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ASSESSING THE EMISSION IMPACTS OF IVHS IN AN UNCERTAIN FUTURE

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ABSTRACT

Analysts today would like to assess the emissions impacts likely to result from future implementation of intelligent vehicle and highway system (IVHS) concepts. This requires making assumptions about the simultaneous emergence of technologies and policies. Assumptions about emission characteristics of the future vehicle fleet, the penetration of electric vehicle technologies, and the impacts on driver behavior of future policies has 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 characteristics of current vehicle characteristics and driving behavior. Then, each IVHS technology is re-assessed with some change in a future assumption - be it technology or policy based - to determine the expected air quality impacts. It is found that future assumptions profoundly affect the expected air quality impacts of the three IVHS technologies, in most instances improving their outlook. The authors recommend that transportation planners and researchers consider synergism of technologies and policies, since this is the more likely way in which changes in the transportation paradigm will emerge. The authors acknowledge that assumptions about the future can be used to aid in the formulation of effective solutions to transportation problems.

INTRODUCTION

Currently, there is a great deal of funded research and advocacy for intelligent vehicle and highway systems (IVHS). Advanced highway technologies 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]." Advanced technologies applied to motor vehicles and the infrastructure are generally known as Intelligent Vehicle and Highway Systems (IVHS). 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 are expected to accrue.

Simultaneous with IVHS research, is research on advanced emissions controls, transportation policy options, advanced vehicle designs, and transportation demand strategies. Again, researchers are trying to quantify the possible emissions reductions from implementation of their specific technology or transportation control measure.

The results of any analysis are contingent upon the assumed future vehicle fleet profile, the driving behavior of the future driving population, and the penetration of competing technologies. Unfortunately, it is rare to see an analysis regarding IVHS to assume simultaneous penetration of 'other' technologies. And similarly, it is rare to see an analysis of electric vehicles assuming that IVHS technologies have been applied grand scale. It is extremely important if not critical, to assume simultaneous penetration of technologies, and to consider the impact of a wide array of future vehicle fleets and transportation policies.

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' 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. The results of the paper assumed explicitly that significant changes in the composition of the current vehicle fleet did not occur, and penetration of simultaneous technologies also did not occur.

This paper re-considers the emission impacts of three IVHS technology bundles with one major difference - in each case the future is expected to change in either; the characteristics of the future vehicle fleet or future policy measures. This analysis is believed to provide a more realistic assessment of IVHS technologies, as emerging technologies and policy options are likely to emerge simultaneously, rather than individually.

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 paradigm. Then, the body of the paper discusses the potential air quality impacts under changing assumptions about the future transportation paradigm. This is done by assuming changes in characteristics of the future vehicle fleet, or changes in policy options. The analysis is not meant to be an exhaustive discussion of all possible future outlooks, but rather it is meant to consider likely and promising combinations of future outlooks. In the discussion three IVHS technologies are considered - Advanced Traffic Management Systems, Advanced Traveler Information Systems, and Advanced Vehicle Control Systems.

MOTOR VEHICLE EMISSIONS [10]

There are several key factors that determine the emissions inventory from motor vehicles. They are: specific 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

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, refueling, and modal operations. The elevated emissions of CO, NOx, PM_{10}, and SOx, 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

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. These estimates, of course, are dependent upon the composition of the vehicle fleet, with the average gram per mile emission rate being an important indicator, and fuel economy a decent surrogate.

Currently, vehicles in the US are required to meet Corporate Average Fuel Economy Standards, which were enacted in 1975, as part of the Energy and Policy Act [24]. Although fuel economy is not a direct measure of emissions from motor vehicles, it is a decent surrogate measure. As of 1988, manufacturers of light duty vehicles must sell vehicles whose average fuel economy is 26.0 miles per gallon. If fuel economy was to change dramatically for vehicles, then emissions would likely change dramatically also.

