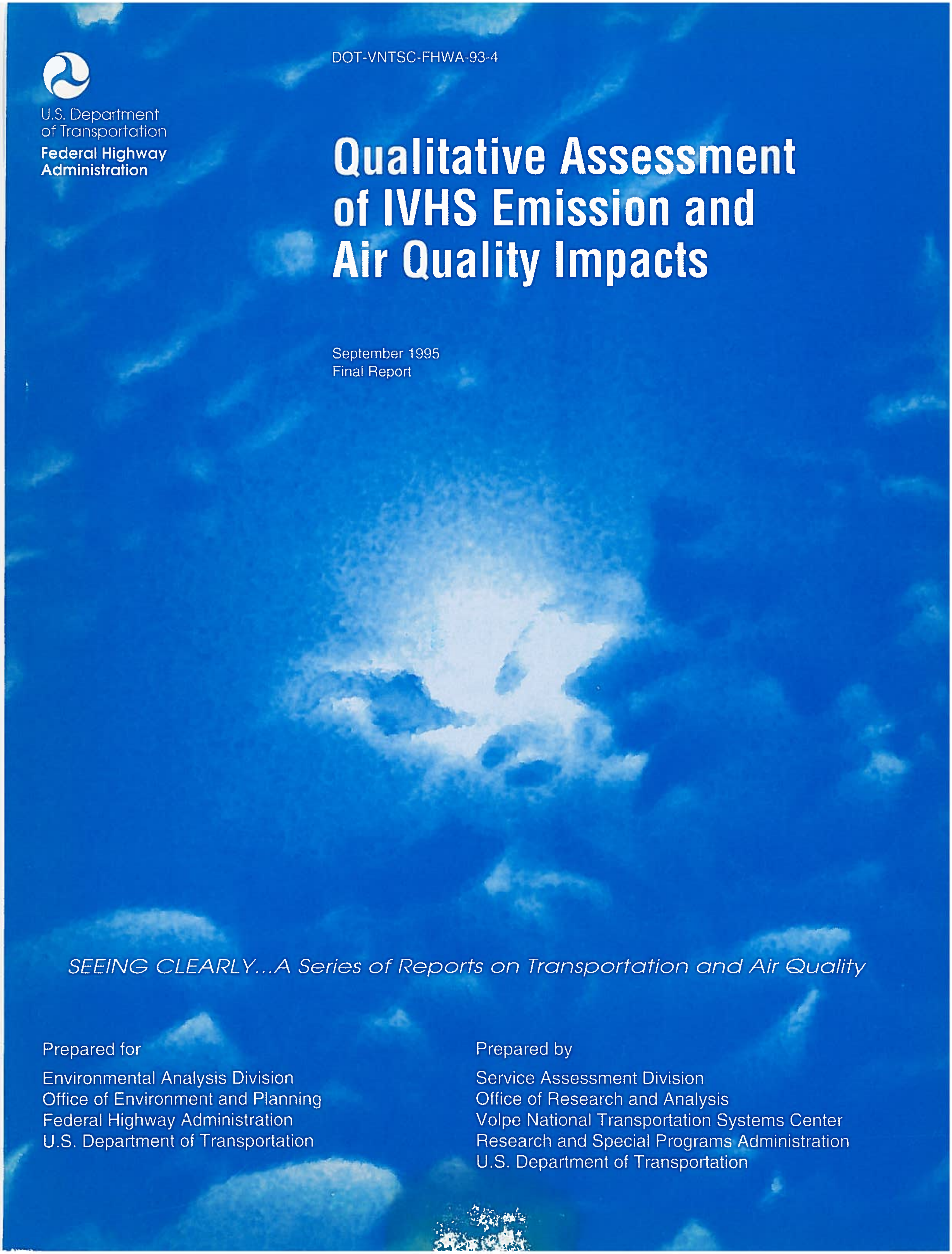


U.S. Department
of Transportation
**Federal Highway
Administration**

DOT-VNTSC-FHWA-93-4

Qualitative Assessment of IVHS Emission and Air Quality Impacts

September 1995
Final Report

SEEING CLEARLY...A Series of Reports on Transportation and Air Quality

Prepared for

Environmental Analysis Division
Office of Environment and Planning
Federal Highway Administration
U.S. Department of Transportation

Prepared by

Service Assessment Division
Office of Research and Analysis
Volpe National Transportation Systems Center
Research and Special Programs Administration
U.S. Department of Transportation

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
September 1995

3. REPORT TYPE AND DATES COVERED
Final Report
March - July 1993

4. TITLE AND SUBTITLE
Qualitative Assessment of IVHS Emission and Air Quality Impacts

5. FUNDING NUMBERS
HW465/H4039

6. AUTHOR(S)
Sergio J. Ostria

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Jack Faucett Associates*
4550 Montgomery Avenue, Suite 800 North
Bethesda, MD 20814

8. PERFORMING ORGANIZATION REPORT NUMBER
DOT-VNTSC-FHWA-93-4

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Federal Highway Administration
Environmental Analysis Division
Office of Environment and Planning
400 7th Street, SW
Washington, DC 20590

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
*on contract to:
U.S. Department of Transportation
Research and Special Programs Administration
Volpe National Transportation Systems Center
Cambridge, MA 02142

12a. DISTRIBUTION/AVAILABILITY STATEMENT

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

To the extent that an Intelligent Vehicle Highway System (IVHS) improves traffic operations and increases the efficiency of the transportation system, emission benefits are expected. However, some policymakers are concerned that by increasing the number of vehicle trips and vehicle miles are traveled, IVHS may also have detrimental emission effects. Detrimental effects would partially offset the emission benefits gained from improved traffic operations and a more efficient transportation system. There is little evidence, however, that IVHS strategies will induce travel to the point that increases in roadway supply brought about by efficiency improvements are quickly and completely absorbed by additional traffic. Only those strategies that can cause wholesale increases in capacity, such as automated highways, are likely to have induced traffic repercussions. Yet, air quality problems associated with traffic congestion, poor vehicle maintenance, wasted travel, and too many vehicle trips may be alleviated by an array of IVHS products, user services, and technologies that improve the level of service on highways, promote mode sifts that favor travel on high occupancy vehicles, and supplement conventional emission control programs such as inspection and maintenance. IVHS may enable emission benefits to be realized without compromising economic development and the public's need and desire for mobility.

14. SUBJECT TERMS
Intelligent Vehicle Highway System (IVHS), emission control, air quality

15. NUMBER OF PAGES
140

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
Unclassified

18. SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

19. SECURITY CLASSIFICATION OF ABSTRACT
Unclassified

20. LIMITATION OF ABSTRACT

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC

LENGTH (APPROXIMATE)

1 inch (in) = 2.5 centimeters (cm)
1 foot (ft) = 30 centimeters (cm)
1 yard (yd) = 0.9 meter (m)
1 mile (mi) = 1.6 kilometers (km)

AREA (APPROXIMATE)

1 square inch (sq in, in^2 = 6.5 square centimeters (cm^2)
1 square foot (sq ft, ft^2 = 0.09 square meter (m$_2$)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)
1 acre = 0.4 hectares (he) = 4,000 square meters (m^2)

MASS - WEIGHT (APPROXIMATE)

1 ounce (oz) = 28 grams (gr)
1 pound (lb) = .45 kilogram (kg)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)

VOLUME (APPROXIMATE)

1 teaspoon (tsp) = 5 milliliters (ml)
1 tablespoon (tbsp) = 15 milliliters (ml)
1 fluid ounce (fl oz) = 30 milliliters (ml)
1 cup (c) = 0.24 liter (1)
1 pint (pt) = 0.47 liter (1)
1 quart (qt) = 0.96 liter (1)
1 gallon (gal) = 3.8 liters (1)
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)

TEMPERATURE (EXACT)

[(x-32)(5/9)] ^{o}F = y ^{o}C

METRIC TO ENGLISH

LENGTH (APPROXIMATE)

1 millimeter (mm) = 0.04 inch (in)
1 centimeter (cm) = 0.4 inch (in)
1 meter (m) = 3.3 feet (ft)
1 meter (m) = 1.1 yards (yd)
1 kilometer (km) = 0.6 mile (mi)

AREA (APPROXIMATE)

1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square meter (m^2) = 1.2 square yeards (sq yd, yd^2)
1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 hectare (he) = 10,000 square meters (m^2) = 2.5 acres

MASS - WEIGHT (APPROXIMATE)

1 gram (gr) = 0.036 ounce (oz)
1 kilogram (kg) = 2.2 pounds (lb)
1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons

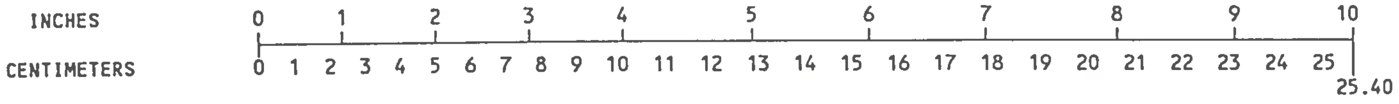
VOLUME (APPROXIMATE)

1 milliliters (ml) = 0.03 fluid ounce (fl oz)
1 liter (1) = 2.1 pints (pt)
1 liter (1) = 1.06 quarts (qt)
1 liter (1) = 0.26 gallon (gal)
1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)

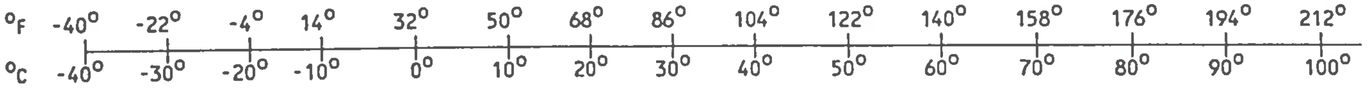
TEMPERATURE (EXACT)

[(9/5) y + 32] ^{o}C = x ^{o}F

QUICK INCH-CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT-CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NBS Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50. SD Catalog No. C13 10286.

PREFACE

Intelligent Vehicle Highway Systems (IVHS) have generated considerable enthusiasm in the transportation community as potential strategies to reduce highway congestion, improve highway safety, enhance the mobility of people and goods, and promote economic productivity in the U.S. transportation system. Until recently, most of this enthusiasm has materialized in the form of research and development efforts concentrating on the technological feasibility of IVHS strategies and other technical issues involved with technology design, implementation, and operation. Section 6054(d) of the 1991 Intermodal Surface Transportation Efficiency Act requires the U.S. Department of Transportation to prepare a report to Congress on the *nontechnical* constraints and barriers to IVHS implementation. Included in the spectrum of nontechnical issues is the potential impact of IVHS technologies on urban air quality. This study assesses qualitatively the potential effects of various IVHS strategies on pollutant emissions from motor vehicles, and presents a framework for further research to develop the tools that are needed to quantify these effects.

TABLE OF CONTENTS

LIST OF TABLES

EXECUTIVE SUMMARY

BACKGROUND AND MOTIVATION

Intelligent Vehicle Highway Systems (IVHS) have generated considerable enthusiasm in the transportation community as potential strategies to reduce highway congestion, improve highway safety, enhance the mobility of people and goods, improve energy efficiency, and reduce the environmental impacts of transportation. But, while many people have promoted the emission and air quality benefits of IVHS, information on the likely impacts of specific IVHS strategies is limited. This study assesses qualitatively the potential emission impacts of IVHS and sets a framework for further research to develop the tools needed to quantify these effects.

