel time. While some will substitute non-travel activities, some may undertake new travel activities.

Engine Idling

IVHS technologies are very likely to decrease the amount of idling time experienced by motor vehicles in the future. 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 to 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 the environmental 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 impacted by IVHS technologies, unless there is a significant 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, 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 the future fleet. Fuel 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 (Deluchi, Wang, and Greene, 1992). 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 vehicle technologies can be readily programmed to avoid undertaking enrichment activities. For example, intelligent vehicles can be pre-programmed for on ramp 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 on ramp but also causes congestion on the freeway on ramp 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 system wide 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 on ramps, arterials, and collectors that feed into the freeway system (Johnston and Page, 1991). 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.

Identification of IVHS Technology Bundles Most Likely To Improve Air Quality

Intelligent vehicle highway system supporters provide various arguments favoring various IVHS system configurations. Among the arguments are increased capacity, increased safety, exportable technology development, and reduced congestion. Supporters have yet to make bold statements as to the air quality benefits of IVHS technologies for several important reasons. First, as previously discussed, the current modeling regime is not adequately structured to make air quality impact determinations. Second, little is known about the true operational impacts of many proposed IVHS technologies, and pilot projects are still in their infancy. Finally, the primary focus of IVHS supporters has been on implementation and technical issues, with little research focus on air quality issues. For IVHS technologies to be seriously considered, we must quantify the emission impacts of various technology bundles.

The purpose of this section is to discuss the air quality impacts of the various IVHS technologies bundles. These impact assessments are qualitative in nature, as we are currently unable to quantify them. In making air quality impact assessments, technologies are assumed to be implemented exclusively, and other implementable programs (for example market strategies and electric vehicles) are not implemented simultaneously. Certainly, if other programs are employed then the conclusions

presented here are likely to change. The uncertainties with the technologies are discussed, as well as the expected impact on driver behavior such as mode choice and commute times and distances.

Advanced Traffic Management Systems

Advanced Traffic Management Systems (ATMS) are technologies designed to optimize vehicular flows on the transportation network, and usually utilize real-time traffic information. Examples of ATMS include signal timing optimization, ramp metering, electronic toll collection, incident detection, rapid accident response, and integrated traffic management. Generally speaking, ATMS can be broken into two categories, those that aim to improve recurrent congestion problems such as ramp metering, and those that aim to improve non-recurrent congestion such as rapid accident response. These two general classifications are discussed in turn.

As an example of a strategy designed to combat recurrent congestion, signal timing optimization implemented through the Fuel Efficient Traffic Signal Management (FETSIM) program is expected to improve fuel efficiency by minimizing stop delay and inertial losses (California Energy Commission, 1983; Los Angeles Department of Transportation, 1988; Deakin, Skabardonis, and May, 1984). Similarly, ramp metering is designed to regulate flow onto congested freeways, as to prevent the freeways from deteriorating to level of service of D, E, or F, smooth ramp flows, and reduce weaving at the freeway merge (Transportation Research Board, 1985).

Although ATMS strategies designed to combat recurrent congestion offer air quality benefits, they will likely be less effective and less certain than those strategies aimed at non-recurrent congestion. Recurrent congestion, caused when travel demand exceeds roadway capacity, accounts for approximately 40% of all congestion. On the other hand, non-recurrent congestion, resulting from incidents and accidents, accounts for the remaining 60% of congestion delay occurring during both the peak and off-peak periods (Cambridge Systematics, 1990; Federal Highway Administration, 1986). These characteristics describe two important differences in terms of potential air quality improvements. First, by sheer accounting of vehicle hours of delay, the potential benefits for non-recurrent congestion may be greater than the potential benefits of relieving recurrent congestion. The more important difference, however, is characterized in the difference between transportation system operation during peak compared to off-peak times.

During peak travel times when heavy congestion occurs, a high proportion of the transportation system is operating with demand exceeding capacity. Under these conditions, IVHS capacity expansion improvements along selected routes, such as freeway on-ramps and clusters of intersections may result in a spatial re-allocation of system-wide congestion (the notable exception being the relief of bottlenecks where

downstream capacity is sufficient to handle the increased traffic flow). If traffic accommodated by the increased IVHS capacity cannot be accommodated at the system endpoints or constriction points (i.e. non-IVHS-improved locations), effective mitigation involves either moving the congestion to portions of the system that continue to operate with excess capacity (which are usually difficult to find during peak periods), or removing vehicles from the network. Removing vehicles cannot be controlled by proposed IVHS scenarios (except where advanced public transit systems are provided a heavy advantage), so shifting congestion onto less congested segments becomes the natural solution to this secondary problem. The potential air quality impacts (i.e. emissions and the location of resulting pollutant concentrations) associated with congestion transfer, changes in average vehicle speeds, and changes in modal operations cannot be adequately assessed with existing models.