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 [25]. In this program, motor vehicle emissions (NMOG, CO, NOx, and HCHO) are required to be reduced from a fleet average of 0.25 grams per mile NMOG in 1994 to 0.062 grams per mile in 2003. The program also mandates the sale of zero emission vehicles starting at 2% of all purchases in 1997 to 10% in 2003.

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

Driving behavior is a big determinant of emissions. As more and longer trips are made by individuals, their average mileage increases, therefore increasing emissions. Furthermore, as drivers tolerate increasing levels of congestion, emissions increase geometrically.

Driving behavior can be characterized by trip type, trip length, and trip purpose for the average American. This behavior on the aggregate determines the demand for the transportation system. The demand for the transportation system is a function of transportation costs and transportation supply. Transportation costs are vehicle costs, fuel costs, driving costs, and alternative transportation costs. Transportation supply is the availability of transport modes and routes.

As an example of current driving 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 [26]. The average American also chose their personal auto, van, or truck over public transit at an average ratio of 43:1[27].

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 annual maintenance cost of about 40.96 cents per mile [28].

Congestion is also a good indicator of driving behavior. By 1987, almost 70% of all urban interstate roads were congested during peak periods [29]. 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 have little flexibility.

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.

AIR QUALITY IMPACTS OF IVHS UNDER UNCERTAIN FUTURE CONDITIONS

This section looks at the likely emissions impacts of three intelligent vehicle and highway systems (IVHS) technologies under changing future conditions. The conditions in particular are those concerned with the composition of the future vehicle fleet, and assumptions about future transportation policies. The sections begins by providing a description of the current emission assessment process used to determine emissions from motor vehicles in a given area. Then, IVHS technology bundles are discussed in turn, contrasting the emissions impacts of the technologies under current conditions and then under changed future conditions. 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 can bring about.

Assessing the Marginal Impacts of IVHS Scenarios

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. In addition, we must make assumptions about the future of the transportation system, irrespective of implementation of IVHS technologies. For example, if a road-pricing strategy were implemented with an IVHS scenario, then assumptions about transportation demand would have to be modified, since road-pricing would theoretically some people off of the system.

In an earlier paper, the emission impacts of IVHS technology bundles were assessed assuming the current transportation system remains unchanged into the future. In the following analysis, IVHS technology bundles are assessed assuming changes in different aspects of the current transportation paradigm. The assumed changes will be represented by: changes in emission-producing vehicle activities brought about by likely alternative emission control strategies; changes in the typical cross section of the future vehicle fleet brought about by technological innovation; and by changes in driver behavior brought on mostly by transportation control measures.

Air Quality Impacts of IVHS Technology Bundles

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.

A strategy designed to combat recurrent congestion is signal timing optimization, an example being the Fuel Efficient Traffic Signal Management (FETSIM) program, which is expected to improve fuel efficiency by minimizing stop delay and inertial losses [[30], [31], [32]]. 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 [33].

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 [34]. We found that 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 [35, 36]. 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 periods. During peak travel periods, a high proportion of the transportation system is operating with demand exceeding capacity, while during off-peak periods there is significantly more excess capacity.

These findings, however, were based on an unchanged future transportation paradigm. Suppose we were to consider simultaneous application of technologies, resulting in a much different future transportation paradigm.

For example, suppose that vehicle manufacturers were to discover the many benefits of "Supercars[37]" and significantly retooled auto manufacturing plants to meet the new demand and market. Considering that near-term design vehicles could attain fuel economy of approximately 150 miles per gallon [38], 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%. With motor vehicle emissions reduced this significantly, the emissions impacts of ATMS's (and all other IVHS technologies) would essentially become a minor consideration. The major consideration would become congestion or mobility, safety, cost, and political acceptability.

