

ASSESSING THE EMISSION IMPACTS OF IVHS IN AN UNCERTAIN FUTURE

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ABSTRACT

To assess the emissions impacts likely to result from future implementation of intelligent vehicle and highway system (IVHS) concepts, requires making assumptions about the simultaneous emergence of technologies and policies. Emission characteristics of the future vehicle fleet, the penetration of electric vehicle technologies, and the impacts on driver behavior of future policies will have profound implications on research findings. This paper first summarizes the likely impacts of three IVHS technologies (advanced traffic management systems, advanced traveler information systems, and advanced vehicle control systems) given the characteristics of the existing vehicle fleet and current driving behavior. Then, each IVHS technology is revisited with changes in future assumptions - be they technology or policy based - to examine the potential air quality impacts. Assumptions about future conditions profoundly affect the expected air quality impacts of the three IVHS technologies. The emission reduction effectiveness of IVHS systems at the margin can be amplified or diminished by alternative assumptions, because projected trends in the vehicle fleet and transportation system characteristics can lead toward synergistic or competing air quality effects. Ongoing policy decisions currently evolve in an ad-hoc process, where new policies are based upon existing conditions and typically in made in response to current politically-salient problems. Hence, the transportation system can evolve along multiple potential paths. In preparing transportation system analyses, the authors recommend that transportation planners and researchers consider the wide range of technologies and policies that may be implemented and note the synergism that may result from multiple strategy implementation. Furthermore, by examining the potential interactions of technology and policy decisions (i.e. by varying implementation assumptions) prior to making policy decisions, analytical results can be used to help develop rational-comprehensive transportation plans that provide more cost-effective solutions to transportation problems.

INTRODUCTION

Currently, there is a great deal of advocacy and funded research for the application of advanced technologies to motor vehicles and the transportation infrastructure. These intelligent vehicle and highway systems (IVHS) are currently "...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]." An essential characteristic of IVHS is that communications technologies are applied to the transportation sector. These advanced transportation technologies range widely in scope, from 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. 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 may accrue.

Concurrent with IVHS research, research on advanced emissions controls, advanced vehicle designs, alternative fuels, transportation demand strategies, and other transportation policy options continues. Researchers typically attempt to quantify the potential emissions reductions expected to result from the implementation of the specific technology or policy upon which they are focused. Yet, the results of these projections are dependent upon the future conditions assumed to exist.

Future conditions of concern include such important items as vehicle fleet composition, the driving behavior of the future population, penetration of competing technologies, and other factors that can significantly affect vehicle activity or emission rates. Unfortunately, it is rare to see an analysis of IVHS implementation scenarios that assumes simultaneous penetration of 'other' technologies, such as alternative fueled vehicles. Similarly, it is rare to see an analysis of electric vehicle impacts that assumes wide scale implementation of IVHS technologies. Yet, as will be discussed later, the interactions between electric vehicles and IVHS technologies may yield significant synergistic benefits from an air quality standpoint. It is extremely important to assume a range of simultaneous technology penetration, and to consider the impact of a wide array of future vehicle fleets and transportation policies. Only when a range of future technology penetration is analyzed are analysts likely to include the scenario that will actually exist in the future. Plus, by examining the potential interactions of technology and policy decisions (i.e. by varying key assumptions) prior to making policy decisions, analytical results can be used to help develop transportation plans that are more cost-effective and provide more effective long term solutions to transportation problems.

In an earlier paper [6], some of the general relationships important for determining the potential impacts of IVHS systems were explored. Problems were noted in the capabilities of existing 'UTPS type' vehicle activity models to estimate IVHS emissions impacts. A second, more detailed paper [7], explored the emissions implications of deploying IVHS "technology bundles [8]" by examining potential effects upon important emission-producing vehicle activities and those parameters that affect emission rates. A third paper [9] discussed which IVHS systems were most likely to reduce emissions, and how these systems could be specifically designed to improve air quality. This paper re-considers the emission impacts of three IVHS technology bundles with one major difference ... in each case, the future is hypothesized to change in either the characteristics of the vehicle fleet or the policy measures that will already have been implemented. More detailed analyses along these lines may provide a more realistic assessment of IVHS technology impacts, given that new technologies and policy decisions are likely to emerge simultaneously, rather than independently.

