Air Quality Impacts of IVHS: An Initial Review

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Abstract

Advanced transportation technologies, ranging from the provision of real-time traffic flow information to fully automated in-vehicle control systems, are promoted as a means of not only reducing congestion, but also to make vehicle travel "...more energy efficient and environmentally benign."[1] In this paper, we explore the air quality implications of deploying advanced technologies, hereafter referred to as Intelligent Vehicle Highway System (IVHS) technologies.

Introduction

Because motor vehicles account for such a huge proportion of air pollutant emissions in urban areas -- about half the hydrocarbon and nitrogen oxide emissions, and over 80% of carbon monoxide emissions, according to government estimates -- any changes in the number and use of vehicles could have a relatively large effect on total urban emissions. While government forecasts of air pollutant emissions anticipate vehicles playing a shrinking role relative to other sources -- because of increasingly stringent new and in-use vehicle emission standards -- recent evidence suggests that the vehicle pollution problem is actually much worse than reported. And thus the actual proportion of vehicle emissions in the urban emission inventory is actually much greater than indicated above. A recent

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

National Research Council study[2] concludes that motor vehicles emit 2-4 *times* as much hydrocarbon and carbon monoxide pollutants as estimated by the U.S. Environmental Protection Agency (USEPA) and California Air Resources Board (CARB).

This problem of emission underestimation has important analytical implications for IVHS implementation -- it indicates that the state of knowledge of emission estimation is poor. Given this poor state of knowledge, it is impossible to determine in a definitive manner the overall emission impact of IVHS. What is possible, and what we do in this paper, is to examine fundamental relationships between travel and emissions that are relevant to IVHS implementation, and explore preliminary evidence of likely IVHS emission impacts. Current research at the University of California, Davis, is aimed at quantifying these effects more precisely.

Overview of Emission Effects

The implementation of IVHS -- where IVHS is defined broadly to include advanced traffic and traveler information systems and automated vehicle control systems, i.e., Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Services (ATIS), Advanced Vehicle-Control Systems (AVCS) -- will have a mixed effect on emissions (and energy use). The two principal effects of IVHS, from an emissions perspective, are the following: 1) increased road capacity, leading to more tripmaking and therefore an emissions increase; and 2) better traffic management, better use of traffic information, and use of automated controls, leading to more efficient travel and smoother flows (less variation in vehicle speed), and therefore an emissions rate decrease. The net effect is impossible to determine at this time because the impact on tripmaking is still uncertain and, as suggested above, the relationship between speed, acceleration, and emissions is poorly understood.

An assessment of changes in vehicle miles traveled (VMT), trips, and congestion are important because they affect emissions from the vehicle activity side -- VMT because emissions are a function of how much a vehicle is used, trips because vehicles emit a large proportion of their emissions during the first few minutes of a trip when the engines are cold, and congestion because slow and erratic speed profiles result in much greater emissions than smooth travel at moderate speeds. Indeed, it is sometimes argued that unrestrained traffic congestion may

2. National Research Council, *Rethinking the Ozone Problem in Urban and Regional Air Pollution* (Washington, D.C.: National Academy Press, 1991).

be "... the single largest contributor to poor air quality and wasteful fuel consumption".[3] That may be true for emissions as we indicate below.

The complex tradeoffs between increased travel demand, changes in congestion delay, and improved smoothness of traffic flow are the subject of this paper. Below, we first examine the effects of IVHS on tripmaking, and then on driving cycles and driving conditions -- in both cases with respect to emission impact.

Impacts On Tripmaking

The use of IVHS information, management, and control technologies could have the following effects on tripmaking:

- Generate more and longer trips because of faster travel times;
- Generate longer trips as a result of diversions;
- Generate shorter trips through access to better information about routes and destinations;
- Shift trips to single occupant vehicles because of faster travel times;
- Shift trips to transit and paratransit if advanced information and traffic management technology is applied to and favors those modes.

In general, the use of better traffic information for travelers will result in shorter and fewer vehicle trips -- because drivers will not get lost, will find parking more easily, will choose the shortest route, and will switch in some cases to transit and paratransit (e.g., carpools and jitneys) -- although it may also result in some longer trips as drivers take detours to avoid accidents and congested routes.

As indicated above, more and better use of real-time traffic and routing information should result in somewhat less vehicle travel. Fully deployed ATMS/ATIS in those areas currently experiencing severe congestion may yield significant improvements. The benefits of traffic monitoring and control can be seen in the City of Los Angeles, where computerized traffic monitoring and control of street signalization and ramp metering systems have: increased average speeds in localized areas by 14%, reduced travel time by 13%, reduced stops by 35%, energy consumption by 12%, and emissions of hydrocarbons and carbon monoxide by 10%.[4] Many believe that these benefits can be readily extended, by providing information and route recommendations to vehicle drivers

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3. Euler, Gary W., "Intelligent Vehicle/Highway Systems: Definitions and Application", *ITE Journal*, (November 1990), pp. 17-22.

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

throughout the system; although, there is not yet an analytical or empirical basis for these claims. Computer simulations for the Santa Monica freeway in Los Angeles indicate that route guidance systems are not likely to provide significant benefits during recurrent congestion conditions, although route guidance systems are likely to yield significant travel time savings during incident-related congestion.[5],[6]

Anticipated reductions in tripmaking believed to result from greater use of information may be somewhat overstated. It can be argued that the provision of perfect information can lead to even higher congestion levels: when individuals make route decisions designed to minimize their travel time, congestion can be increased in some areas, yielding a net increase in total travel time for all trips.[7] Arnott, de Palma and Lindsey argue that providing more information may simply cause drivers to change departure times, condensing the peak period and possibly exacerbating net congestion.[8] Nevertheless, de Palma suggests that it may be possible to reduce total travel times by designing efficient information systems that provide information selectively.[7]

The introduction of automated vehicle controls will have a more predictable effect on tripmaking than information and traffic management. By increasing roadway capacity and making travel easier and faster, automated controls will clearly increase vehicle travel. Fully automated traffic lanes are anticipated to increase freeway traffic flow rates 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.