Shifting congestion during peak periods makes emissions estimations difficult at best. For example, do air quality benefits from ramp metering (which clearly reduces congestion on the congested freeway) offset the additional idle emissions created on surface streets and intersections, and the emissions associated with hard accelerations at the on ramp for vehicles to achieve freeway merge speeds. Although the answer to this question will not be quantified for some time, the effect of shifting congestion is clear: traffic smoothing on one segment at the expense of increased modal activity on another segment has the potential to result in minimal or no net air quality benefits.

In addition to the two reasons cited above, a system-wide reduction in congestion during peak times may invite trips to be taken that were previously not being taken. This result, known as latent demand, is difficult to measure but again may further reduce the potential air quality benefits.

Similar to ramp metering and signal timing optimization programs, electronic toll collection administered during peak periods may not result in significant overall air quality benefits. Congestion presently occurring at manual toll collection booths results in decreased congestion on segments downstream from the tollbooths (i.e. on downstream roadways and intersections). During peak-periods, manual toll collection has many parallels to ramp metering used to reduce congestion on freeways. As an example, administering electronic toll collection on the San Francisco Bay Bridge during peak periods may result in increased congestion in the downtown area. In summary, the improvement in air-quality due to electronic toll collection during peak periods is uncertain, and the potential inducement of congestion downstream should be investigated further.

ATMS aimed at reducing non-recurrent congestion, on the other hand, are likely to provide more certain air quality benefits. Since non-recurrent congestion accounts for a large share of total delay, the potential for air quality benefits is likely to be higher than for recurrent congestion. However, the proportion of non-recurrent congestion that occurs during peak periods is not specified in the literature. Thus, the

relief of some incident congestion delay during peak periods will likely increase recurrent congestion delay estimates.

Nevertheless, we can be confident that relief of incident delay will be beneficial for air quality. The reasons for the potentially large improvement in air quality become clear when contrasted with those for recurrent congestion. Contrary to peak times, the proportion of the transportation system operating under a 'demand greater than capacity' situation is significantly less, and 'excess' capacity is typically more available. Thus, when vehicles are re-routed via ATMS onto alternate routes, congestion shifts are not likely to occur, since the alternate routes will more effectively handle the increased traffic. Other ATMS technologies such as rapid response incident management can also clear blocked lanes and bottlenecks that would otherwise create significant accrued vehicle hours of delay. Electronic toll collection also seems to provide clear benefits during off-peak times, since flow will be smoothed and congestion consequences downstream may be less severe than during peak times.

Advanced Traveler Information Systems

Advanced Traveler Information Systems (ATIS) are designed to provide information to individuals about routes and system conditions so that travel times can be minimized. These technologies include on-board electronic maps, electronic route guidance and planning, changeable message signs, externally linked route guidance systems, vehicle condition warning systems, emergency mayday beacons, and ride share information availability.

The key elements in assessing the air quality impacts of ATIS are the impact of 'perfect' information on driver route and mode choices. If drivers are re-routed during peak periods and they barter decreased travel time for increased vehicle miles of travel along an alternative route, the extra miles of travel will partially offset the air quality benefits from avoiding the congested route. This is especially true if the alternative routes are also congested. If alternative routes are not congested, then the smoothed flow resulting from avoided congestion may reduce emissions. Again we see that as far as route choice is concerned, the time of day (peak versus off-peak) becomes an important factor in assessing air quality impacts, with off-peak emission reductions more likely.

If mode choice is affected by ATIS, then mode switching decisions may affect air quality. Estimation of the impact of mode switching is difficult however, since there is little information indicating that improved access to ride share information will have a significant impact. Furthermore, assuming that mode switching will occur, the secondary impacts such as latent demand may make air quality impact estimation more difficult.