Section 6054(d) of the 1991 Intermodal Surface Transportation Efficiency Act requires the U.S. Department of Transportation to prepare a report to Congress regarding *nontechnical* constraints and barriers to IVHS implementation. Included in the spectrum of nontechnical issues is the potential impact of IVHS technologies on urban air quality. The effects of IVHS strategies on vehicle emissions will be determined by the tradeoffs among: 1) possible increases in travel demand due to increases in effective roadway capacity or improvements in level of service; 2) possible decreases in travel demand due to the availability of more complete travel information and to operational improvements in public transportation systems; and 3) reduced vehicle emission *rates* resulting from better traffic management.

The distinct characteristics of the technologies and systems that comprise IVHS preclude performing a travel and emission impact analysis that attempts to generalize effects across all systems. Rather, emission analyses must focus on individual systems or groups of systems that are likely to have similar effects on transportation network performance and vehicle emissions. In this study, the IVHS products, user services, and technologies that are likely to have similar effects on the transportation system and on vehicle emission profiles have been grouped into eight separate technology bundles:

1. ***Traffic and incident management systems*** that can improve the level of service on roadways through efficiency improvements in centralized traffic control, leading to reduced recurrent and nonrecurrent congestion;

2. ***Route guidance systems*** that can provide motorists with information on highway conditions and route availability, thereby improving level of service by diverting traffic from congested roadways to those with excess capacity;

3. ***Accident reduction systems*** that can reduce nonrecurrent congestion by minimizing the likelihood and number of collisions through real time, on-board warnings and automatic control of vehicle operations during emergency situations;

4. ***Vehicle control systems*** that can increase roadway capacity by allowing vehicles traveling on appropriately equipped roadways to operate at closer following distances and at more constant speeds;

5. ***Commercial vehicle inspection systems***, including weigh-in-motion systems and automated safety inspection systems, which can reduce congestion at weigh stations and reduce the number of hot starts experienced by gasoline and diesel heavy-duty vehicles;

6. ***Trip guidance and public transportation systems*** that can increase the utilization of high-occupancy vehicles, promote more efficient trip planning, and enhance the overall efficiency of the transportation system;

7. ***Enabling technologies for travel fees*** that can help to change the price signals sent to users of the transportation system, so that higher charges at peak periods and over longer trips can compensate for the higher congestion and environmental costs of peak period and long distance travel; and

8. ***Emission control enabling technologies*** that can help to mitigate emissions from gross-polluting vehicles and can supplement conventional inspection and maintenance programs.

The analysis of potential emission impacts of these technology bundles is based on three sources of information: 1) an evaluation of relevant studies conducted by academia and government; 2) a video-conference on IVHS and Air Quality involving experts on mobile source emissions, travel demand, and IVHS that took place on March 8, 1993; and 3) results from the National IVHS/Air Quality Workshop held at the South Coast Air Quality Management District in Diamond Bar, California on March 29-30, 1993.

GENERAL RESULTS

To the extent that IVHS improves traffic operations and increases the efficiency of the transportation system, reductions in emissions are expected to occur. However, some policymakers are concerned that by increasing the number of vehicle trips and vehicle miles traveled, IVHS may have the potential to increase motor vehicle emissions. Detrimental effects would partially offset the emission benefits gained from improved traffic operations and a more efficient transportation system. There is little evidence that IVHS strategies will induce sufficient new travel to absorb fully the increases in roadway supply brought about by the efficiency improvements they are designed to produce. Studies have shown that even large capacity enhancement projects may not result in relatively high levels of induced traffic.[1] Coupled with the possibility that out-of-pocket travel costs may increase as a result of IVHS

---

[1] Institute of Transportation Studies, University of California at Berkeley, *The Air Quality Impacts of Urban Highway Expansion: Traffic Generation and Land-Use Impacts*, April 1993.

deployment, the induced travel effects of most IVHS strategies seem likely to be quite small. Only those strategies that can cause significant increases in roadway capacity, such as automated highways, seem likely to result in significant levels of induced traffic.

In the future, the effects on vehicle emissions associated with IVHS technologies that improve traffic flow and level of service may become less significant as the per-mile emission rates of the U.S. vehicle fleet continue to decline in response to tighter new car emission standards, and as the U.S. Environmental Protection Agency and the California Air Resources Board develop new certification processes to control emissions from vehicle operating modes that are not well-represented in current emissions testing procedures. Sharp acceleration (enrichment) and deceleration (motoring) events occur when driving conditions are characterized by congestion, and future vehicle testing procedures and emission controls are likely to be redesigned to reduce vehicle emissions under these operating conditions.

Unlike other IVHS technology bundles, vehicle control systems may have the potential to induce traffic by significantly increasing the vehicle-carrying capacity of some roadways. However, the induced traffic effect of capacity expansion will probably occur over a prolonged period of time, perhaps extending as far as twenty years. However, one major study shows that even after twenty years, traffic induced by capacity expansion is likely to remain below the level that would be required to produce the same relationship of traffic volume to roadway capacity ratios that prevailed prior to a capacity expansion project.[2] Thus any additions to effective roadway capacity produced by advanced IVHS technologies are unlikely to result in a highway system characterized by higher travel volumes and the same level of congestion that prevailed prior to their implementation. Moreover, vehicle control systems that can significantly increase capacity, such as automated highways, will not be implemented for many years. By that time, emissions from motor vehicles may be much lower than current levels as cleaner vehicles continue to be cycled into the fleet, fuel specifications change (e.g., reformulated gasoline and alternative fuels), and advanced emission control technologies (e.g., electrically heated catalysts) become feasible.

---

[2] Ibid.

The potential travel, traffic, and emission impacts of the various technology bundles are summarized in the tables at the end of this section. Table E-1 presents the potential short-term, corridor-level impacts, while table E-2 presents potential short-term, regional-level impacts. Table E-3 presents potential long-term, corridor-level impacts, and finally, table E-4 provides the potential long-term, regional-level impacts.

FURTHER RESEARCH

The development of quantitative IVHS emission impact estimates will require extensive research and data collection to support both development of model-based estimation and direct measurement of those impacts. The areas that need immediate attention are discussed below.

- *Mobile Source Emissions Modeling:* Changes in the speed profiles of vehicle trips cannot be accounted for accurately in current versions of MOBILE and EMFAC. The baseline exhaust emissions data contained in both models are based on a standardized driving cycle that was originally developed to duplicate the speed-time profile of a road route in the Los Angeles metropolitan area in the late 1960s. New drive cycles need to be constructed to represent a wide variety of roadway functional classes and driving situations.

- *Travel Demand Modeling:* To quantify the emission effects of IVHS deployment, models of trip generation, trip distribution, mode choice, and network assignment must be improved. For instance, the underlying relationship between land use and transportation requires further research, as does the impact of IVHS on trip chaining and the ability of transportation demand models to account for this phenomenon. Induced travel demand effects of IVHS deployment also need to be better understood and modeled in the trip generation framework.

- *Traffic Simulation Modeling:* The vision of IVHS planners is to develop integrated networks of highways, freeways, and urban roads. Simulating the potential effects of such extensive integration requires models that simulate traffic flow under an integrated system, rather than current models that simulate traffic at the single-corridor level. New models must be able to accept and interpret real time traffic data received from surveillance points along the network, and to represent real time demand and supply conditions along a corridor or over the entire regional network. In this manner, interactive signal coordination systems can be tested and eventually deployed, and the full efficiency effects and corresponding emission impacts of traffic and incident management systems and route guidance systems can be better assessed.

- *Travel Behavior Analysis:* The effectiveness of IVHS in reducing congestion, promoting high-occupancy vehicle travel, improving safety, and increasing the overall efficiency of the movement of people and goods on the surface transportation system largely depends on behavioral changes on the part of system users that are caused by advanced technologies, products, and services. While it is evident that imperfect information on traffic conditions, for example, has contributed to the congestion problems currently faced by many metropolitan areas across the country, the degree to which travelers will make effective use of improved travel information for their trip, route, and mode decisions is not well understood.

- *Operational Field Tests:* Operational field tests currently underway will help to determine the operational reliability of IVHS actions, their scope and timing of implementation, and their likely impacts on traffic operations. However, these operational field tests have generally not been planned to directly assess the environmental effects of actions being tested. Operational field tests should explore opportunities presented by technological developments in measurement instrumentation to obtain direct estimates of the emission and air quality ramifications of various IVHS actions.

Table E-1. Potential short-term, corridor-level impacts of IVHS technology bundles.

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	Hydrocarbon Emissions	Carbon Monoxide Emissions	Oxides of Nitrogen Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Uncertain	Uncertain	Uncertain
Route Guidance Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Commercial Vehicle Inspection Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

- The short term is defined in this study to be from 2000 to 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high-occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips, and those impacts that reflect mode shifts from high-occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or very small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

Table E-2. Potential short-term, regional-level impacts of IVHS technology bundles.

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	Hydrocarbon Emissions	Carbon Monoxide Emissions	Oxides of Nitrogen Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Route Guidance Systems	Positive	Positive	Uncertain	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Commercial Vehicle Inspection Systems	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain	Uncertain
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

- The short term is defined in this study to be from 2000 to 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high-occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips, and those impacts that reflect mode shifts from high-occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or very small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

Table E-3. Potential long-term, corridor-level impacts of IVHS technology bundles.

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	Hydrocarbon Emissions	Carbon Monoxide Emissions	Oxides of Nitrogen Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Uncertain	Uncertain	Uncertain
Route Guidance Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Positive	Insignificant	Negative	Insignificant	Uncertain	Uncertain	Uncertain
Commercial Vehicle Inspection Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

- The long term is defined in this study to be beyond 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high-occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips, and those impacts that reflect mode shifts from high-occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or very small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

Table E-4. Potential long-term, regional-level impacts of IVHS technology bundles.

	Traffic Flow	Vehicle Trips	Trip Distance	Mode Shifts	Hydrocarbon Emissions	Carbon Monoxide Emissions	Oxides of Nitrogen Emissions
Traffic and Incident Management Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Route Guidance Systems	Positive	Positive	Uncertain	Insignificant	Positive	Positive	Uncertain
Accident Reduction Systems	Positive	Insignificant	Insignificant	Insignificant	Positive	Positive	Negative
Vehicle Control Systems	Positive	Uncertain	Negative	Insignificant	Uncertain	Uncertain	Uncertain
Commercial Vehicle Inspection Systems	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant
Trip Guidance and Public Transportation Systems	Positive	Positive	Insignificant	Positive	Positive	Positive	Uncertain
Enabling Technologies for Travel Fees	Positive	Positive	Positive	Positive	Positive	Positive	Positive
Emission Control Enabling Technologies	Insignificant	Insignificant	Insignificant	Insignificant	Positive	Positive	Positive

- The long term is defined in this study to be beyond 2010.
- Positive impacts reflect improvements in traffic flow, reductions in vehicle trips or trip distance, or mode shifts from single occupancy vehicles to high-occupancy vehicles.
- Negative impacts reflect increases in congestion, vehicle trips, and those impacts that reflect mode shifts from high-occupancy vehicles to single occupancy vehicles.
- Insignificant impacts reflect no changes (or very small changes) in traffic flow, the number of vehicle trips, trip distance, or mode shifts.
- Uncertain impacts are those for which changes in traffic flow, tripmaking, trip distance, or mode cannot be even qualitatively assessed given the current state of knowledge.