The increases in vehicle travel resulting from the use of automated controls are related to several phenomena: latent demand for travel, more dispersed land use patterns, longer trips, and shifts to single-occupant vehicles.

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

6. Al-Deek, H., M. Martello, A. May, and W. Sanders, *Potential Benefits of In-Vehicle Information Systems in a Real Freeway Corridor Under Recurring and Incident Induced Congestion*, (UCB-ITS-PRR-88-2), Institute of Transportation Studies, University of California, Berkeley, Berkeley, CA, 1988.

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

8. Arnott, de Palma and Lindsey 1990.

If travel speeds increase and congestion and travel times decrease, then more people will travel more.[9] But how many people will travel how much more? How much latent demand is there for travel on congested urban freeways? The answer is currently not known.[5,10]

One reason individuals will travel more is because they (and employers) want to take advantage of cheaper land, which is usually at the periphery of urban areas. Urban and suburban land use densities are likely to decrease, or at least not increase as much as they would otherwise. There is evidence that as jobs follow individuals to the urban periphery, door-to-door travel times may not necessarily increase; but even if door-to-door travel times do not increase, trip distances and therefore emissions may. Varaiya and Shladover suggest that if the effective speed on new 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.[5] IVHS-induced suburbanization would be consistent with the suburban sprawl patterns that have occurred over the past forty years since the advent of limited-access highways; nonetheless, increased travel will lead to further increases in transportation energy consumption and vehicle emissions.

The question of mode shifts is also difficult to answer definitively. The diversion from higher-occupancy modes, such as buses and carpools, to single-occupant vehicles, would yield an increase in VMT. The impact is difficult to discern, however, without more detailed modeling of interactions between travel time, trip generation, and mode choice.

In summary, the use of some IVHS technologies will result in increased use of vehicles, the use of others will result in less vehicle use, and still others will have mixed effects. Ideally, the magnitude of each of the above effects could be measured.

Indeed, if IVHS is to be seriously considered as an environmentally-benign congestion management tool, tripmaking effects will need to be measured. Unfortunately, at this time, for most of these effects neither theoretical nor empirical evidence exists to make such a determination.

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9. Stafford, Frank P, *Social Benefits of IVHS Systems, Automated Highway/Intelligent Vehicle Systems: Technology and Socioeconomic Aspects*, Warrendale, PA: Society of Automotive Engineers, Inc., 1990, pp. 77-82.

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

Impacts On Driving Cycles And Emissions

Greater use of information and automated controls will lead not only to changes in the number and length of trips, but also to changes in the speed and acceleration profiles of the trips. Changes in speed profiles could prove to have a larger effect on emissions than changes in tripmaking. Speed profiles would change as a result of changes in congestion levels, spatial shifts in congestion, use of automated controls, and shifts in trips between different types of road facilities. For instance, if the number of accidents and the volume of stop-and-go traffic could be reduced, speeds would be higher and smoother. With some IVHS options, spatial shifts in congestion, and therefore speed profiles, would occur in a complex fashion. For instance, if some roads were automated, say freeways, and others were not, then congestion is likely to be spatially pushed onto connecting roads serving the freeways.

Figures 1 to 3 present the relationships between speed and emissions for automobiles, as embodied in the emission model (EMFAC7F) currently used by the CARB. These figures present the multiplier that determines the emission rate for any operating speed, compared to the average emissions for the vehicle class at 16 mph (the baseline emission rate, which is a component of the Federal Test Procedure). Thus, in Figure 1, the carbon monoxide emission rate (grams/mile) at 30 mph is modeled to be roughly 60% of the baseline exhaust emission rate for an average speed of 16 mph. The relatively steep curves suggest that maintaining average speeds at a moderate level -- not too slow nor too fast, say between 20 and 60 mph -- can yield substantial emission reductions. The speed correction factor curves are derived from test cycles that employ varied average speed, but none of the test cycles are characterized by extremely smooth flow. Thus, as we indicated above, the emission benefits IVHS systems that provide smooth flows for moderate to high speeds are probably even greater than indicated by Figures 1 to 3.

Figures 4 and 5 present two speed "traces" used by the USEPA to test motor vehicles. The first is the highway fuel economy test, intended to represent a typical speed profile for vehicles operating on a relatively uncongested urban freeway. The second cycle is the SC36 test cycle, which might represent a vehicle trip along a partially congested nine-mile segment of urban freeway. In practice, speed profiles vary greatly. Current research sponsored by the California Air Resources Board into what speed profiles are typical for various urban areas is likely to help establish baselines for measuring the potential benefits of IVHS systems.

If speed profiles could be smoothed, by reducing stop-and-go driving conditions and increasing free flow speeds, significant emission reduction and fuel economy benefits may be achieved. By eliminating acceleration and deceleration components of a vehicle trip, inertial energy losses are minimized, and emissions associated with these modes of activity are avoided. Although it is still impossible to specify the magnitude of these emission benefits, as explained below, the benefits may be large enough to balance the increased emissions resulting from the increased tripmaking of IVHS.

Earlier it was noted that actual vehicle emissions -- especially reactive organic gases and carbon monoxide -- now appear to be much greater than previously realized.[2] Much of this underestimation may be related to the unrepresentative driving cycle tests (e.g., the codified Federal Test Procedure) used in measuring vehicle emissions and to develop existing emission models.[11,12,13] These tests do not include speeds over 57 mph nor sharp accelerations (i.e. greater than 3.6 mph/sec), both believed to be very high-emitting activities.