Advanced Vehicle Control Systems

Advanced Vehicle Control Systems (AVCS) encompass technologies designed to provide lateral and or longitudinal control of vehicles, and those designed to control vehicles throughout their trip. The main thrust of AVCS technologies is to improve highway capacity by both reducing headways at all speeds and by reducing lateral space requirements between vehicles. In addition, congestion events and accidents caused by driver behavior such as rubbernecking, response to bottlenecks, etc., can be mitigated. In theory, roadway capacity can be doubled or quadrupled with AVCS. AVCS may not, however, lead to improvements in air quality. There are many reasons to doubt that air quality benefits from AVCS, through changes in modal activity or increased travel speeds on roadways, will occur.

AVCS technologies are appealing because constant inertial losses occurring due to congested stop and go conditions is a recipe for high emissions. However, a closer look may reveal some interesting consequences of AVCS. First, existing stop and go traffic is likely to experience higher operating speeds when AVCS are implemented. Level of service C or B traffic may be improved to level of service A. The air quality benefits from eliminating the stop and go conditions are obvious, although they cannot be reliably quantified. However, negative air quality impacts can result from high-speed operations. Current empirical data suggests that average emissions are lowest at average speeds of around 40 to 45 mph. Given this, increasing traffic speeds beyond 45 mph via AVCS is likely to partially offset the emission reductions achieved from smoothing vehicle flow (especially if very high vehicle speeds and loads are employed).

Potentially more serious is the congestion effect that may occur at the 'ends' of automated segments. Since 'automation' will occur in stages, with the primary candidates being heavily congested freeways and highways, the end of the automated segments can become serious bottlenecks. If bottlenecks cannot be eliminated (e.g. expanding off ramp and connecting arterial capacity to store vehicles) automated systems will experience failure. At the very least, the congestion conditions will need to be addressed when they arise. Since demand at any given point is migratory over the long-term, determining the appropriate extent of automation becomes problematic. In summary, the potential for congestion at the end of automation, surface streets, and collectors may potentially offset the air quality improvements intended by flow smoothing.

Besides the problems mentioned above, increased capacity and travel speeds on automated segments may lead to the latent demand effect over the long term, further exacerbating the effects at automation ends, and offsetting air quality benefits.

A long term issue associated with automation is its potential effect on land use. The notion that travel time budgets remain fairly constant over the long term suggests that travelers with access to automated commutes could relocate farther from their

workplace. This possible suburbanization effect could have serious implications as to air quality, since many additional trips could be generated from the sprawl effects.

On the other hand, if automation were coupled with single occupant electric vehicle usage, for example, the potential air quality benefits could be substantial. One possible scenario could be light-weight overhead infrastructure designed to support single occupant automated electric vehicles linking suburbs with a central downtown area. The limited range of the network (and electric vehicles), the aim at peak period travel, and the provision of single occupant vehicles to appease consumer demand might provide a system with the potential to significantly reduce emissions from the transportation system. The message should be clear: linking automation with other technologies might provide an air quality outlook much different than for automation alone, and may be the only way in which to feasibly implement the technology providing an air quality benefit.

Commercial Vehicle Operations

Commercial Vehicle Operations (CVO) are technologies designed to improve the efficiency of freight transportation. The primary goal is to minimize time spent in inspection and weigh facilities, and to improve the safety of hazardous material transport. As the impact on air quality of CVO technologies are even less certain than for other IVHS technologies, no real conclusions can be drawn. Clearly, however, the reduced stop and go driving characteristics of commercial vehicles at required stops and the reduced weaving effects from re-entry into traffic streams will have positive effects on air quality. Truck involved accidents may be reduced, thereby reducing congestion. In addition, the reduction of truck idling times will provide an air quality benefit.

Advanced Public Transportation Systems

Advanced Public Transportation Systems (APTS) range in scope from computerized ride share matching (perhaps in-vehicle), to video transit schedule displays. They could also include automated HOV lane enforcement, automated fleet maintenance and tracking, and electronic billing. In essence, the APTS technologies are aimed at making public transit and shared modes more accessible and attractive to potential users. As the potential changes from APTS technologies is difficult if not impossible to predict, especially given concurrent changes due to other IVHS applications, the potential air quality impacts of APTS are presently unknown. However, significant shifts in mode will yield changes in vehicle fleet composition and can potentially yield lower emission rates.

Emergency Vehicle Services

Emergency Vehicle Services (EVS) include systems designed to give priority to emergency vehicles such as ambulances and fire trucks. An example might be a communication device in emergency vehicles that is electronically connected to signalized intersections, providing the vehicle with intersection right-of-way control. These technologies are designed to provide non-transportation services (human safety) and are unlikely to significantly impact air quality.