1. INTRODUCTION

Intelligent Vehicle Highway Systems (IVHS) have generated considerable enthusiasm in the transportation community as potential strategies to reduce highway congestion, improve highway safety, enhance the mobility of people and goods, and promote economic productivity in the country's transportation system.[3] Until recently, most of this enthusiasm has materialized in research and development efforts concentrating on the technological feasibility of IVHS strategies and other technical issues involved with technology design, implementation, and operation. Section 6054(d) of the 1991 Intermodal Surface Transportation Efficiency Act requires the U.S. Department of Transportation to prepare a report to Congress on the *nontechnical* constraints and barriers to IVHS implementation. Included in the spectrum of nontechnical issues is the potential impact of IVHS technologies on urban air quality. While IVHS technologies are expected to alleviate urban traffic congestion, the resulting improvement in travel speeds could lead to further increases in the number of vehicle trips and the number of total vehicle miles traveled. On the other hand, by reducing congestion and improving traffic flow, advances in traffic management are likely to decrease emission rates per vehicle-mile of travel.

Some policymakers are concerned that the detrimental emission effects of increasing the number of vehicle trips and vehicle miles traveled may partially offset the potential emission benefits of improved traffic operations and system efficiencies that are brought about by IVHS. In response to this concern, activity has begun on two fronts: 1) assessing the impacts of IVHS technologies on emissions and air quality; and 2) assessing the role of IVHS in *enabling* the implementation of transportation control strategies, such as road pricing, congestion pricing, or emission fees. While state-of-the-art modeling techniques and lack of field data on IVHS effects constrain quantitative assessments of these impacts, preliminary qualitative estimates can be constructed based on the likely travel and emission effects of IVHS technologies. Qualitative analyses can help identify the types of tools necessary to evaluate reliably the travel demand and emission consequences of specific intelligent vehicle highway systems.

---

[3] This is enhanced by the significant funding for IVHS research and development provided in the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). For example, the ISTEA Corridors Program earmarks $501 million over six years for the development and deployment of advanced traffic management systems.

The objectives of this study are to assess qualitatively the potential effects of various IVHS strategies and to outline a framework for further research to develop the tools that are needed to quantify the effects. Specifically, this report attempts to:

- Identify and define the representative sample of IVHS strategies that are likely to affect travel demand and emissions;
- Determine the likely travel and emission effects of these technologies; and
- Identify the means necessary to develop quantitative evaluations of the environmental implications of IVHS.

Section 2 of this report presents the methodology that is employed in this study. First, an overview of the major issues defining the possible relationships between IVHS, travel, and emissions is provided. Then, individual technologies or systems are grouped into bundles that address similar aspects of the transportation system, and are thus likely to have similar travel and emission repercussions. Finally, the analytical framework is outlined with respect to geographic scale (e.g., corridor versus regional impacts), timing (e.g., short-term versus long-term impacts), and comparison baseline (e.g., with or without changes in the composition of the vehicle fleet as a direct result of IVHS).

Section 3 presents our assessment of the potential travel and emission impacts of each technology bundle. These assessments are based on three sources of information: 1) an evaluation of relevant studies conducted within academia and government; 2) a video-conference on IVHS and air quality involving experts on mobile source emissions, travel demand, and IVHS that took place on March 8, 1993; and 3) results from the National IVHS/Air Quality Workshop held at the South Coast Air Quality Management District in Diamond Bar, California on March 29-30, 1993. For each technology bundle, the analysis begins with a detailed definition of the bundle in terms of its likely users, its location in the transportation system, the basic mechanics of its operation, its likely operational reliability, and its expected market penetration in both the short term and long term. Following this background discussion, the expected type and magnitude of the travel and emission impacts are presented.

Finally, the specific analytical tools that will be necessary to quantify the travel and emission impacts of IVHS are discussed in section 4. The discussion focuses on the theoretical and modeling advances that are required from the transportation demand, traffic simulation, and mobile source emission modeling communities, and on the types of data that will be needed to support modeling advances within the context of IVHS.

2. STUDY METHODOLOGY

The concept of IVHS centers on the deployment of advanced communications technology to improve the efficiency of the transportation system not only by increasing the capacity of existing infrastructure, but also by providing real time information to travelers to better inform their decisions regarding the frequency, scheduling, and routing of specific trips. IVHS America[4] has classified the various technologies and systems that comprise IVHS into the following six functional areas:

1. *Advanced traffic management systems* include a group of techniques for controlling and optimizing traffic flows on road networks. These techniques employ sensing devices in the road or on the vehicle to measure traffic flows, computer models to simulate that flow and anticipate changes in it, and control strategies to manage traffic through the centralized control of traffic signals and freeway access.

2. *Advanced traveler information systems* provide travelers with information on congestion, navigation and location, traffic conditions, alternate routes, and transit schedules. These systems use visual and auditory presentations to inform drivers of their current locations, aid them in planning their routes, and help guide them to desired destinations.

3. *Commercial vehicle operations* include technologies to improve the efficiency of freight and fleet control by private fleet operators, transit, police, fire, and ambulance fleets. These technologies also facilitate regulation of commercial traffic through, for example, vehicle weigh-in-motion, automated safety inspections, and automatic credentials checking.

---

[4] IVHS America is a nonprofit educational and scientific association incorporated in August 1990 to plan, promote, and coordinate the development and deployment of IVHS in the United States.

4. *Advanced vehicle control systems* include individual vehicle controls, cooperative driver-vehicle-highway systems, and, eventually, full automation on certain roadways. These systems combine sensors, computers, and control systems in vehicles and the highway infrastructure to warn and assist drivers or to intervene in the driving task.

5. *Advanced public transportation systems* apply advanced electronic technologies to the deployment and operation of high-occupancy, shared-ride vehicles, including buses, rail, and paratransit vehicles. Applying these technologies will improve the efficiency and attractiveness of high-occupancy travel modes, thereby presumably increasing ridership.

6. *Advanced rural transportation systems* is a relatively new functional area that has been added by IVHS America in recognition of the need to account for rural transportation in the development and application of advanced transportation systems and technologies. The types of products and user services that comprise this functional area have yet to be determined.

The underlying electronic, computer, communications, and control technologies embedded in advanced transportation systems are the foundations of the six functional areas that comprise IVHS. These technologies combine to form a number of products and user services distinct to each functional area, and it is these products and services that will eventually bring about the transportation system efficiencies that are expected to result from deploying specific IVHS technologies. Consequently, an understanding of the products and services that comprise each functional area is a necessary prerequisite to an emissions impact assessment of IVHS. Appendix A describes the systems that define the functional areas of IVHS as they have been described in the literature.[5]

---

[5] Much of the discussion presented in appendix A is drawn from the following reports and studies:
IVHS America, *Strategic Plan for IVHS in the United States*, May 1992.
NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Congestion*, December 1991.
MOBILITY 2000, *Proceedings of a National Workshop on IVHS*, March 1990.

As the conceptual framework of IVHS has developed, various goals for its implementation have also evolved. These goals include: reduced congestion, improved economic productivity, increased personal mobility, improved safety, reduced environmental impact, improved energy efficiency, and the development of a competitive U.S. IVHS industry. While many people have promoted the emission and air quality benefits of IVHS, there is in fact only limited research and information available on the likely impacts of specific IVHS strategies. This section presents the methodology that has been employed in this study to arrive at qualitative estimates of these likely impacts.

Section 2.1 provides an overview of those issues that bear upon the relationships among IVHS, travel, and emissions. These issues were identified from the same sources of information used to formulate the potential travel and emission impacts that are presented in section 3, including a comprehensive literature review, a video-conference involving experts on travel demand, mobile source emissions, and IVHS, and a national workshop on IVHS and air quality. A selected list of literature is presented in appendix D, while brief descriptions of the video-conference and national workshop, along with corresponding lists of participants and agendas, are provided in appendices B and C, respectively.[6]

In order to evaluate the environmental effects of IVHS it was necessary to regroup IVHS actions into technology bundles that best serve a travel and emission analysis. Section 2.2 introduces the technology bundles that are the focus of the analyses in section 3.

Finally, section 2.3 presents the analytical framework that was used to assess qualitatively the travel and emission impacts of IVHS deployment, including the impact classification scheme, the time and geographic scales of analysis, and the baseline used for comparison.

---

[6] Where relevant, *abbreviated* references are also footnoted in the text. The reader will find more complete references in appendix D.

2.1 OVERVIEW OF ISSUES

The potential effects of IVHS strategies on vehicle emissions depend on the relative magnitude of potential increases in travel demand due to expansion of effective roadway capacity or improvements in level of service, possible reductions in travel demand due to more complete travel information and improvements in public transportation systems, and reduced vehicle emission *rates* resulting from better traffic management.[7] On the one hand, IVHS could *increase* travel demand, as faster travel speeds increase the number or length of trips, shift trips from high-occupancy vehicles to single occupancy vehicles, or induce some entirely new trips.[8] On the other hand, IVHS could *reduce* automobile travel by increasing the attractiveness of mass transit and ridesharing, causing travelers to cancel or delay trips during poor traffic conditions, and reducing the length of trips through route guidance, or reducing wasted travel produced by navigational errors.[9] IVHS will also enable more efficient use of the existing system infrastructure capacity by reducing recurrent and nonrecurrent congestion, and, by improving traffic flow, all of which are likely to reduce average vehicle emission rates.

Insofar as IVHS does change the number of trips taken at the corridor or regional level, this change will influence total mobile source emissions. The possible effect of changes in the

---

[7] In general, the *capacity* of a facility is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane or roadway during a given time period under prevailing roadway, traffic, and control conditions. The time period used in most capacity analysis is 15 minutes, which is considered to be the shortest interval during which stable flow exists. Roadway conditions refer to the geometric characteristics of the street or highway. Traffic conditions refer to the characteristics of the traffic stream using the facility. Control conditions refer to the types and specific design of control devices and traffic regulations using the facility.

The concept of *levels of service* is defined as a qualitative measure describing operational conditions within a traffic stream, and their perception by motorists and/or passengers. A level of service definition generally describes these conditions in terms of such factors as speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience, and safety.

The reader is referred to the *Highway Capacity Manual, Special Report 209* prepared by the Transportation Research Board in 1985 and revised in May 1992 for a more detailed and comprehensive description of terms.

[8] Daniel Sperling, Randall Guensler, Dorriah Page and Simon Washington, *Air Quality Impacts of IVHS: An Initial Review*, 1992.

[9] Steven E. Shladover, *Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

number of vehicle trips is augmented by the emission consequences of cold starts. Under cold start conditions, when the vehicle has been turned off for some time and the catalytic converter is cold, hydrocarbon and carbon monoxide emissions are significantly higher than after the vehicle is warmed up. This occurs partly because catalytic emission control systems do not provide full control until they reach a given operating temperature. In addition, richer fuel-air mixtures must be provided to the cylinders under cold operating conditions to ensure proper engine starting and performance, and the excess fuel cannot be completely burned in the combustion process because of the lack of sufficient oxygen present in the engine's cylinder.[10]

For a typical engine-on to engine-off trip, emissions under cold start conditions have been estimated to account for approximately 50 to 70 percent of total trip emissions (for 1981 and later model year vehicles).[11] As a result, IVHS strategies that change the number of automobile trips may have effects on overall vehicle emission that are disproportionate to their effects on total vehicle miles traveled (VMT).

As with the number of trips taken in a given area over a specified time frame, changes in trip distance can also have important emission repercussions. IVHS strategies such as route guidance systems may affect the length of certain types of trips. Commuter trips, for example, may be lengthened as motorists react to the availability of more complete information by taking longer routes to avoid heavily congested corridors. Similarly, full implementation of advanced vehicle control systems may increase travel, thereby inducing households and firms to locate farther away from each other. In contrast, route guidance systems may decrease trip distances for recreation trips or other types of trips that require travelers to find their desired destinations. In these cases, trip distances would be shortened as drivers reduced the amount of wasted travel resulting from imperfect information. Together, these changes in the number of vehicle trips and in the average distance of each trip will account for changes in total vehicle miles traveled.