Power enrichment (acceleration) and motoring (deceleration) events are discrete vehicle activities capable of producing significant emissions, but are not currently modeled.[14,15,16,17,18,19] Indeed, recent laboratory testing indicates that high acceleration rates are significant contributors to instantaneous emission rates, and that one sharp acceleration may cause as much pollution as does the entire remaining trip.[11]

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

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

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

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

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

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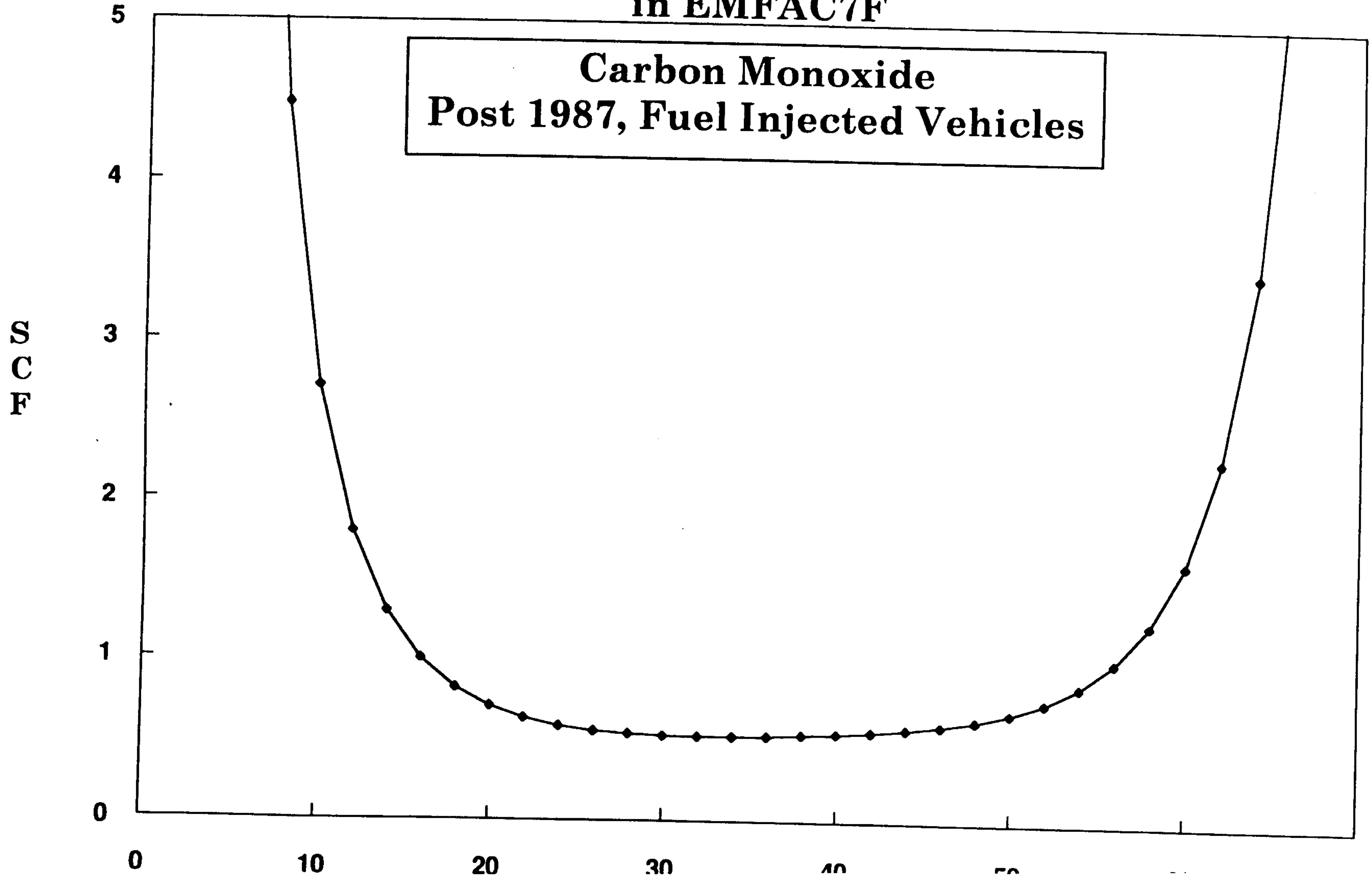
17. Calspan Corporation, *A Study of Emissions from Light-Duty Vehicles in Six Cities, Buffalo, NY*, Prepared for the Environmental Protection Agency (Document #APTD-1497), Office of Mobile Source Air Pollution Control, Ann Arbor, MI, March 1973.

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

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

Figure 1

Speed Correction Factor (Multiple of the Average Emission Rate at 16mph) vs. Average Vehicle Speed in EMFAC7F