At the very least, a significant change in the future vehicle fleet such as this would temporarily diminish the relative importance of emissions from motor vehicles. Suddenly becoming extremely important would be area sources, indirect sources, and point sources. Of course, introduction of 'supercars' could not occur overnight, so the concern over air quality from ATMS would diminish over time. Modal activities of vehicles, of great concern today, would become increasingly less important. Also, peak versus off-peak travel concerns would also become less critical, since 'supercars' incorporate engine off at idle, and emissions associated with congestion would diminish considerably.

Under this scenario, ATMS's could be used to accomplish what it is ideally intended - to minimize travel times on a transportation network, to improve mobility and reduce vehicle delays, and to improve 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 [39].

Consider, however, that future vehicles included, along with vehicle condition warning systems, information about emission control performance and emissions performance. For example, as part of an air pollution policy initiative, future vehicles could contain a digital readout of instantaneous emission rates, as well as cumulative emissions. The cumulative emissions could be used to determine yearly registration fees - an air pollution tax if you will. Thus, drivers who pollute more - pay more, while drivers who drive conservatively and own fuel efficient vehicles pay less.

With this kind of information to drivers and the air pollution tax in place, driving behavior could change significantly (depending of course, on the cost per gram of emissions). Extreme modal activity, for example, could be reduced significantly. Also, people would be less inclined to tamper with vehicles and more inclined to keep vehicles 'tuned up' with such a scheme. High highway speeds might also be reduced, as emissions sharply increase after about 50 mph. Finally, drivers may drive less, or trip-chain more, since a traditionally fixed driving cost (registration fee) has been turned into a variable cost.

Under the transportation control measure described above, the relative importance of modal activity would decrease, while overall congestion levels might also decrease, since drivers might seek out less expensive travel times. Of course, the magnitude of these impacts is highly speculative. The impacts of ATIS applied in this manner could be potentially very beneficial to air quality, in addition to the other operational benefits to congestion relief and improved safety.

Advanced Vehicle Control Systems

Advance 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. As iterated in an earlier paper however, AVCS may not lead to improvements in air quality [40].

In summary, the potential adverse air quality impacts assuming an unchanging vehicle fleet are[41]: Existing stop and go traffic is likely to experience higher operating speeds (meaning higher emissions) when AVCS are implemented; Since demand at any given point is migratory over the long-term, determining the appropriate extent of automation becomes problematic, resulting in severe congestion at automation endpoints and nearby local arterials and connectors[42]. 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. The possible suburbanization effect of significantly reduced travel times could create many additional trips and could encourage additional urban sprawl effects.

On the other hand, if automation were applied simultaneously with electric vehicle technology, then the air quality outlook might be much different. For example, a grade-separated and automated infrastructure for half-width electric vehicles could be developed to provide access to and from CBD's form outlying suburbs [43]. 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 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. Commuters diverted to the separate traveled way would create additional capacity on the existing transportation system, thereby decreasing modal activity and congestion of conventional vehicles[44]. 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.

CONCLUSIONS

This paper looked at the likely air quality impacts of several IVHS technology bundles if the technology were in place today - and compared these to air quality impacts of the same technology bundles under significantly different conditions. The varied conditions included simultaneous application of other technologies, adoption of transportation control measures, and complete revision of the current vehicle fleet.

We found that 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, we found that certain IVHS technology bundles 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 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 design, major benefits to air quality could likely be realized.

The findings of this paper should be clear. First, 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 - synergism of ideas has much more potential than idealistic single-track ideas. Although we can not predict the future, we can shape the future with transportation investments. Proposals should consider simultaneous application of technologies, as to maximize the intended benefits of the technologies, and to minimize their externalities.

Secondly, researchers should interpret the implications of this paper accurately - our assumptions about the future can profoundly affect the outcome of our results. It is extremely important to consider all feasible future scenarios - and not always focus on a single determinable outcome. IVHS technologies will emerge into the future alone - but rather, they will emerge simultaneously with many other technologies and policies. Perhaps it is worthwhile to search for combinations of these that will produce desirable outcomes.

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