---

[10] Sierra Research, Inc., *Evaluation of "MOBILE" Vehicle Emissions Model*, April 1993.

[11] EPA considers a cold start for a catalyst-equipped vehicle to occur after the engine has been turned off for one hour. For non-catalyst vehicles, a four-hour engine off period distinguishes a cold start. In between these periods, engine-on events are considered hot starts. Moreover, the duration of cold start operating conditions under the federal test procedure (FTP) is by definition 505 seconds (i.e., the "Bag 1" portion), after which the vehicle is operating under stabilized conditions.

Implementation of certain IVHS strategies may also have repercussions for traffic operations, and thus for the speed and acceleration profiles of trips. Unlike changes in trip frequencies and lengths, which affect overall mobile source emissions, changes in traffic flow may influence the emission *rates* of vehicles by changing the sequence of operating modes in which veahicles function. For example, by reducing congestion, IVHS is likely to smooth out traffic flow along a particular corridor. Smoother traffic flows may alter a vehicle's operational characteristics by reducing speed variations, thereby altering both the emissions profile and cumulative emissions produced by a given trip.

Power enrichment (acceleration) and motoring (deceleration) events are discrete vehicle operating modes that are each capable of producing significant emissions. High vehicle emissions during rapid vehicle acceleration result from enrichment of the engine's fuel-air mixture, which achieves maximum engine power but creates high levels of unburned hydrocarbons and carbon monoxide.[12] Recent laboratory tests indicate that high acceleration rates are significant contributors to instantaneous emission rates, and that in some cases one sharp acceleration can cause as much pollution as the entire remaining trip.[13]

Less well known are the emissions created during vehicle deceleration, which are caused by a rapid closing of the engine throttle. During rapid throttle closing, emissions of unburned hydrocarbons and carbon monoxide are high because combustion is poor. Most current vehicles with fuel injection systems stop the addition of fuel during vehicle decelerations, but the resulting rapid throttle closing still causes a "spike" of unburned hydrocarbons and carbon monoxide.

The number of episodes of power enrichment and rapid throttle closing, as well as the emission they generate, are a function of the smoothness of traffic flow. Vehicles operating in unsteady

---

[12] Oxides of nitrogen, NO_x, are inherently low during this type of engine operation, although increases may be seen in vehicles with highly efficient NO_x control.

[13] Daniel Sperling, Randall Guensler, Dorriah Page and Simon Washington, *Air Quality Impacts of IVHS: An Initial Review*, 1992.

traffic may experience numerous rapid throttle closing events without coming to a full stop, or even without sharp vehicle decelerations. Together with the accelerations interspersed among these rapid throttle closing events, vehicles experience high levels of emissions under stop-and-go or other variable speed conditions. Driver habits may also influence the number of throttle closing and enrichment events. Drivers who anticipate speed changes and plan for them will likely cause fewer rapid power enrichment and motoring events than aggressive drivers who do not attempt to drive smoothly. Therefore, IVHS strategies that decrease speed variation by improving traffic flow may help to reduce the per-mile emissions rates of vehicles, possibly offsetting the effect of increased trip distance on total emissions.

The emissions of federally and California-certified new vehicles are determined by subjecting sample vehicle to the federal test procedure (FTP). Recent criticism of the FTP led Congress, as part of the Clean Air Act Amendments of 1990, to require the U.S. Environmental Protection Agency to evaluate the FTP and to determine whether it is still an appropriate test for vehicle emissions certification. A revised FTP could result in new motor vehicles that better control emissions during acceleration and deceleration, as well as during high-speed travel. If this occurs, the potential IVHS emission benefits that result from smoother traffic flow would be reduced.

Certain IVHS technologies will undoubtedly improve the level of service at which roadways operate by improving the efficiency of traffic controls, reducing congestion, and promoting better interface between the road and the vehicle. Various other IVHS technologies are also well suited for enhancing the effectiveness and logistics of transportation demand management programs, particularly road pricing schemes. In these situations, the emissions and air quality impacts of IVHS depend less on the technologies themselves than upon how extensively and effectively they are used to manage travel patterns. This fundamental distinction between the direct travel impacts of IVHS actions and the use of other IVHS technologies to facilitate non-technological approaches to demand management was the center of much discussion in the recent National IVHS/Air Quality Workshop held in Diamond Bar, California (see appendix D).

Motorists currently pay for road travel through excise taxes on fuel, oil, and certain equipment, through vehicle operating costs, and through other taxes that are used to fund transportation projects. However, the complete costs of each vehicle's use of roads and highways is not reflected in these payments. Certain IVHS technologies can play an integral role in programs that attempt to change the price signals sent to users of the transportation system. Through automatic vehicle identification, for example, road use fees can be set to vary over time and distance so that higher charges can be levied at peak periods and over longer trips, thereby compensating for the higher congestion and environmental costs of peak period and long distance travel. The role of IVHS as an enabling technology for the implementation of road pricing strategies (such as congestion pricing) is one that demands further attention and analysis.

On-board engine diagnostics, which monitor a vehicle's emissions, and remote sensing devices, which measure exhaust pollutants from moving vehicles, are examples of IVHS technologies that can facilitate the identification, repair, or removal from service of gross-emitting vehicles, thus supplementing conventional control strategies such as vehicle inspection and maintenance programs. According to the National Research Council, fewer than ten percent of vehicles account for approximately sixty percent of the ozone-forming and carbon monoxide emissions attributable to mobile sources (although vehicles that are gross emitters of one of these pollutants are not necessarily responsible for high emissions of others).[14] Since mobile sources account for nearly two-thirds of the total smog-producing emissions in a few U.S. metropolitan areas, it follows that only ten percent of the vehicles operating in many regions of the country may account for more than one-third of their overall smog.[15] Therefore, identifying these gross emitters and repairing them or removing them from the fleet can result in significant emission and air quality benefits.

Based on the discussions presented above, the possible effects of deploying IVHS on emissions can be summarized as follows:

---

[14] National Research Council, *Rethinking the Ozone Problem in Urban and Regional Air Pollution*, 1991.

[15] Lamont C. Hempel, *Exploring the Transportation-Environmental Nexus: The Role of IVHS in Reducing Urban Air Pollution Caused by Congestion and Super-Emitting Vehicles*, March 1993.

- Some systems are likely to improve the level of service at which certain road and highway facilities operate, by improving traffic flow and reducing congestion. Sufficiently widespread improvements in level of service provided by the highway system could lead to increases in the number of vehicle trips, the number of cold starts, and the level of mobile source emissions. Similarly, advanced vehicle control systems may increase effective roadway capacity, and the resulting increase in travel speeds could lead to increases in travel and in the vehicle emissions associated with it.

- Other types of systems may influence trip lengths; for example, those strategies that divert trips from congested corridors to corridors with excess capacity may increase trip distances and emission levels, depending on the net effects of longer trip distances and smoother traffic flow on total trip emissions. On the other hand, systems that provide more complete information to travelers who are uncertain about exact trip destinations or specific routes may reduce trip distances, thereby reducing the emissions they generate.

- Various systems will promote better traffic management, leading to more efficient traffic control, reduced congestion, and smoother traffic flows. Smoother traffic flows may reduce emission rates and total trip emissions. Likewise, vehicle control strategies which minimize the occurrence of acceleration and deceleration events can reduce the frequency with which vehicles operating in modes that produce high emissions.

- Systems that have the effect of shifting trips from single occupancy vehicles to high-occupancy vehicles, or that reduce travel demand by means of pricing programs, are likely to have positive emissions and air quality ramifications.

- IVHS technologies such as remote sensing devices and on-board diagnostic systems have the potential to reduce mobile source emissions by identifying and mitigating emissions from gross-polluting vehicles, thereby improving the effectiveness of inspection and maintenance programs.

The relationships outlined above highlight the complexity and dynamic nature of the interaction between IVHS and emissions. Clearly, even a qualitative assessment of the emission impacts of IVHS is difficult without a structured analytical framework. The following subsections describe the framework that is employed in this study.

2.2 TECHNOLOGY BUNDLES FOR AN EMISSION ANALYSIS

The distinct characteristics of the technologies and systems that comprise the functional areas defined by IVHS America preclude an emissions impact analysis that attempts to generalize effects across all IVHS actions. Even within a functional area, different systems may have different impacts on the factors that influence emissions, such as the number of trips using each mode, trip distance, total vehicle miles traveled, traffic flow, and vehicle emission rates. For example, advanced traffic management systems include traffic signalization systems and freeway and corridor control systems. While each of these may directly improve traffic flow, their emission effects may be quite different. On the one hand, traffic signalization systems may reduce delays experienced in the network and thereby provide area-wide emission benefits from smoother traffic flows. On the other hand, freeway and corridor control systems, such as ramp metering, may have high localized emission consequences as additional vehicles undergo an enrichment process as they accelerate rapidly while entering a freeway.

Therefore, to determine accurately the emission impacts of IVHS, analyses must focus on individual systems or groups of systems with common effects on the operation and use of the transportation network. An evaluation of the impacts of each individual system, however, may not be the most useful analytical approach, since technologies or products are likely to be implemented in groups. Some of these product combinations may have synergistic emission impacts, while others may have competing impacts. In addition, the role of IVHS as enabling technologies for transportation demand strategies, specifically pricing strategies, greatly enhances the attractiveness of IVHS as a means to improve air quality. This enabling characteristic of

IVHS must be directly addressed when conducting an emission analysis, but often takes a secondary role in the literature on the structural development of IVHS. Therefore, it is useful to regroup the systems that comprise IVHS America's six functional areas into *technology bundles*[16] that are likely to have similar effects on travel behavior and transportation system performance, and thus on emissions.

Table 2-1 groups individual IVHS technologies into bundles that are expected to have similar impacts on emissions through their changes in traffic operations and travel demand. *Traffic and incident management systems* span three IVHS America functional areas and include strategies designed to reduce congestion and improve traffic flow. For example, traffic signalization systems and freeway and corridor control systems each attempt to reduce recurrent congestion on different functional classes of roadway by improving traffic management. Similarly, incident detection and emergency mayday systems strive to reduce nonrecurrent congestion by better managing delays caused by traffic accidents, temporary freeway blockages, road maintenance operations, and adverse climatic conditions. Thus, strategies included under traffic and incident management systems are expected to improve the level of service on roadways through improvements in the efficiency of centralized traffic control. With the possible exception of ramp metering, individual systems included in this bundle are expected to have similar travel and emission impacts.

Route guidance systems include two functional areas defined by IVHS America, but primarily include those products and user services represented by advanced traveler information systems. The systems included in this technology bundle also attempt to improve systemwide levels of service by diverting traffic from congested roadways to those with excess capacity. While the effectiveness of traffic and incident management systems will eventually lie with the ability of

---

[16] The bundles that will be the focus of the travel and emission analysis in this study actually represent IVHS products, services, systems, *and* technologies. Therefore, the term *technology bundle* may be somewhat of a misnomer.

Table 2-1. IVHS technology bundles for an emission analysis.