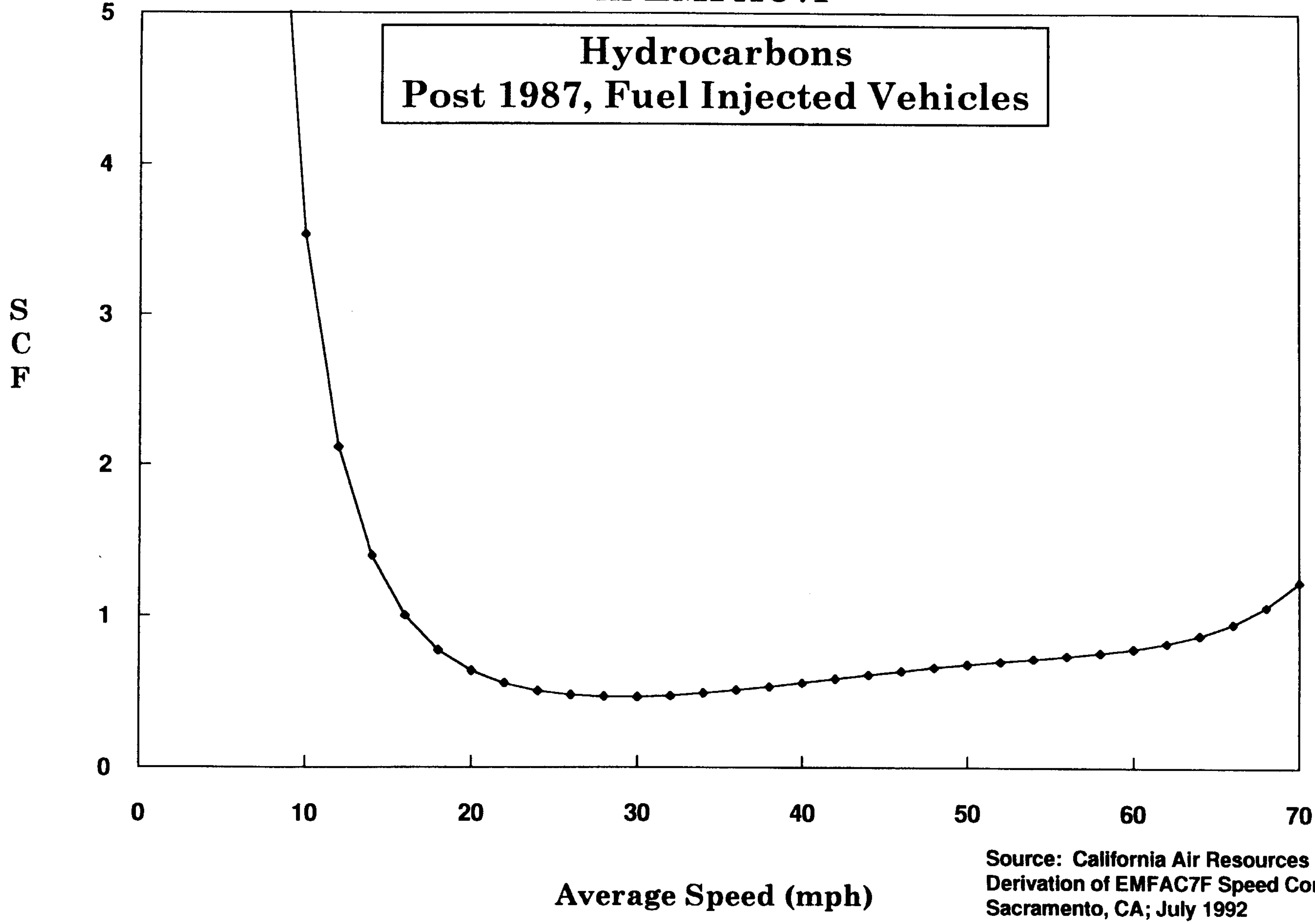


Average Speed (mph)

Derivation of EMFAC7F Speed Correction Factors; Sacramento, CA; July 1992

Figure 2

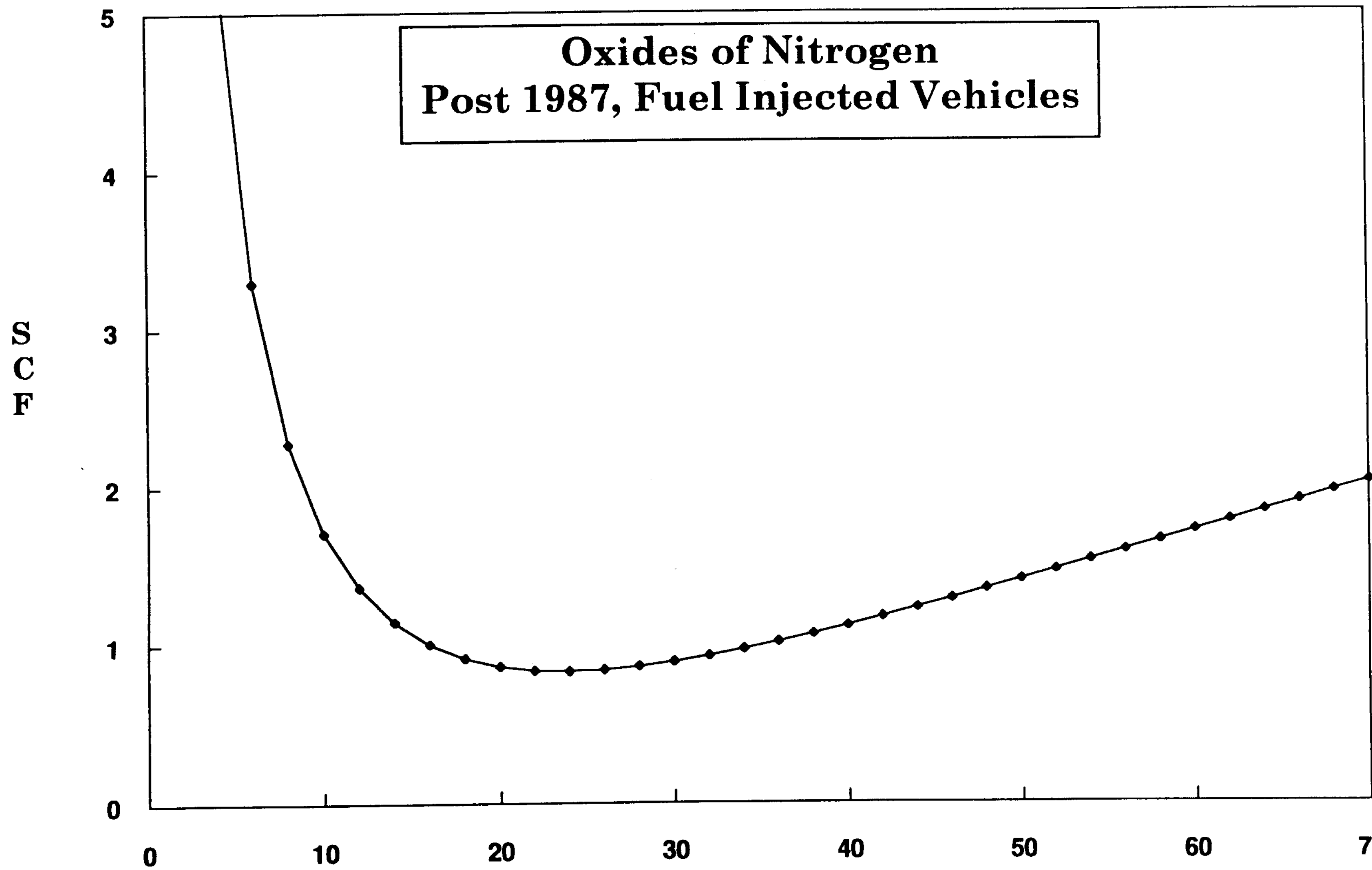
Speed Correction Factor (Multiple of the Average Emission Rate at 16mph) vs. Average Vehicle Speed in EMFAC7F