First, factors that contribute to motor vehicle emissions are reviewed. These factors also happen to be the most likely to be effected by changes in assumptions about the future transportation system. Then, the body of the paper discusses the potential air quality impacts under changing assumptions about the future transportation paradigm. Three IVHS technologies are considered - advanced traffic management systems (ATMS), advanced traveler information systems (ATIS), and advanced vehicle control systems (AVCS). This paper is not meant to be an exhaustive discussion of possible futures. Rather, it is meant to provide a brief glimpse into three possibilities.

MOTOR VEHICLE EMISSIONS

There are several key factors that determine the emissions from motor vehicles: vehicle activities that produce emissions, the composition of the current vehicle fleet, and characteristics of current driving behavior. These three factors constitute the main components of emission estimation that would be effected by changes in assumptions about the future. Each of these factors is briefly discussed in turn.

Emission-Producing Vehicle Activities [10]

Motor vehicles pollute, whether they are running or simply parked in a driveway. General vehicle activities known to produce vehicle emissions include: vehicle miles traveled, engine starts, engine shut downs, idling, exposure to temperature fluctuation, and refueling operations. The elevated emissions of CO, NO_x, PM₁₀, and SO_x, arising under certain vehicle activities generally result from engine conditions that exacerbate incomplete combustion and from catalytic converter temperatures too low to facilitate efficient control of exhaust gas emissions [11,12,13,14,15].

High power and load conditions, such as rapid acceleration or high speed activities, also produce significant emissions [16,17,18,19,20,21], 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 [22]. In addition, unloaded vehicle deceleration events appear to be capable of producing significant emissions [23]. While vehicles are in operation, hydrocarbon, carbon monoxide, and oxides of nitrogen "emission puffs" occur, and are likely associated with enrichment events that correspond to either high rates of acceleration or deceleration. This is easily explained by the fact that acceleration and deceleration related emissions occur over a period of seconds, unlike emissions from hot and cold starts which typically take several minutes.

If factors controlling the activity-based emissions from motor vehicles are significantly changes, say through computer control chip mandates or vehicle design changes, then vehicle activities that currently effect vehicle emissions may change dramatically.

Vehicle Fleet Composition

Fleet average emission rates are dependent upon the composition of the vehicle fleet. Vehicle characteristics such as weight, engine size, horsepower, model year, accrued vehicle mileage, fuel delivery system (e.g. carbureted or fuel injected), emission control system, onboard computer control system, control system tampering, inspection and maintenance history, etc., are all important emission-related parameters [10]. Plus, fuel characteristics such as oxygen content, volatility, sulfur content, aromatic content, metals content, all affect the magnitude of various emissions associated with vehicle activity [10].

As an example of interaction between policy measures, consider the interaction between policies designed to reduce emissions and policies designed to improve fuel economy. Vehicle fuel economy and emission rates are not directly related, i.e. emission rates are not a direct function of gasoline consumption across vehicles. For example, some strategies that reduce vehicle emissions will decrease

fuel economy, e.g. supplemental air injection which requires energy, while other measures that reduce emissions also increase fuel economy, e.g. multi-point fuel injection which provides improved combustion. Nevertheless, as a rough aggregate measure, fleet fuel economy can be viewed as the forgotten emission control strategy [24]. Vehicles are required to meet Corporate Average Fuel Economy Standards, enacted in 1975 as part of the Energy and Policy Act [25]. As of 1988, manufacturers of light-duty vehicles must sell vehicles whose average fuel economy is 26.0 miles per gallon. If CAFE standards were to increase dramatically, the downsizing of vehicles and engines that may result has the potential to dramatically change in-use vehicle fleet emissions. Plus, refueling emissions associated with reduced fuel consumption and smaller vehicle fuel tanks might provide emission reductions from the entire fuel chain as well. The point here is not to dwell upon whether increased CAFE standards will significantly decrease emissions, but simply to point out that the policy decisions made in the fuel economy arena are inexorably tied to policies in the air quality arena, that the relationships are extremely complex, and that interactions should not be ignored in a thorough policy alternatives analyses.