Traffic and Incident Management Systems Traffic Signalization Systems (ATMS) Freeway and Corridor Control Systems (ATMS) Real Time Changeable Message Road Sign Display Systems (ATIS) Incident Detection Systems (ATMS) Emergency Mayday Systems (ATIS) Hazardous Material Information Systems (CVO)	***Vehicle Control Systems*** Radar Braking Systems (AVCS) Vehicle Speed Control Systems (AVCS) Automatic Headway Control Systems (AVCS) Automatic Steering Control Systems (AVCS) Automated Highway Systems (AVCS)
Route Guidance Systems Electronic Route Planning and Information Systems (ATIS) Radio Data Systems (ATIS) On-Board Navigation Systems (ATIS) Externally Linked Route Guidance Systems(ATIS)	***Commercial Vehicle Inspection Systems*** Automatic Credentials Checking (CVO) Electronic Permitting and Payment (CVO) Electronic Recordkeeping (CVO) Weigh-in-Motion (CVO) Automated Safety Inspections (CVO) Automated Driver Data Processing (CVO) Traffic Data Collection Systems (CVO)
Accident Reduction Systems SmartRamp Designs (CVO) Site Specific Highway Warning Systems for Trucks (CVO) Antilock Braking Systems (AVCS) Intersection Hazard Warning Systems (AVCS) Collision Avoidance Systems (AVCS)	***Trip Guidance and Public Transportation Systems*** Ridesharing Information Systems (ATIS) Traveler Information and Service Systems (APTS) Traffic Management Systems (APTS) Transit and Fleet Management Systems (APTS)
Enabling Technologies for Travel Fees Automatic Vehicle Identification Automatic Vehicle Location Automatic Vehicle Classification Electronic Toll Collection (ATMS) Smart Cards (APTS)	***Emission Control Enabling Technologies*** Remote Sensing Devices Vehicle Condition Warning Systems (ATIS)

The functional area from which a specific system originates is presented in parenthesis. ATMS corresponds to advanced traffic management systems. ATIS corresponds to advanced traveler information systems. CVO corresponds to commercial vehicle operations. AVCS corresponds to advanced vehicle control systems. APTS corresponds to advanced public transportation systems. Appendix A provides detailed definitions of each specific system, or systems, included in a particular technology bundle.

a network's control center to manage the system, the effectiveness of route guidance systems are likely to depend upon how many vehicle operators employ the systems that comprise this technology bundle.[17]

Accident reduction systems involve products and services from two distinct functional areas (commercial vehicle operations and advanced vehicle control systems), both of which are designed to promote and improve safety in the movement of people and goods. In contrast to traffic and incident management systems and route guidance systems, the traffic operations benefits from accident reduction systems will be indirect, since these reduce the nonrecurrent congestion associated with accidents. The systems included in this technology bundle are not expected to have direct effects on roadway capacity, although collision avoidance systems do incorporate technologies and products that are the foundation for advanced vehicle control systems.

Vehicle control systems do offer the potential to increase roadway capacity. By removing or minimizing the human element from the vehicle operation process, systems in this technology bundle will allow those vehicles traveling on an appropriately equipped roadway to operate at closer following distances and at more constant speeds. One estimate is that these systems could allow a four-lane freeway to safely carry the traffic that requires at eight lanes under today's operating conditions.[18] Because the travel and emission impacts of strategies that affect roadway capacity may be different than those of strategies that affect levels of service, vehicle control systems have been grouped separately.

---

[17] During the Video-Conference on IVHS and Air Quality it was suggested that route guidance systems be broadened to ensure that this technology bundle include the comprehensive range of options available to travelers before and during a trip. The recommendation was made that trip guidance systems be included, such as those included under advanced public transportation systems. However, it was decided that the two bundles should be treated separately because their objectives are different. Route guidance systems focus on increasing the efficiency of route selection on the part of the motorist *during a trip*, thereby diverting traffic from congested highways and roads to those with excess capacity. Trip guidance systems, on the other hand, focus on mode choice *prior to a trip*. Mode shifts are likely to have different emissions effects than those generated by route diversion. As shown in table 2-1, trip guidance systems are included in a separate technology bundle that addresses mode choice.

[18] IVHS America, *Strategic Plan for Intelligent-Vehicle Systems in the U.S.*, May 1992.

The products and user services included in *commercial vehicle inspection systems* are designed to increase the productivity of vehicles engaged in the movement of goods and services. With the exception of weigh-in-motion systems and automated safety inspection systems that can potentially reduce or eliminate congestion at weigh stations and reduce the number of hot starts, it is not evident that any productivity effects of these systems will necessarily translate into emission effects. This does not imply, however, that the impact of other technology bundles on commercial vehicle travel and emission characteristics will be inconsequential. As with passenger vehicles, commercial vehicles are likely to be influenced by technology bundles that affect roadway level of service and traffic flow.

Trip guidance and public transportation systems include those IVHS strategies that have the potential to reduce the number of vehicle trips in a given urban area. By improving the efficiency and reliability of public transit through, for example, fleet management and control systems, this technology bundle may shift some trips from single occupancy vehicles to high-occupancy vehicles. In addition, by using systems that provide more complete and useful information prior to a trip, travelers may decide to cancel or delay trips during poor traffic conditions or may select high-occupancy modes to reach their desired destinations. As a result, this bundle has the potential for improving the efficiency of the transportation system by increasing the number of trips that are serviced by high-occupancy vehicles and by improving trip planning on the part of travelers.

The IVHS technologies that can facilitate the implementation of road pricing strategies, such as congestion pricing, are shown in table 2-1 under the bundle entitled *enabling technologies for travel fees*. As discussed above, these technologies are specially suited to enhance the effectiveness of road pricing programs by changing the price signal sent to users of the transportation system.

Finally, *emission control enabling technologies* include on-board diagnostic systems and remote sensing devices that can directly help to mitigate motor vehicle emissions. The potential of these technologies to control emissions suggests that they be treated separately from other IVHS products when conducting an emission analysis.

2.3 ANALYTICAL FRAMEWORK

Widespread deployment of IVHS in a metropolitan area is likely to influence many aspects of its transportation system performance and air quality. Yet given the current state of knowledge and lack of field data, many of these potential travel and emission effects are difficult to anticipate even qualitatively. The underlying relationships between transportation system performance and travel behavior, are not well understood, thereby adding to the uncertainty that is surely to accompany any assessment of the likely emissions impacts of IVHS. Nevertheless, some preliminary assessments can be constructed that rely on what *is* known about the potential impacts of IVHS on the transportation system, the influence of the transportation system's performance on travel behavior, and finally, the relationship between travel and vehicle emissions. But even this approach requires a structured analytical framework that recognizes the spatial and temporal differences in potential emission impacts likely to result from deploying different IVHS technologies.

Qualitative estimation requires a thorough dissection of the likely impacts of IVHS on the aspects of travel behavior that influence mobile source emissions, including traffic flow, the number of vehicle trips, trip distance, and mode shifts from single occupancy vehicles to high-occupancy vehicles. In this study, the effects of each IVHS technology bundle on will be assessed using the following impact classification scheme:

- Emissions <u>reductions</u> are likely to result from improvements in traffic flow, reductions in the number of vehicle trips or in their average lengths, or mode shifts from single occupancy vehicles to high-occupancy vehicles.

- Emissions <u>increases</u> may result from increases in congestion, the number of vehicle trips, or average trip length, as well as from mode shifts from high-occupancy vehicles to single occupancy vehicles.

- Minimal emissions changes are likely to result where IVHS promotes only minor changes in traffic flow, the number of vehicle trips, trip lengths, or the use of different travel modes.

- Uncertain effects on emissions are associated with IVHS technologies; changes in traffic flow, tripmaking, trip distance, or mode shifts cannot be even qualitatively assessed given the current state of knowledge.

As with this study, most other studies that attempt to *describe* IVHS impacts on emissions follow similar qualitative approaches, and make no attempt to assign magnitudes to anticipated to impact categories.[19] This primarily due to the uncertainty regarding the effects of specific IVHS actions on each aspect of travel behavior that influences motor vehicle emissions. This uncertainty was reflected in the Video-Conference on IVHS and Air Quality conducted as part of this study, during which experts were reluctant to specify limits for categorizing the impacts of IVHS strategies as low, medium, or high. Although the approach followed in this study builds on previous analyses, none of the most important potential effects of IVHS on travel and emissions are still subject to differing interpretations. Until more is known about the likely affects of each IVHS technology bundle on travel behavior and transportation system performance, attempting to assign numerical magnitudes to their prospective effects on vehicle emissions is not necessarily more useful than carefully assessing the likely direction of these impacts.

The emission impacts of IVHS are likely to occur at three levels of the transportation system. For example, traffic and incident management systems will probably have more pronounced impacts, at the corridor level than at the regional level. Similarly, ramp metering systems are likely to affect localized emission levels more than overall regional emissions. As a result, defining the geographic scale of emission impacts likely to be associated with each technology bundle will allow for a more representative analysis, and thus a more accurate depiction of the

---

[19] As examples, the reader is referred to the following:
Deborah Gordon, *Intelligent Vehicle/Highway Systems: An Environmental Perspective*, March 1990.
NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Congestion*, December 1991.
Randall Guensler, Daniel Sperling, and Simon Washington, *IVHS Technologies and Motor Vehicle Emissions*, 1993.

effects of IVHS on regional compliance with the 1990 Clean Air Act Amendments. The geographic scale employed in this study focused on impacts at the regional and corridor levels, although where appropriate, potential effects on localized emission concentrations will also be noted.

The analytical framework for an IVHS emission impact analysis must also reflect the likely time sequence for implementing different IVHS actions. Vehicle control and warning systems, for instance, are not likely to be fully implemented until well into the 21st century, while traffic and incident management systems have already been deployed on a limited scale. Other "first generation" systems, such as ramp metering, are currently being widely deployed across the country. The exact timing with which different IVHS technologies are implemented will depend on many factors, some of which may be unrelated to the pace of their technological development. For example, legal barriers such as liability concerns may have important effects on the pace of IVHS deployment, particularly for more far-reaching technologies such as vehicle control systems.

Despite their potential significance for the timing with which many IVHS technologies will actually become operational, evaluating each legal or institutional barrier is beyond the scope of this report. The basis for assessing the likely timing of IVHS implementation in this study will be the pace of technology development and operational feasibility. Even under such a limited criterion, consensus is difficult to reach on what defines the short term and the long term with respect to IVHS deployment. It is probable that most systems will be implemented first at the corridor level, and then in specific metropolitan-wide applications. This study follows the recommendation of experts who participated in the Video-Conference on IVHS and Air Quality by defining the short term to be the period 2000 to 2010 and the long term as beyond 2010. Although this definition is somewhat arbitrary, it envisions the implementation of first or second generation systems in the short term and the deployment of more technologically complex or advanced systems in the longer term.

It is also important to view the emission impacts of IVHS in light of advancements in vehicle emission control technologies and other emission control strategies. The "car of tomorrow" is likely to be quite different from current model year vehicles. For example, the development of electrically heated catalysts and more advanced combustion control processes is likely to significantly reduce new vehicle emissions, and the absorption of these vehicles into the fleet could significantly reduce the overall average emissions rate. Similarly, the penetration of reformulated fuels or alternatively fueled vehicles may eventually have similar positive effects on fleet-wide emissions rates. In the long term, it is conceivable that the emission impacts of most IVHS actions may be negligible, particularly if the future vehicle fleet of zero or very low emission vehicles.

In the short term, however, evolutionary rather than revolutionary changes in emission control technologies are likely to occur, and more concrete projections can be made. The baseline for comparison employed in this study for both short-term and long-term analyses reflects these moderate evolutionary changes in emission control technologies. Here, moderate changes include continued replacement of older vehicles by those meeting the "Tier I" emissions standards, limited penetration of alternatively fueled vehicle into passenger and commercial vehicle fleets (e.g., some rental car or other vehicle fleets conducive to centralized refueling systems), changes in fuel specifications (reformulated gasoline and/or diesel) fuel and the subsequent application of advanced emission control technologies (e.g., electrically heated catalysts). The IVHS emission impacts that are presented in section 3 reflect this comparison baseline.