Source: California Air Resources Board, Derivation of EMFAC7F Speed Correction Factors; Sacramento, CA; July 1992

Figure 3

Speed Correction Factor
(Multiple of the Average Emission Rate at 16mph)
vs. Average Vehicle Speed
in EMFAC7F

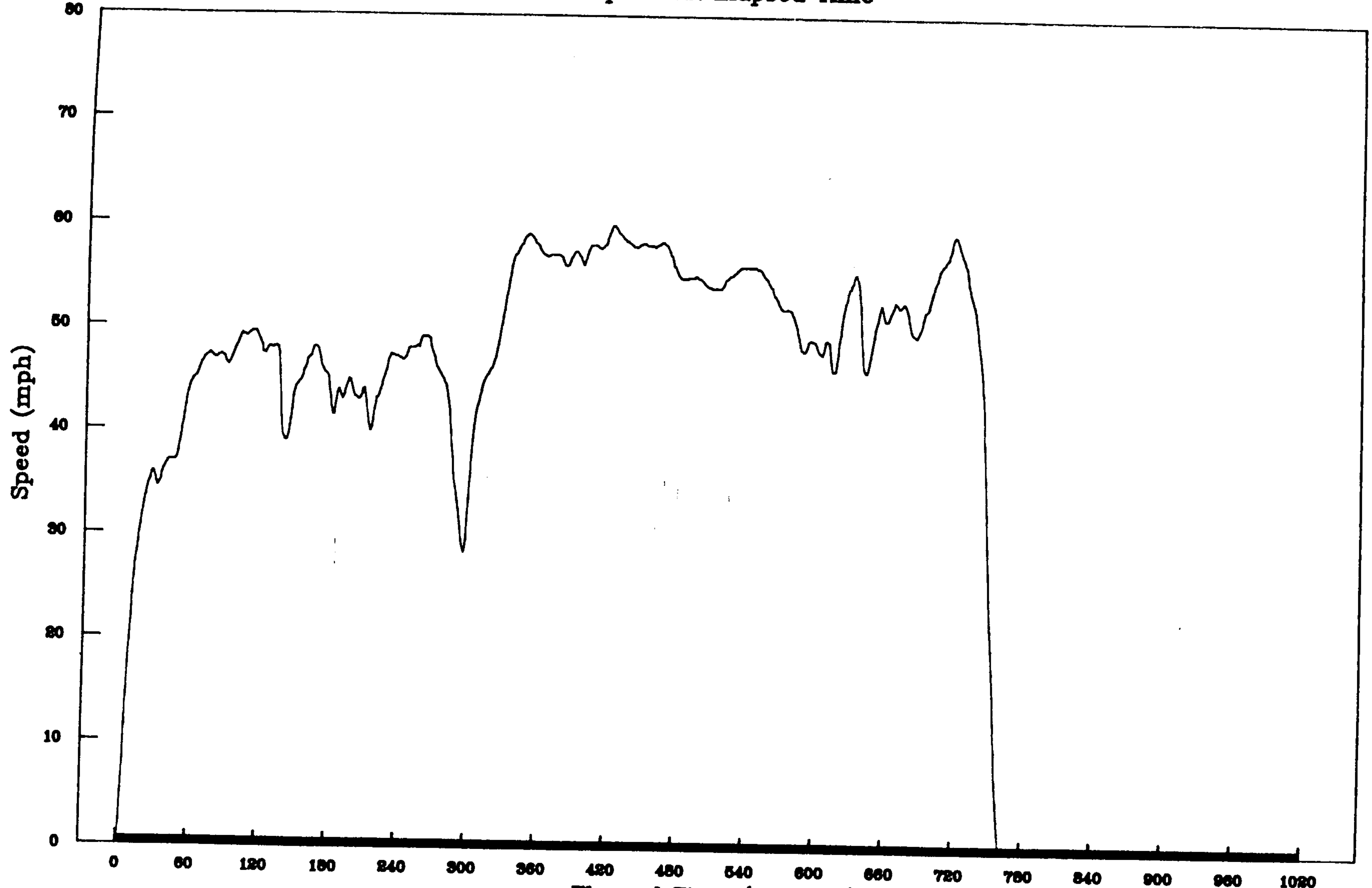


Source: California Air Resources Board,

Figure 4

HIGHWAY FUEL ECONOMY TEST

Speed vs. Elapsed Time

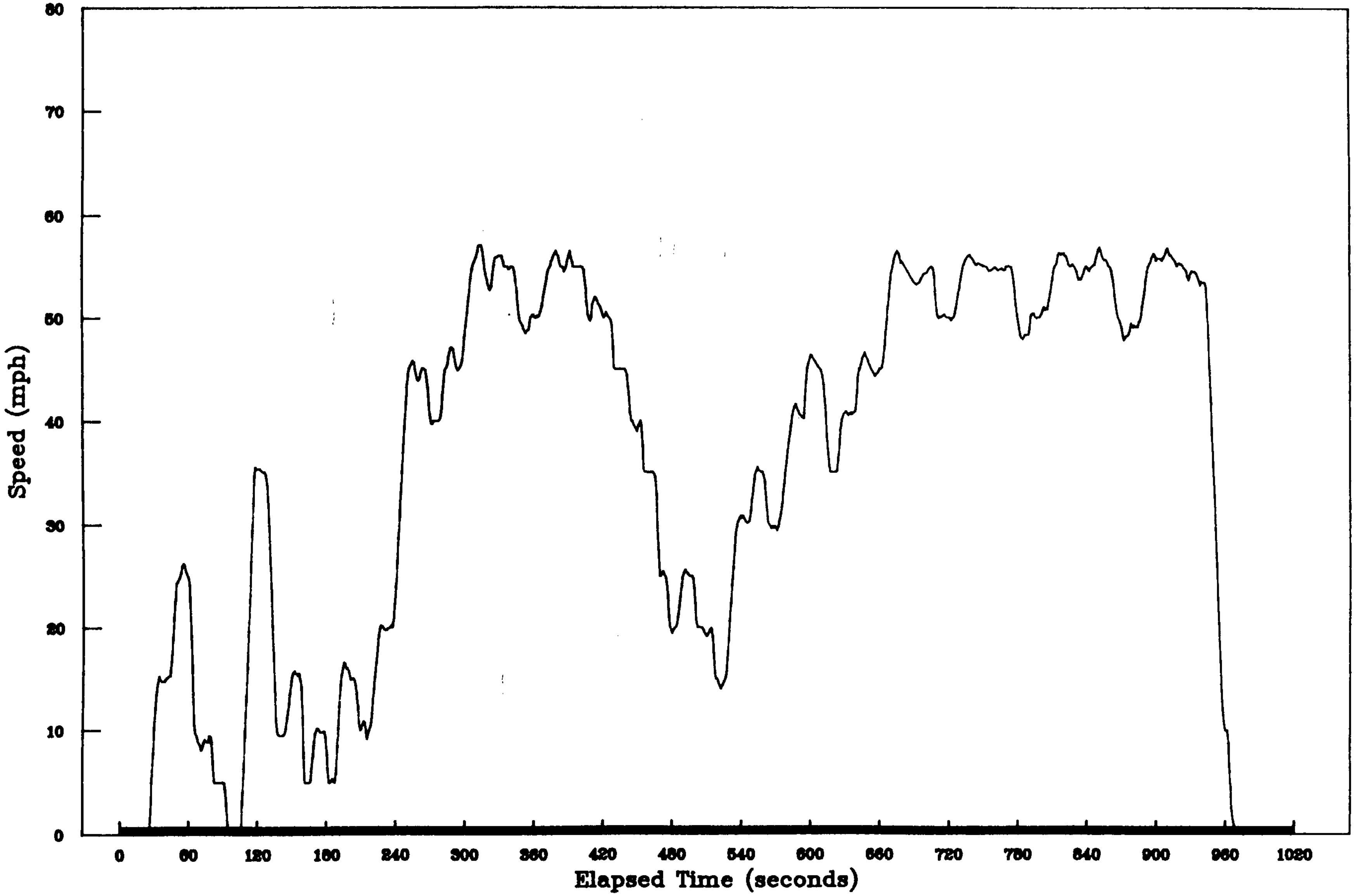


HFET: Hot Transient Test, 765 Seconds, 10.26 Miles, 48.27 MPH Average Cycle Speed