A more direct measure of emissions for the vehicle fleet is embodied in the California Low-Emission Vehicle Program, which is a technology-forcing standard that mandates the reduction of emissions from motor vehicles sold in California [26]. In this program, new motor vehicle emissions of non-methane organic gases must be reduced from 0.25 grams per mile in 1994 to 0.062 grams per mile in 2003 on a sales-weighted average. The program also mandates the sale of zero-emission vehicles starting at 2% of sales in 1997 and increasing to 10% in 2003. The program allows a large degree of flexibility in corporate compliance plans, in that manufacturers can produce any combination of low emitting vehicle classification in any fuel types desired, provided that their sales-weighted average complies with the standard and that they sell the minimum required percentage of zero-emission vehicles. Hence, predicting the future fleet composition is very difficult. If fleet characteristics change more rapidly than expected, by any number of transportation technologies or policies, then the estimated emissions impacts of a future vehicle fleet may be significantly different than the typical fleet of today.

Driver Behavior

According to national statistics, the average household in 1990 traveled 4,853 miles going from home to work, 1,743 miles shopping, 3,014 miles for other family or personal business, and 4,060 miles for social or recreational purposes - a total average annual mileage of 15,100 [27]. The average American also choose their personal auto, van, or truck over public transit at an average ratio of 43:1 [28]. Also in 1990, Americans paid an average of about \$1.15 per gallon including tax for regular unleaded fuel, paid an average price for a domestic and import vehicle of \$15,641 and \$17,010 respectively, and paid an average prorated cost of about 41 cents per mile [29].

Driving behavior can be characterized by trip type, trip purpose, trip length, time-of-day, etc. Travel behavior determines the demand for the transportation system. The demand for the transportation system is a function of transportation costs (e.g. time, fuel, parking, etc.) and transportation supply (e.g. land use configuration, mode availability, routes, congestion levels, etc.). As more and longer trips are made by individuals, vehicle miles of travel increase, as do vehicle emissions. Furthermore, vehicle operating conditions and the operating environment, such as altitude, temperature, humidity, whether the engine is in cold or hot start mode, average vehicle speed, engine load (e.g. air conditioning, heavy loads, or towing), and potential influences of driving behavior can also affect the magnitude of emission rates associated with vehicle activities.

Congestion is also a good indicator of driving behavior. By 1987, almost 70% of all urban interstate roads were congested during peak periods [30]. The amount of congestion experienced by drivers provides an indicator of the value of their trip in accordance with the value of their time. Presently, the cost of sitting in traffic appears to be fairly low compared to the value or utility of completing a specified trip - especially during peak times when trip makers may have little flexibility. As drivers tolerate increasing levels of congestion, emissions increase geometrically.

Again, if driver behavior is affected through the use of technology, policies, or transportation demand management, then the drivers could behave much differently in the future. This behavior could even affect location decisions made by households and businesses, ultimately affecting land uses. Ultimately, changes in driver behavior would also bring about changes in emissions, the direction and magnitude of the change determined by many factors.

ASSESSING MARGINAL AIR QUALITY IMPACTS OF IVHS SCENARIOS

Many IVHS technologies have the potential to change the amount of vehicle activity that will occur. In addition, IVHS technologies also have the potential to affect both the vehicle and environmental characteristics that impact the magnitude of activity-specific emission rates. To assess the marginal impacts of IVHS strategies, one must make assumptions about the characteristics of the future transportation system, irrespective of implementation of IVHS technologies. For example, if a road-pricing strategies were implemented regionally as well as an IVHS scenario, assumptions about future transportation demand would have to be modified, since road-pricing would theoretically remove some vehicles from the system during peak periods.

The procedure for evaluating the potential air quality impacts of any proposed transportation strategy involves developing a baseline emission inventory, a future baseline emission inventory (i.e. in the absence of the proposed strategy) , and a future emission inventory with the proposed strategy in place. To assess the marginal emission impacts of the proposed strategy, 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.

This section discusses the possible emissions impacts of three intelligent vehicle and highway systems (IVHS) technologies under alternative future conditions. IVHS technologies are discussed in turn, contrasting the emissions impacts of the technologies under current conditions with those under alternative future conditions. The conditions in particular are those concerned with the composition of the future vehicle fleet and assumptions about future transportation policies. The assumed changes include: changes in the typical cross section of the future vehicle fleet brought about by technological innovation, changes in driver behavior brought on mostly by transportation control measures, and changes in emission-producing vehicle activities brought about by likely alternative emission control strategies. The purpose of exploring changes in the future transportation paradigm is to illustrate the possible wide range of uncertainty of applying IVHS technologies, and to illustrate the possible air quality benefits that simultaneous emergence of transportation technologies may bring about.