Consideration must also be given to efforts by the U.S. Environmental Protection Agency and the California Air Resources Board to develop new motor vehicle emission certification processes. A recent study by the National Research Council concluded that motor vehicles may emit two to four times as much hydrocarbon and carbon monoxide as commonly estimated by the U.S. Environmental Protection Agency and the California Air Resources Board.[20] Much of this underestimation may be related to the driving cycle tests used to measure vehicle emissions both in the emissions certification process for new vehicles, and in the development

---

[20] National Research Council, *Rethinking the Ozone Problem in Urban and Regional Air Pollution*, 1991.

of existing emission models.[21] Specifically, the FTP, which is used to certify that new light-duty vehicles and light-duty trucks are in compliance with federal or California emission standards, fails to include a variety of vehicle operating conditions that are now commonly observed (high speeds, such as speeds over 57 miles per hour, rapid acceleration, and sharp decelerations). In fact, a recent report by the U.S. Environmental Protection Agency assessed average driving behavior and concluded that driving speeds and acceleration rates are much higher than those represented by the current FTP.[22] Activities such as these are now believed to be significant contributors to instantaneous vehicle emission rates, and thus to the total emissions generated by typical vehicle trips. As a result, the FTP may no longer accurately represent overall emissions levels associated with current driving conditions. Consequently, the U.S. Environmental Protection Agency will conduct a battery of tests in 1993 to quantify emissions under "off-cycle" driving patterns (i.e., those outside the range of operating conditions included in the FTP).[23]

Assuming that such emissions are found to be significant, and that the U.S. Environmental Protection Agency and California Air Resources Board develop new certification procedures to assure that new vehicles comply with revised emission standards, automobile manufacturers will be required to bring these off-cycle emissions under control. The types of controls that the automobile industry may be required to adopt include engine recalibration, catalyst changes, or possibly base engine changes.[24] But as off-cycle emissions are controlled by new certification processes, emissions under stop-and-go and high-speed driving conditions will be mitigated. (As discussed above, enrichment and motoring events occur when driving conditions are characterized by congestion.) Since these advance emission controls will be designed to reduce emissions under the vehicle operating conditions that many IVHS strategies are intended to

---

[21] Daniel Sperling, Randall Guensler, Dorriah Page and Simon Washington. *Air Quality Impacts of IVHS: An Initial Review,* 1992.

[22] U.S. Environmental Protection Agency, *Federal Test Procedure Review Project: Preliminary Report*, May 1993.

[23] U.S. Environmental Protection Agency, *Inside E.P.A - Weekly Report,* June 25, 1993.

[24] Ibid.

reduce the frequency of, their effects on vehicle emissions may decline as these new controls are widely deployed.

Finally, the issue of potential increases in travel resulting from widespread deployment of IVHS needs to be addressed when formulating an analytical framework for an emissions impact assessment. "Latent" travel demand is represented by trips that would provide utility to those making them, but that they forgo because of associated costs in terms of time and/or money. Significant long-term improvements in the transportation system, usually in the form of increases in roadway capacity, may induce additional travel by reducing the money cost or time requirements for tripmaking, with the concomitant *potential* for increases in emissions.[25] Whether or not the transportation system efficiency gains that are brought about by IVHS will induce travel in significant amounts is the subject of debate. For example, participants at the Video-Conference on IVHS and Air Quality generally concurred that the induced travel potential of most IVHS strategies will be quite small. On the other hand, participants at the National IVHS/Air Quality Workshop were less willing to dismiss the induced travel impacts of IVHS.

This phenomenon is not unique to transportation: all goods and services offered at non-zero prices have unsatisfied demand. When the price of such a good or service falls, demand increases as current consumers purchase more of the good, and additional consumers find the product within their willingness to pay. Lower prices may result from production efficiencies, new technologies, and various other factors that can influence the cost of producing goods and services, or from excess supply as prices adjust to clear the market. Effective prices can also decline as the quality of products improve or as they incorporate more characteristics that are valued by consumers. Automobiles are an example of a product where prices have increased as new technology made products safer, more fuel efficient, less polluting, and more attractive to consumers. Indeed, technological changes in the automobile, such as AM/FM radio, air conditioning, power steering, and automatic transmissions may have led to changes in travel. Similarly, many IVHS technologies may change the nature of travel, making it easier, faster, safer, and generally more convenient. These enhanced attributes may increase the money cost

---

[25] Steven E. Shladover, *Potential Contribution of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

of travel but decrease the time cost or inconvenience of travel, on balance increasing its attractiveness.

Travel demand is also influenced by many factors not directly related to the costs of making individual trips. For example, economic factors such as per capita income, as well as demographic factors such as the age distribution of a region's population have important ramifications for travel demand. By definition, induced travel reflects increases in travel demand *beyond* those that are brought about by economic and demographic factors. Changes in travel cost in terms of both time and money may induce travel, *given* current economic and demographic conditions.[26] As a result, the effect of IVHS on induced travel may well depend on the impact of IVHS on travel cost measured in terms of both its time and money components.

Significant improvements in the effective capacity of an area's transportation system or in the efficiency with which it functions brought about by IVHS may reduce travel times, thereby reducing travel costs and potentially inducing some new travel. Of course, the extent of induced travel will depend on the sensitivity of travel demand to changes in travel cost. Depending on the type of trip, travelers may be relatively insensitive to changes in travel cost that are brought about by reduced travel times, and may not significantly alter their travel behavior. This situation seems likely to characterize commuter trips, for example.

On the other hand, the implementation and operation of IVHS strategies is also likely to increase the monetary costs borne by users of the transportation system.[27] Potential increases in out-of-pocket travel costs brought about by IVHS may actually reduce the number of vehicle trips that

---

[26] In economic parlance, changes in economic and demographic factors cause shifts in the travel demand curve, while changes in travel cost generate movements along the demand curve as the supply curve shifts in response to changes in the marginal cost of production or other factors that cause supply shifts. In this simplified context, travel demand is inversely related to travel cost (both time and money) -- increases in travel cost generate decreases in travel demand. The magnitude of changes in travel demand brought about by changes in travel cost depends on the price elasticity of demand, or the sensitivity of travelers to changes in travel cost.

[27] The potential effect of IVHS implementation and operation on the out-of-pocket aspect of travel cost has largely been ignored in the debate concerning induced travel from IVHS deployment. Yet, highways in this country are operated under the *user pays principle* and there is no clear evidence that the implementation and operation of IVHS will not result in increased out-of-pocket travel costs through changes in excise taxes to support the Highway Trust Fund and state and local highway funding.

some people take, possibly by shifting some of their trips to high-occupancy travel modes. This potential effect on travel demand again depends on the type of trip and on the sensitivity of travelers to changes in travel cost.

Studies that have attempted to quantify the effects of highway projects on travel volumes have focused mainly on major capacity expansions. One comprehensive study of the relationship between roadway capacity and urban traffic was recently conducted by the Institute of Transportation Studies (ITS) at the University of California at Berkeley.[28] The ITS study quantified the expected relationship between capacity increases and travel volumes in order to assess the air quality impacts of traffic generation and land use changes brought about by capacity enhancement projects. Although the ITS study focused on lane additions, many of the results may apply to other types of capacity enhancement projects, including those that may result from the implementation of advanced vehicle control systems.

To summarize the relationship between capacity and induced traffic at the corridor level, the ITS study estimated capacity-demand elasticities, which measure the percent increase in traffic that results from a capacity expansion of one percent. Using traffic count data from 18 expanded highway segments located within urban counties in California, the analysis produced three important results. The ITS study found that capacity expansion does induce traffic on the expanded facility, but that this effect occurred over an extended period of time (up to 20 years) after the completion of the project. Finally, even after 20 years, the additional traffic induced by expansion fell considerably short of the increases that would have been necessary to produce the same relationship of traffic volume to roadway capacity that prevailed prior to the expansion projects.

The third result is summarized by the estimated capacity-demand elasticities for individual facilities derived in the study which range between 0.10 and 0.60, depending on the number of years after expansion. At the regional level, the ITS study produces capacity-demand elasticities ranging from 0.20 to 0.50, depending on intraregional versus interregional travel data. Other

---

[28] Institute of Transportation Studies, University of California at Berkeley, *The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Impacts*, April 1993.

factors, such as income and population, were found to be more important determinants of travel growth. Therefore, the authors of the study conclude that capacity expansion reduces volume-capacity ratios, thereby increasing the level of service at which the expanded facility operates over an extended period of time. Thus the hypothesis that increased roadway capacity will result in a new system with equal congestion but more vehicles was not supported by the ITS study. Similar before-and-after studies appear to support this conclusion; studies in New York, for example, show that increased capacity through lane expansion only led to a 1.5 percent increase in automobile trips into Manhattan.[29]

Since even large capacity enhancement projects may not result in correspondingly large increases in vehicle travel, it appears unlikely that those IVHS strategies that improve traffic flow, reduce congestion, and then provide modest improvements in roadway levels of service will lead to significant amounts of induced traffic. Coupled with the possibility that out-of-pocket travel costs may increase as a result of IVHS deployment, the induced travel effects of most IVHS strategies seem likely to be small. Only those strategies that produce large increases in the effective capacity of large parts of a transportation network, such as widespread implementation of automated highways, seem likely to have significant induced traffic repercussions. Thus the analysis in section 3 is based on the plausible assumption that the induced traffic effects of improvements in roadway levels of service resulting from most IVHS actions are likely to be quite small, while capacity increases generated by advanced vehicle control systems, for example, may have more substantial effects on traffic volumes. Even these effects, however, are likely to materialize only over a prolonged period of time following the development of these systems.

---

[29] John Suhrbier, Video-Conference on IVHS and Air Quality, March 8, 1993.

3. EMISSION AND TRAVEL IMPACTS OF IVHS TECHNOLOGY BUNDLES

The effects of IVHS on traffic operations and travel demand will depend on the systems that are implemented, the geographic scale and timing of their implementation, and travelers' use of those systems in the short term and long term. The variability of technology and operational reliability among the systems causes the long- and short-term effects to vary, as well as the effects at the network and corridor levels. The emission effects of each technology bundle will depend upon its impact on traffic and travel, as well as on changes in the composition of the in-use vehicle fleet and the resulting changes in vehicle emission rates.

This section qualitatively assesses the potential travel and emission consequences of deploying IVHS technologies, using the analytical framework that is presented in section 2. Sections 3.1 to 3.8 analyze the potential travel and emission effects of the technology bundles presented in table 2-1. The discussion presented for each technology bundle begins with a brief definition of the systems comprising the bundle. More comprehensive and detailed descriptions of the products, user services, and technologies that comprise the systems are presented in appendix A. Following the definitions is an assessment of the short and long term market penetration of the various systems. Finally, the expected short and long-term travel, traffic, and emission impacts of the systems are discussed at both the corridor and regional levels based on the assumptions of market penetration. Section 3.9 uses the conclusions that are derived from the evaluation of each technology bundle to summarize the potential emission effects of IVHS.

3.1 TRAFFIC AND INCIDENT MANAGEMENT SYSTEMS

System Definitions

The systems comprising this technology bundle are designed to reduce recurrent and nonrecurrent congestion levels by improving traffic signalization, incident detection, and corridor control. Brief descriptions of the systems are provided below.

- *Traffic signalization systems* allow vehicle movements to be controlled through time and space segregation, speed control, and advisory messages. Advances in traffic signalization incorporate real time data on network capacity and demand.

- *Incident detection systems* are designed to minimize delays and network inefficiencies caused by nonrecurrent congestion and to detect dangerous road conditions, typically consisting of a small computer or distributed microprocessor system that automatically monitors signals from vehicle detectors spaced along a highway.