Figure 5

SPEED CYCLE 36

Speed vs. Elapsed Time



SC36: Hot Transient Test, 996 Seconds, 9.92 Miles, 35.85 MPH Average Cycle Speed

Figure 6

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

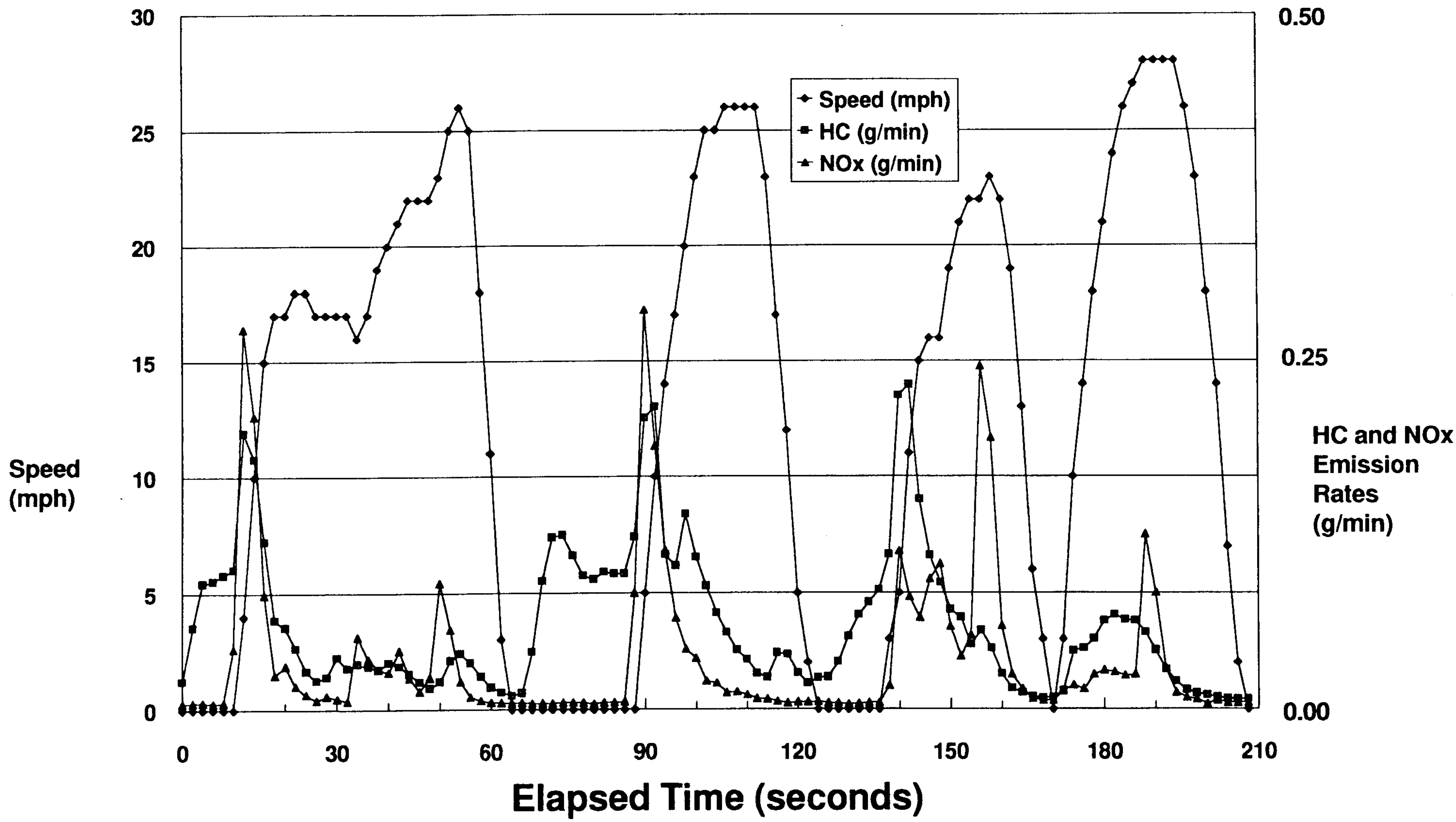
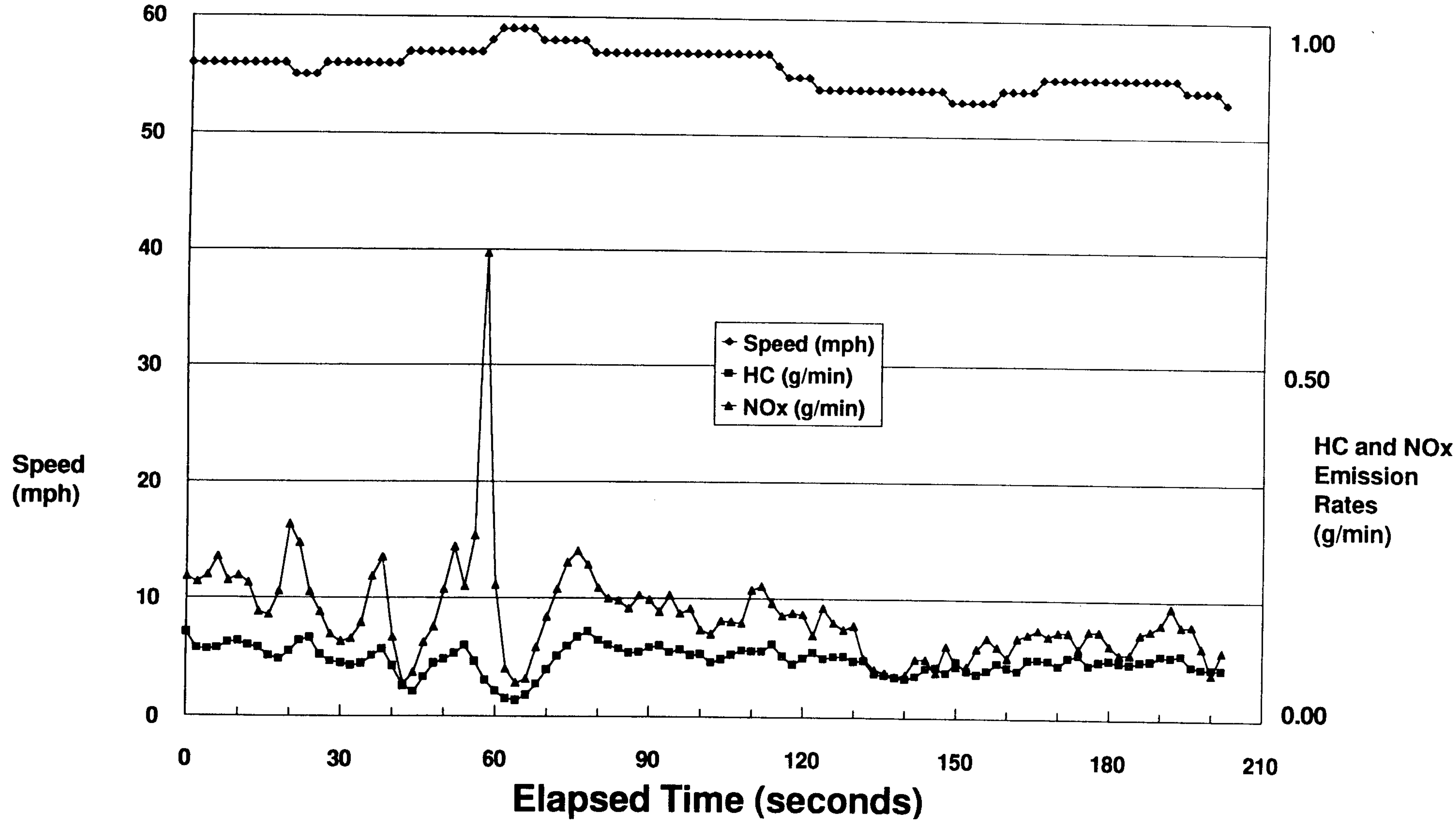