Advanced Traffic Management Systems

Advanced traffic management systems (ATMS) are technologies designed to optimize vehicle flow on the transportation network, typically utilizing 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.

A strategy designed to combat recurrent congestion is signal timing optimization is the Fuel Efficient Traffic Signal Management (FETSIM) program, which is expected to improve fuel efficiency by minimizing stop delay and inertial losses [31, 32, 33]. 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 [34].

Rapid accident response systems and incident detection, however, can be used to reduce non-recurrent events. Information about accidents, incidents, and construction work events are relayed to a central traffic management center, who then optimizes signals, ramp meters, etc., to minimize delays and maximize throughput. Roving and real-time dispatched service vehicles are also used to clear accidents and incidents quickly.

Our previous paper iterated the likely air quality impacts of such systems, emphasizing the importance between off-peak and peak travel, and recurrent and non-recurrent congestion events [35]. We found that although ATMS strategies designed to combat recurrent congestion are likely to 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 [36, 37]. These characteristics describe two important differences in terms of potential air quality improvements. First, by simple accounting of vehicle hours of delay, the potential benefits for non-recurrent congestion appear greater than the potential benefits of relieving recurrent congestion. But the more important difference is characterized in the difference between transportation system operation during peak compared to off-peak periods. During peak travel periods, a large percentage of the core transportation system is operating under conditions where demand exceeds capacity, which means that there is significantly less excess capacity for re-routing of traffic. Thus, potential air quality benefits for recurrent congestion are less significant than for non-recurrent congestion.

These findings, however, were presented in light of one assumed future transportation paradigm. Suppose we were to consider simultaneous application of technologies, resulting in a significantly different future transportation system. For example, suppose that vehicle manufacturers were to discover the many benefits of "supercars[38]" and auto manufacturing plants were retooled to meet the new demand and market. Considering that near-term design vehicles could attain fuel economy of approximately 150 miles per gallon [39], the emissions reductions could be substantial. Widespread adoption of this technology could, over the long term, essentially cut current motor vehicle emissions by around 60% to 75%. In addition, high acceleration or high speed activities, of great concern today, may become increasingly less important with advanced vehicle combustion technologies or alternative fuels.

Also, peak versus off-peak travel concerns would also become less critical, since 'supercars' incorporate engine off at idle, and emissions associated with congestion may diminish considerably.

Hence, in this revised supercar scenario, the emission benefits associated with non-recurrent congestion relief and the minor emission benefits associated with recurrent congestion relief in previous analyses would already have been allocated to 'supercar' implementation before ATMS was even implemented. Of course, introduction of 'supercars' could not occur overnight, so the projected emission changes associated with ATMS would likely diminish over time. With motor vehicle emissions reduced significantly under the alternative scenario described, the marginal emission impacts of ATMS (and all other IVHS technologies) would essentially become a minor consideration. Under a 'supercar' scenario, the major consideration of ATMS would be minimized travel times on a transportation network, improved mobility and reduce vehicle delays, and improved traffic safety.

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.

Again, with the current vehicle fleet, the importance of off-peak and peak travel periods and recurrent versus non-recurrent congestion events is important when considering the air quality impacts of these technologies [40]. Consider, however, that future vehicles may be capable of monitoring information about emission control performance through the use of onboard diagnostic systems. Furthermore, as the cost and size of remote and onboard sensing devices is reduced through technology advances, future vehicles may be capable of monitoring and recording instantaneous emission rates, as well as cumulative emissions. The cumulative emissions could be used in assessing annual registration fees that incorporate a pollution fee component. Thus, drivers who pollute more would pay more, while more conservative drivers or drivers that own low emission vehicles would pay less.

With emission information available to drivers and with an emission fee system in place, driving behavior may change significantly (depending of course, on the fee per gram of emissions and the demand elasticity). High emission activities associated with speed and acceleration, for example, might be reduced significantly. Also, people would be less inclined to tamper with vehicles and more inclined to keep vehicles 'tuned up' under such a pricing scheme. Finally, drivers may drive less, or trip-chain more frequently, when a traditionally fixed driving cost (registration fee) is converted into a variable cost.