- *Freeway and corridor control systems* include ramp metering, express lanes (e.g., high-occupancy vehicle lanes), message signs allowing for variable speed control, and corridor control strategies. These capacity management techniques are designed to reduce the occurrence of congestion by maximizing vehicle throughput and improving level of service.

- *Real time changeable message road sign display systems* represent the next generation of current static road signs, providing up-to-date information to travelers using freeways or arterial roadways.

- *Emergency mayday systems* reduce delays associated with slow response and incident clearing operations through signals sent by a vehicle communication system to the traffic network. The network processes the information and relays it to incident clearance crews.

- *Hazardous material information systems* can help to better identify and clear incidents that involve hazardous materials.

Market Penetration

In the short term, the systems in this technology bundle affecting traffic and travel are likely to be limited to first and second generation traffic signalization, incident detection, and corridor and freeway control systems. Since first generation systems are not responsive to real time traffic conditions, their effectiveness in reducing delays and improving level of service along corridors will be limited. In the long term, the integration of traffic management strategies that are based on real time traffic conditions may become a reality in many cities across the country as advances are made in traffic signalization systems, incident detection systems, freeway and corridor control systems, variable message signs, and other techniques.

First generation traffic signalization systems, such as optimized vehicle actuation, have proven effective in reducing delays at traffic lights. But technical as well as operational problems still need to be addressed for later generation systems, including partially or fully adaptive coordination.

In contrast, many freeway and corridor control strategies are widely applied today. For example, second generation ramp metering systems that vary signal phasing continuously as ramp and freeway flows are monitored in real time have been implemented in various urban regions across the country. Chicago uses them to control traffic at 91 expressway locations. The total instrumented network covers 110 highway miles, with 1,650 loop detectors.[30] Expressways in the Los Angeles metropolitan area also us them. Express lanes and variable speed control strategies have been widely incorporated in many cities across the U.S. The penetration of most freeway and corridor control systems can be extensive in the short term. Incorporating corridor control strategies that strive to integrate the entire network of freeways and arterial roads can only occur in the long term.

Widespread penetration of incident detection systems may also occur in the short term. A number of operational automatic incident detection systems have been implemented in the U.S. and Europe. In the United Kingdom, for example, an experimental incident detection system has been deployed on the M1 and M4 motorways, and has since been extended to cover 50 miles of the congested M1 motorway. In Holland, electronic roadside sensors that automatically detect dangerous road conditions likely to cause accidents and congestion were installed in 1985.

---

[30] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, December 1991.

Variable message signing is linked to the sensors in order to caution drivers to slow down as necessary.[31]

Expected Travel, Traffic, and Emissions Impacts

The combination of traffic signalization systems, incident detection systems, and freeway and corridor control systems is likely to result in higher efficiency gains throughout the network than at the corridor level. This simply follows from an extension of benefits across a wider area. In the long term, these systems may allow for an integrated approach to traffic management based on real time data on congestion, actual travel speeds, and the occurrence of incidents. Such an integrated system can lead to regional improvements in roadway levels of service, even after accounting for any resulting increases in total traffic volumes. The potentially negative emission consequences of ramp meters alone do not seem likely to offset the potential emission benefits generated by this technology bundle through improved traffic flow and level of service at the network level.

At the regional level, implementation of traffic and incident management systems is thus likely to reduce CO and HC emissions, although NO_X emissions may increase as average travel speeds increase. Yet without details regarding the number of ramp meters deployed in a *specific* network and the emissions significance of their deployment, the regional emission impacts of this technology bundle cannot be fully assessed.

The short-term effectiveness of traffic management systems will depend on the sophistication of computer algorithms that simulate traffic conditions. But when combined with incident management systems, first and second generation systems may result in some congestion relief. For example, the Los Angeles Automated Traffic Surveillance and Control (ATSAC) system, implemented in the Coliseum area in July 1984, showed improvements in level of service. The 118 signalized intersections and 396 detectors were installed covering an area of 4 square miles. Signal timing was automatically adjusted to reflect changing traffic conditions using partially adaptive coordination systems. The system was coupled with incident management systems to

---

[31] Ibid.

detect and manage unusual traffic conditions, such as accidents and special events. In total, ATSAC measured improvements of 13.2 percent in travel time, 14.8 percent in average travel speed, and 35.2 percent in vehicle stops. Models were then employed to translate these level of service improvements into potential emission impacts. A 10 percent potential reduction in hydrocarbon (HC) and carbon monoxide (CO) emissions was estimated.[32] This estimated emission impact highlights the potential emission benefits that can result from first and second generation traffic and incident management systems. The potential role of incident management systems is revealed by the fact that more than half of the delays that occur on freeways are typically due to incidents.[33] Therefore, effective systems to mitigate delays caused by traffic accidents, temporary freeway blockages, road maintenance operations, and climatic conditions can have a significant effect on freeway congestion during both peak and off-peak periods.

Freeway and corridor control systems can also improve traffic flow significantly along a corridor, although the resulting travel time and emissions benefits will vary according to the levels of congestion prevailing before the implementation of controls. For example, the implementation of ramp metering on expressways in the Chicago area was found to reduce peak period congestion by up to 60 percent and accidents by up to 18 percent. On Houston's Gulf Freeway, ramp metering reduced travel times by 25 percent and accidents by 50 percent. Many other North American cities have reported similar favorable experiences from implementing ramp control.[34]

The emission repercussions of ramp metering are less certain, however. Although ramp metering does improve traffic flow and level of service downstream, more vehicles may undergo sharp acceleration as they merge onto the freeway at mainline speeds from a full stop than was the case before meters were installed. It is not clear whether the additional emissions generated by these accelerations will offset the corridor level emission benefits (from smoother traffic flow downstream) that are brought about by ramp metering itself and the other systems in this bundle.

---

[32] Steven E. Shladover, *Potential Contribution of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

[33] Ibid.

[34] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Congestion*, December 1991.

The net emission consequences cannot be assessed without a better understanding of modal emissions and other factors that establish this relationship — such as the percentage of vehicles that undergo severe enrichment events relative to the total volume of traffic, and the increase in the frequency of these events with and without ramp metering. Moreover, if motor vehicle manufacturers are required to improve the control of off-cycle emissions, such as those that occur during sharp acceleration, the emission consequences of both smoother traffic flow and ramp metering are likely to change. Given the lack of data and analytic tools, the corridor level emission impacts of traffic and incident reduction systems remain uncertain in both the short and long terms. See table 3-1 below.

Table 3-1. Traffic and incident management systems.

	Short-term Impacts		Long-term Impacts	
	Corridor	**Regional**	**Corridor**	**Regional**
Traffic Flow	Positive	Positive	Positive	Positive
Vehicle Trips	Insignificant	Insignificant	Insignificant	Insignificant
Trip Distance	Insignificant	Insignificant	Insignificant	Insignificant
Mode Shifts	Insignificant	Insignificant	Insignificant	Insignificant
HC Emissions	Uncertain	Positive	Uncertain	Positive
CO Emissions	Uncertain	Positive	Uncertain	Positive
NO_x Emissions	Uncertain	Negative	Uncertain	Negative

3.2 ROUTE GUIDANCE SYSTEMS

Definitions

The systems included in this technology bundle are designed to provide motorists with information on highway conditions and route availability, in order to help them choose the best possible route prior to or during a trip. The more advanced products and user services rely heavily on automatic vehicle monitoring and location technologies, which are described in appendix A. Brief descriptions of specific types of route guidance systems are provided below.

- *Radio data systems* use a radio frequency to broadcast traffic information to motorists, keeping them abreast of current network traffic conditions, traffic incidents, or highway construction and maintenance activities.

- *On-board navigation systems* inform motorists about their current location and how it relates to the desired destination. Information is extracted from an on-board computer that does not interface with a traffic control center, relying instead on software contained within the computer's memory. However, this lack of interface with traffic control centers makes on-board navigation systems entirely static and nonresponsive to real time traffic conditions.

- *Electronic route planning and information systems* link path-finding computer algorithms to highway network data bases. Routes can be selected to minimize journey time, distance, or cost, thereby accounting for real time road and traffic conditions.

- *Externally linked route guidance systems* provide real time information on traffic conditions and suggest alternative routes to circumvent congested roads *during* the trip itself. These systems involve communication between an external network traffic management system that provides real time information on road and traffic conditions and on-board guidance equipment.

Market Penetration

Advanced communication and computer technologies developed in the past two decades have enabled the development and successful testing of the systems included in this technology bundle. Although the reliability of route guidance systems depends on the specific system in question, tests in Japan have proven even the most advanced systems, such as externally linked route guidance systems, to be effective (see appendix A). The penetration of these systems into the in-use vehicle fleet is a function of economic factors rather than technological constraints. These economic factors could result in low short-term penetration rates into the vehicle fleet.

The marketability of and consumer receptiveness to route guidance systems are currently not fully understood. The costs may be partially borne by vehicle owners. Elaborate route guidance systems may be very expensive initially (roughly $3,000),[35] thereby reducing their attractiveness to the general motorist public.

As with other high-priced, high-technology consumer items available in motor vehicles, route guidance systems may initially be offered in luxury passenger vehicles, or in commercial vehicles. Productivity gains from better route guidance will be an important financial consideration to commercial carriers. Advertiser subsidies or other programs that reduce the cost of these systems to consumers may accelerate short-term penetration.

Penetration is likely to increase as prices decrease and benefits are more widely perceived. Long term implementation is expected to be high, as prices fall and the systems penetrate the in-use fleet through both retrofit and new vehicle purchases.

Expected Travel, Traffic, and Emissions Impacts

Potential travel and emission effects of route guidance systems are summarized in table 3-2. Improved traffic flow will result in decreases in CO and HC emissions. However, NO_X emissions may increase with higher average travel speeds. Potential reductions in vehicle miles traveled and hot or cold starts will reduce CO, HC, and NO_X emissions. However, the overall net effect on NO_X emissions is uncertain.

The congestion benefits of first generation route guidance systems may be relatively small when compared to the benefits that may be achieved from more advanced second generation

---

[35] IVHS America, *Intelligent Vehicle-Highway Systems in the United States*, May 1992.

systems. Therefore, in the short term, corridor-level improvements in traffic flow brought about by route guidance systems are unlikely to be as large as in the long term.

Motorists currently rely on maps or memory to determine the most convenient route, but these sources can supply only historical data on route availability. First generation route guidance systems, such as traffic information broadcasting systems (e.g., radio data systems or traffic news on AM/FM radio stations), already operate in many urban areas across the country. The congestion information provided is often limited to only a small number of corridors and includes periodic average traffic conditions. On-board navigation systems, a second generation technology not yet implemented, will enhance the motorist's ability to select an alternative route when heavy congestion is encountered by providing a motorist with information on his or her current location and showing how that location relates to the desired destination. However, these route guidance systems are not designed to provide motorists with continuous real time information on traffic conditions and alternative routes. They may reduce the rate of congestion growth over time, as motorists become better informed of available routes and points in the network where recurrent congestion is prevalent, although the full merits of real time data for decision-making may not be fully realized. Supplementary information could describe transient road and traffic conditions, and show the best route currently available. More advanced systems, such as externally linked route guidance systems, may reduce vehicle-hours of delay and improve level of service along a corridor by roughly 7 to 15 percent by providing dynamic routing information that is fully responsive to traffic conditions on the network.[36]

The net effect of these technologies on trip distances or total vehicle miles traveled is difficult to assess for either the short term or the long term. Although traffic flow will be improved along the corridor by diverting traffic from congested corridors to those with excess capacity, traffic diversion may result in longer trips as motorists select less direct routes (that may not significantly affect trip duration) to reach destinations. On the other

---

[36] Kan Chen, *Policy Implications of Driver Information Systems*, January 1992.

hand, on-board navigation systems have the potential to decrease the amount of wasted travel associated with human navigation errors.