Figure 7

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



Second-by-second monitoring of vehicle exhaust emission data has recently become feasible, and modal testing of motor vehicles is now being conducted both in the laboratory and on the road. The Motor Vehicle Manufacturers Association (MVMA) and Association of International Automobile Manufacturers (AIAM) have recently undertaken an extensive program aimed at assessing in-use motor vehicle emissions. By instrumenting a number of vehicles and monitoring oxygen concentrations before and after the catalyst, data can be used to identify non-stoichiometric, high emission, operating modes. Preliminary results indicate that changes in operating mode can yield on-road emission increases.[12]

Second-by-second laboratory tests also indicate that changes in operating mode yield increased emission rates. Figures 6 and 7 present second-by-second emission estimates for a utility vehicle operating under parts of the Federal Test Procedure (FTP) and the Highway Fuel Economy Test (HFET). Figure 6, representing a portion of the FTP cycle, clearly illustrates that hydrocarbon and oxides of nitrogen "emission puffs" occur, and are likely associated with either the high rates of acceleration or deceleration. (The time delay associated with analytical equipment response is unclear, roughly 4-6 seconds, so associating the specific modal event with the resulting emission puffs is not possible from this test.) Surprisingly, even vehicle operations at a relatively stable high speed flow show some variability in emission rates that may be associated with accelerations and decelerations, even though the rates of acceleration and deceleration at these speeds are low (see Figure 7, representing a portion of the HFET). Research in the area of modal emission rates is ongoing. As new data and analyses become available from vehicle manufacturers and academia, the tools for analyzing the emission rate impacts of IVHS flow smoothing will evolve.

Once the relationships between speed, acceleration, and emissions are better understood, one must specify and then compare the baseline non-IVHS conditions to the future IVHS scenarios. Baseline conditions can be modeled using typical speed profile traces, perhaps similar to Figures 4 and 5, once those profiles are developed for the urban areas in question. Although analysis of IVHS impacts on modal emissions are somewhat speculative at this time, sensitivity analyses can be conducted.

Another critical analytical issue is to specify the microscopic behavior of vehicles operating with IVHS technologies. For instance, two trips may have the same average speed, but very different speed profiles and emissions (e.g., one trip may be traveled at a smooth speed, and another traveled part of the time in stop-and-go congestion and part of the time at high freeway speeds). Expressed more formally, two vehicle trips with the same "average speed" can be composed of significantly different modal characteristics (stops, starts, acceleration rates, time at idle, etc.). As indicated above, the empirical models used to develop the speed correction factors for motor vehicle emission rates do not account for modal operations such as acceleration and deceleration;[20,21,22] research by ourselves and others is aimed at improving modal emissions analyses and integrating that work into network travel models.

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 pushes congestion elsewhere, and does so in a non-linear complex manner. For example, ramp metering causes congestion on the freeway onramp, but reduces congestion on the freeway upstream of the onramp. In an ongoing study at UC Davis using travel demand models for the Sacramento region, Johnston and Page find that on a systemwide level, automation of freeways would result in large reductions in vehicle-hours of delay on the freeways, but large congestion increases on the collectors and arterials that feed into the freeway system.[10] Their model does not yet incorporate land use feedbacks; if it did, one would expect the spatial congestion shift from freeways to arterial and collector roads to be even more exaggerated.

The emission tradeoffs between improved flows on freeway links and degraded flows on non-automated connector surfaces is unclear at this time. Acceleration profiles on automated system access ramps are likely to change, probably increasing significantly, and the acceleration/deceleration profiles of the high speed automated flow are likely to be eliminated through computer control. Unfortunately, modal emission rates and relationships for the future vehicle fleet are relatively unknown at this time, and potential tradeoffs 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.

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20. *Energy and Environmental Analysis, Speed Correction Factors for the Updated Version of MOBILE4*, Arlington, VA. Prepared for the U.S. Environmental Protection Agency, Ann Arbor, MI, Contract No. 68-CO-0065, Work Assignment #3, August 1991.

21. Guensler, Randall, and Simon Washington, *Mobile Source Speed Correction Factors, Phase II: Alternative Model Specifications for EMFAC7F*, Institute of Transportation Studies, University of California, Davis, Davis, CA, forthcoming 1992.

22. Guensler, Randall, and Anne B. Geraghty, *A Transportation/Air Quality Research Agenda for the 1990's*, (91-87.2), Air and Waste Management Association, 84th Annual Meeting Proceedings, Pittsburgh, PA, June 1991.

In any case, limiting congestion analysis to only one improved component of the transportation system, without analyzing impacts both upstream and downstream of the improvement, may result in large positive and negative estimation errors. Thus, the effects of IVHS must be analyzed as a system, before the congestion, and therefore emission, effects of IVHS can be estimated.

Conclusions

The implementation of IVHS technologies could dramatically alter our transportation system. For regulatory, legal, and design reasons, it is urgent that the emission impacts of IVHS be better understood. IVHS encompasses a wide variety of technologies. The implementation of some technologies will increase emissions, others will decrease emissions.

Two sets of analytical activities need to be modified and improved to measure these emissions effects: 1) travel demand models need to be modified and upgraded to consider different traffic flow relationships and to be more sensitive to microscale changes; and 2) emissions models need to represent relationships between speed, acceleration, and emissions more accurately. When these analytical tools are available, various IVHS scenarios can be tested. At this time, it is impossible to determine the net effect of IVHS implementation on air pollutant emissions - especially for internal combustion engine vehicles.

Because emissions from electric vehicles are not significantly affected by modal operations, it is quite probable that the comprehensive IVHS systems of the future will be limited to use by electric vehicles only.