If the emission fee transportation control measure described above were in place, the amount of high emission activity will probably decrease, and overall congestion levels might also decrease as drivers seek out less expensive travel times. Of course, the magnitude of these impacts is highly speculative. Clearly, ATIS systems provide operational benefits, in terms of congestion relief and improved safety. However, the impacts of ATIS systems applied in an emission fee future could be even more beneficial to air quality. Emission fee systems provide additional incentive for the use of those ATIS systems that are implemented. Plus, ATIS systems can be programmed to evaluate alternative routes in terms of time and emissions, so that route decisions are made on a more informed basis.

Advanced Vehicle Control Systems

Advanced Vehicle Control Systems (AVCS) encompass technologies designed to provide lateral and/or longitudinal control of vehicles, and may be designed to route and control vehicles throughout the entire trip. The main thrust of AVCS technologies is to improve highway capacity by both reducing headway 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 even quadrupled with AVCS. As iterated in an earlier paper, however, AVCS may not necessarily lead to improvements in air quality [41].

In summary, the potential adverse air quality impacts assuming an unchanging vehicle fleet include [42]:

- Vehicles may experience significantly higher operating speeds when AVCS is implemented, potentially yielding significant emission rate increases (especially for NO_x).
- Determining the appropriate extent of automation is problematic, and severe congestion may result at automation endpoints and on nearby local arterials and connectors[43], yielding increased emission rates.
- Increased capacity and travel speeds on automated segments may provide capacity for latent demand over the long term, increasing vehicle activity and further exacerbating congestion effects at automation endpoints.
- The possible suburbanization effects of significantly reduced travel times could create many additional trips and could encourage additional urban sprawl.

On the other hand, if automation were applied simultaneously with electric vehicle technologies, the air quality outlook may be very different. For example, a grade-separated and automated infrastructure for half-width electric vehicles could be developed to provide access to and from core business districts from outlying suburbs [44]. The infrastructure could be designed specifically for commuters, but could be used also for non-work trips. The limited range of the network (and electric vehicles), the focus on 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. Commuters diverted to the automated electric vehicle infrastructure would create additional capacity on the existing transportation system, thereby decreasing congestion for conventional vehicles[45]. The message should be clear: linking automation with other technologies might provide an air quality outlook that significantly enhanced compared to the independent implementation of the technologies, and may be the only way in which to feasibly implement the AVCS technology so that an air quality benefit is realized.

CONCLUSIONS

This paper discussed the likely air quality implications of several IVHS technologies if these technologies were in place today - and qualitatively compared these to the air quality implications of the same technologies under significantly different future conditions. The varied conditions included simultaneous development of new vehicle technologies or the adoption of an emission-based economic incentives as a transportation control measure. With the current vehicle fleet, IVHS technologies, on the aggregate, do not appear to provide promising or significant benefits to air quality. If assumptions about the future conditions are changed, however, certain IVHS technology bundles may become very promising.

Advanced traffic management systems (ATMS) under a significantly changed vehicle fleet could, for example, achieve their intended purposes of improved mobility, decreased delays, and improved safety. Given the current vehicle fleet, on the other hand, ATMS results in marginal and indeterminable air quality benefits. In this scenario, of course, all of the air quality benefits are associated with the major change in the vehicle fleet, and not the application of ATMS technologies.

Advanced traveler information systems (ATIS), when combined with a variable registration fee that is based on amount of pollution emitted, could be very instrumental in providing air quality benefits. In this case, the technology is used directly to provide the air quality benefit. This combination of technology and policy would likely bring about improvements to air quality greater than application of the technology alone.

Advanced vehicle control systems (AVCS), by themselves, are most likely detrimental to air quality. But if combined with electric vehicle technology in a well designed infrastructure, major benefits to air quality could likely be realized.

Transportation planners and researchers need to widen their perspective on the application of emerging technologies policy ideas. The air quality benefits from application of multiple ideas should be clear - synergistic approaches have much more potential than single-track approaches. Although we can not predict the future, we can shape the future with transportation investments. Proposals should consider simultaneous application of technologies, so as to maximize the intended benefits of the technologies and minimize externalities.

The implication for researchers is that assumptions about the future can profoundly affect the outcome of analytical efforts. It is extremely important to consider all feasible future scenarios - and not always to focus on single determinable outcomes. IVHS technologies will not suddenly appear; rather, they will emerge simultaneously with many other technologies and policies. It is important to search for the combinations of these technologies and policies that are most likely to produce desirable outcomes.

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