Discussion

The shortcomings of the current state of the practice emission inventory for estimating emissions under IVHS technology scenarios were discussed. Clearly, the chain of emissions estimation starting from network modeling with UTPS-type models to emission inventory estimation using CARB or EPA type models is not capable of discriminating between the unique speed time profiles under IVHS and non-IVHS scenarios. This inability to reliably estimate the impacts of various IVHS technology bundles is prompting further research into the current modeling practices.

Despite the shortcomings of current modeling methodologies, we can still qualitatively assess the impacts of various IVHS technologies. In order to make this assessment, vehicle activities known to cause emissions are identified. It is evident that discrete modal activities such as hard accelerations, hard decelerations, and high speed cruises contribute significantly to emissions. In addition, there are significant emissions from cold starts, hot starts, and evaporative emissions. To make a preliminary assessment of IVHS, knowledge of discrete modal events known to cause emissions are used to assess typical speed-time profiles provided under various IVHS technologies.

When studying IVHS technology bundles, it was noted that in general technologies that aim to reduce non-recurrent congestion events are likely to provide the largest air quality benefits. In the same vein, we can expect many measures to be more effective during off-peak than during peak commute times, when congestion is more likely to be shifted around the network. Potentially effective measures include variable message signs, off-peak electronic toll collection, and rapid incident response management. More uncertain are the effects of advanced traveler information systems and advanced vehicle control systems. In fact, these systems may provide little if any air quality benefits. Advanced public transit systems have the potential to significantly reduce vehicle emissions, but only if significant changes in mode share result.

The current assessment assumes that commute distances will remain constant over the long term, travel behavior will not change significantly, the vehicle fleet will remain relatively unchanged into the future, and IVHS will not significantly affect

current mode shares. These assumptions, as well as the effect of studying IVHS technologies in isolation, significantly effect the conclusions. If other transportation measures, such as congestion pricing, alternatively fueled vehicle fleets, or automation of electric vehicles were employed, very different results are expected. Also, if future emission controls significantly change the "off-cycle" emissions behavior of the future vehicle fleet, then current emission modeling problems will change. The most likely solution to air quality problems will be solved with some combination of transportation strategies and technologies rather than IVHS strategies alone. As there are no silver bullets in transportation, this conclusion is not surprising.

Many assumptions must be made in order to assess potential air quality impacts of IVHS. Among these are travel behavior changes such as trip lengths, trip times, and mode changes. Estimating the effect of IVHS on behavior is difficult, especially under conditions of an uncertain future. For example, which transportation strategies other than IVHS will be applied in the future? Which combination of IVHS strategies will be applied, and what will be their synergistic effect? The answers to these questions could have significant impacts regarding the conclusions drawn about IVHS.

Larger than technical uncertainties are uncertainties associated with the temporal implementation of IVHS technologies. IVHS technologies will be implemented over several decades and in many stages, leaving ample time for simultaneous system wide changes to occur. Considering simultaneous changes in emissions controls, transportation control measures, market strategies, and driver behavior, the evolutionary nature of technology diffusion will ensure that the emission impacts of IVHS technologies remain unpredictable into the future.

Research and pilot studies currently in progress should provide interesting insight into the utility of IVHS technologies as air quality management tools. The new models being developed will be better equipped to assess discrete modal events, and will provide the ability to quantitatively assess the emissions of IVHS. In addition, pilot studies currently in progress will provide insight as to the effects of IVHS on driver behavior. The two developments can then be rejoined to determine a more definitive appraisal as to the air quality impacts of intelligent vehicle highway systems.

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

<u>Emission-Producing Vehicle Activity</u>	<u>Emissions Types Produced</u>
Vehicle Miles Traveled	Running - CO, VOC, NO _x , PM ₁₀ , SO _x Evaporative - VOC
Cold Engine Starts	Running - CO, VOC, NO _x , PM ₁₀ , SO _x
Warm or Hot Engine Starts	Running - CO, VOC, NO _x , PM ₁₀ , SO _x
Engine Hot Soaks (Shut Downs)	Evaporative - VOC
Engine Idling	Running - CO, VOC, NO _x , PM ₁₀ , SO _x Evaporative - VOC
Diurnal Temperature Fluctuation	Evaporative - VOC
Vehicle Refueling	Evaporative - VOC
Modal Activities (Accel, Load, etc.)	Running - CO, VOC, NO _x , PM ₁₀ , SO _x

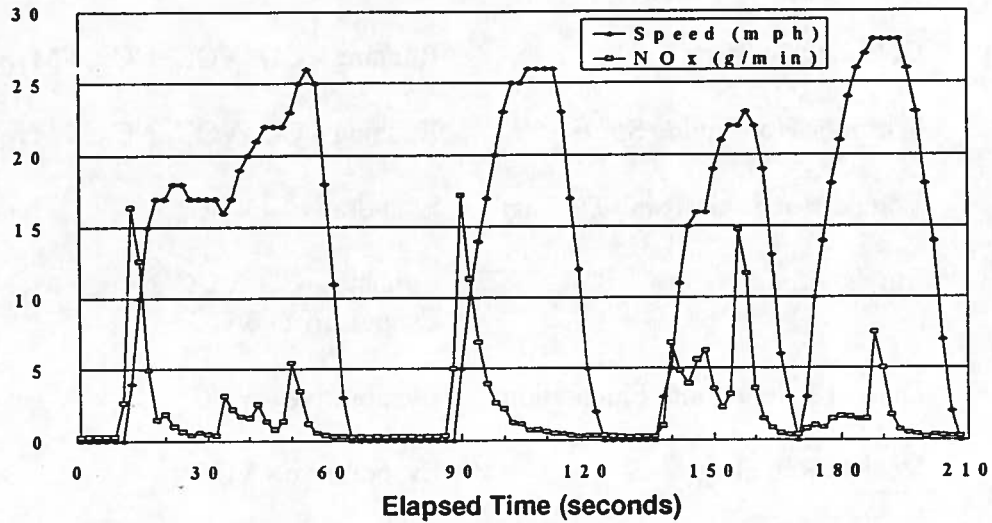
CO = Carbon Monoxide; VOC = Volatile Organic Compounds; NO_x - Oxides of Nitrogen;
 PM₁₀ = Fine Particulate Matter (less than 10 microns in diameter); SO_x = Oxides of Sulphur

Figure 1

**1990 Caravan - FTP Segment
Hot Stabilized Mode**

**Emissions
grams/min**

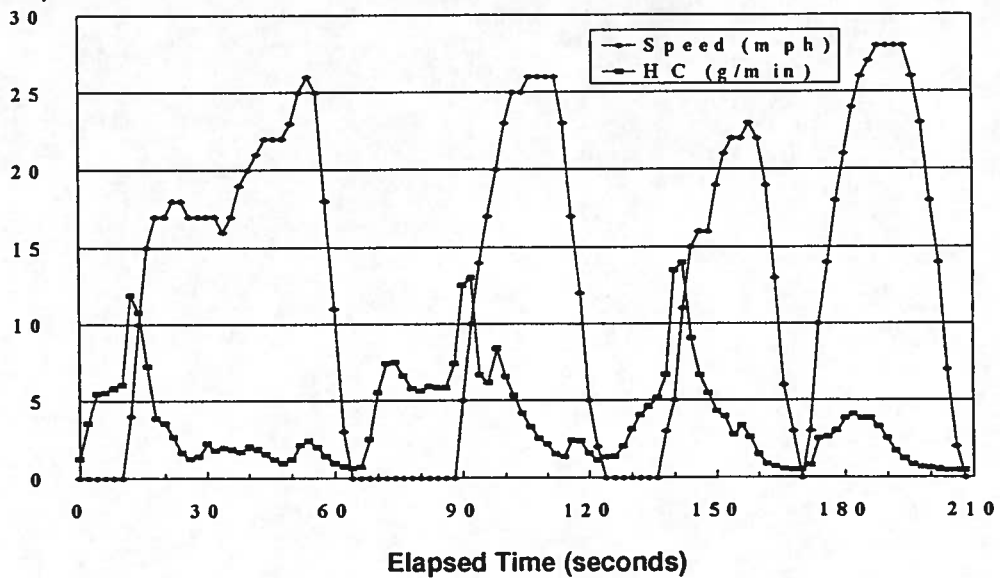
Second-by-Second Speed Vs NOx



**1990 Caravan - FTP Segment
Hot Stabilized Mode**

**Emissions
grams/min**

Second-by-Second Speed Vs HC



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