The effects of route diversion on congestion and emissions along parallel routes should also be addressed. Diverting individual drivers from congested corridors to other routes in the network may result in a rebound effect whereby additional drivers are attracted to less congested routes, possibly increasing emissions along those routes.[37] However, at the regional level emissions should decline, because route guidance systems have the potential to improve levels of service over the entire network, by diverting travel to routes with excess capacity. On balance, however, the congestion and emission impacts along individual routes as a result of route diversion are thus not easily predictable.

Finally, implementing route guidance systems may facilitate trip chaining - the linking of different purpose trips into one extended trip. As more complete and representative travel information is available to motorists prior to or during a trip, the satisfaction of different needs through trip chaining becomes more feasible. The use of route guidance systems for the purpose of product and service advertising may emphasize this effect. Trip chaining can, in turn, reduce vehicle miles traveled and eliminate vehicle cold starts associated with separate trips.

Table 3-2. Route guidance systems.

	Short-term Impacts		**Long-term Impacts**	
	Corridor	**Regional**	**Corridor**	**Regional**
Traffic Flow	Positive	Positive	Positive	Positive
Vehicle Trips	Insignificant	Positive	Insignificant	Positive
Trip Distance	Insignificant	Uncertain	Insignificant	Uncertain
Mode Shifts	Insignificant	Insignificant	Insignificant	Insignificant
HC Emissions	Positive	Positive	Positive	Positive
CO Emissions	Positive	Positive	Positive	Positive
NO_x Emissions	Uncertain	Uncertain	Uncertain	Uncertain

---

[37] Deborah Gordon, *Intelligent Vehicle-Highway Systems: An Environmental Perspective*, March 1990.

3.3 ACCIDENT REDUCTION SYSTEMS

System Definitions

As defined in table 2-1, accident reduction systems encompass technologies that provide real time, on-board warnings to vehicle operators, and technologies that automatically assume control of vehicle operations during emergency situations. Strategies and products that comprise accident reduction systems are described below.

- *SmartRamp designs* for commercial vehicles automatically detect the size, weight, and speed of trucks as they approach ramps and advise the vehicle operator if there is a rollover hazard.

- *Site-specific highway warning systems for trucks* provide truck operators with advanced warning about highway conditions, such as sharp inclines, tight ramps, and approaching intersections.

- *Antilock braking systems* assume control of a vehicle's braking function during moments of excessive braking or severe cornering.

- *Intersection hazard warning systems* are designed to prevent accidents that occur when a vehicle enters an intersection and collides with cross traffic that was not visible to the driver of the vehicle.

- *Collision avoidance systems* incorporate the technologies and products that are the foundation of advanced vehicle control systems, such as radar braking and automatic steering control, either to warn drivers of impending collisions or to automatically assume vehicle control.

Market Penetration

On-board warning systems alert drivers of possible collisions but do not assume vehicle control. These first generation technologies include collision avoidance systems and intersection hazard warning systems. Second generation systems automatically control the vehicle to avoid collisions.

Short-term implementation of the systems in this technology bundle may be limited to SmartRamp designs, site-specific highway warning systems for trucks, and first generation collision avoidance systems. As with other on-board devices, short-term implementation is likely to occur in luxury passenger vehicles and commercial vehicles. In the long term, advances in radar braking and automatic steering control systems will facilitate the penetration of collision avoidance systems that automatically assume vehicle control during emergency situations. These systems are still in the developmental stage. Full-scale implementation of accident reduction systems, at any level of sophistication, will depend on their marketability to both commercial vehicle operators and the motoring public.

Travel, Traffic, and Emissions Impacts

The potential impacts of this technology bundle are summarized below, in table 3-3. Implementing accident reduction systems may translate into reduced HC and CO emissions and increased NO_X emissions, as traffic flow is improved and roadways provide higher levels of service. These emissions impacts are expected to be greater in the long term, with the penetration of systems that assume vehicle control during emergency situations.

Traffic accidents directly contribute to nonrecurrent congestion on roadways across the country. By reducing the likelihood of traffic accidents, accident reduction systems can potentially reduce delays associated with nonrecurrent congestion and improve level of service at both corridor and regional levels. Although effects are likely to be greater in the long term with the implementation of radar braking and automatic steering, some short-term benefits are possible. For example, studies suggest that approximately seven percent of all road accidents could have been prevented if antilock braking systems had been fitted to the involved vehicles.[38] More advanced systems employing on-board devices to warn vehicle operators of impending collisions may result in even fewer traffic accidents. In the long term, collision avoidance systems and intersection hazard warning systems that automatically assume control of the vehicle in emergency situations have the potential to eliminate those accidents that occur because of the inability of drivers to judge speeds and distances correctly — shortcomings often associated with driving in bad weather or at night.

Although accident reduction systems can reduce nonrecurrent congestion along a corridor, relieving a nonrecurrent bottleneck may send additional traffic into areas experiencing recurrent congestion delays. Although the corridor will experience a higher level of service, congestion relief at the network level may not be as great.

Table 3-3. Accident reduction systems.

	Short-term Impacts		**Long-term Impacts**	
	Corridor	**Regional**	**Corridor**	**Regional**
Traffic Flow	Positive	Positive	Positive	Positive
Vehicle Trips	Insignificant	Insignificant	Insignificant	Insignificant
Trip Distance	Insignificant	Insignificant	Insignificant	Insignificant
Mode Shifts	Insignificant	Insignificant	Insignificant	Insignificant
HC Emissions	Positive	Positive	Positive	Positive
CO Emissions	Positive	Positive	Positive	Positive
NO_x Emissions	Negative	Negative	Negative	Negative

3.4 VEHICLE CONTROL SYSTEMS

System Definitions

Systems in this technology bundle remove or minimize the human element from the vehicle operation process, allowing vehicles traveling on an appropriately equipped roadway to

---

[38] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Congestion*, December 1991.

operate at closer driving distances and at more constant speeds. The most basic level of advanced vehicle control systems, on-board sensors, will provide vehicle operators with useful information and warnings. This is a similar concept to the first generation accident reduction systems discussed in section 3.3. More advanced systems will intervene and manage or completely take over vehicle operations. Brief descriptions of each system in this technology bundle are provided below.

- *Radar braking systems* are designed to brake vehicles automatically when predetermined speed and distance relationships are violated.
- *Vehicle speed control systems* include conventional cruise control, speed governors, and variable (or adaptive) speed control.
- *Automatic headway control systems* employ vehicle sensors to maintain constant distances between vehicles traveling on a particular lane of a roadway. Distance monitoring is combined with brake and speed control.
- *Automatic steering control systems* are designed to automate the steering process of vehicle operation and allow vehicles to follow a predetermined path along dedicated highway lanes.
- *Automated highway systems* involve the combination of vehicle control strategies with all other intelligent vehicle-highway systems to produce highways on which vehicles essentially drive themselves.

Market Penetration

Systems included in this bundle will be implemented most widely on freeways, given the complexity of the systems involved and the characteristics of travel on city streets and minor roads. The nature of these systems as on-board equipment may initially limit their penetration into the in-use fleet, and tests to better determine operational reliability are crucial for rapid introduction into the marketplace.

The short-term penetration of variable speed control systems will depend on economic factors and vehicle turnover rates. They are being designed and tested in various programs around the world, including PATH (Partners for Advanced Transit) and PROMETHEUS (Program for European Traffic with Highest Efficiency and Unprecedented Safety). These systems may be available on some vehicle lines within the next few years.

The penetration of some systems included in this bundle may only have significant effects in the long term. Radar braking and automatic steering control systems, the foundation of automatic headway control and automated highway systems, are still in the development stage. Various technical problems associated with radar braking need to be resolved. These include false alarms that can be caused by roadside obstacles, blinding (when radar signals from vehicles traveling in the opposite direction block out the return signals from potential obstacles), and problems caused by poor weather conditions, such as backscatter from rainwater.[39]

Travel, Traffic, and Emissions Impacts

The potential travel and emissions impacts of vehicle control systems are summarized in table 3-4. Short-term effects are associated with vehicle speed control systems, while long-term effects reflect the implementation of more advanced and complex systems, such as automated highways. While the short-term emission repercussions of vehicle speed control systems can be assessed given expectations regarding traffic operations and travel, the complex nature of the relationships among improved traffic flow, induced traffic, and potential land use changes makes it difficult to assess the emission repercussions of vehicle control systems with any degree of certainty.

---

[39] Ibid.

Table 3-4. Vehicle control systems.

	Short-term Impacts		Long-term Impacts	
	Corridor	Regional	Corridor	Regional
Traffic Flow	Positive	Insignificant	Positive	Positive
Vehicle Trips	Insignificant	Insignificant	Insignificant	Insignificant
Trip Distance	Insignificant	Insignificant	Negative	Negative
Mode Shifts	Insignificant	Insignificant	Insignificant	Insignificant
HC Emissions	Positive	Insignificant	Uncertain	Uncertain
CO Emissions	Positive	Insignificant	Uncertain	Uncertain
NO_x Emissions	Negative	Insignificant	Uncertain	Uncertain

Short-term penetration of vehicle speed control systems may smooth traffic flow and improve the level of service on freeways. When traffic density on a freeway is high, disturbances in vehicle flow tend to propagate upstream. A modest brake application by one vehicle to accommodate a lane change by another translates into a more severe brake application by the next vehicle. This phenomenon may continue until some vehicles upstream are brought to a complete stop. Vehicle speed control systems, especially adaptive cruise control, may offset these disturbances by reducing speed differentials and minimizing the frequency of vehicle stops. Smoother traffic flow should reduce delays, improve energy efficiency, and reduce CO and HC emissions. NO_X emissions may increase as average speeds increase on a particular freeway. An added benefit would be nonrecurrent congestion relief from the reduction of rear-end collisions that sometimes occurs from the propagation of flow disturbances.[40]

In the long term, radar braking systems, automatic steering control systems, automatic headway control systems, and even automated highway systems may be implemented. These systems can potentially remove, or minimize, the human element from the vehicle operating process, allowing vehicles traveling on an appropriately equipped highway to operate at closer distances and at constant speeds. Such applications could double or triple the capacity

---

[40] Steven E. Shladover, *Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

of a freeway lane.[41] A four-lane freeway could reasonably be expected to carry safely the traffic that requires at least eight lanes under today's operating conditions.[42]

The travel impacts of these potential capacity increases may be two-fold. If, for example, the effect of implementing these systems on one existing lane of a freeway is comparable to the effect of adding one or two new lanes, then congestion on the freeway can be replaced by freer-flowing traffic. However, if arterial routes in the immediate area of the freeway are also congested, then the new freeway capacity and correspondingly improved level of service may cause some of the traffic on parallel routes to be diverted onto the freeway. This diversion may diminish the benefits to freeway users, yet will improve level of service on parallel routes.[43] Therefore, potential capacity improvements at the corridor level may also have regional impacts on traffic congestion and vehicle emissions.

Large capacity increases may induce traffic at both the corridor and regional levels, as people decide to take trips that they formerly would have foregone because of excessive congestion on the affected freeway or on parallel roads. Results from a recent study conducted by the Institute of Transportation Studies (ITS), University of California at Berkeley,[44] show that capacity expansion does induce traffic on the expanded facility, but that this effect occurs over an extended period of at least two decades. More importantly, however, the study shows that even after twenty years, the additional traffic induced by expansion falls well short of what would be required to produce the same volume-capacity ratios in the absence of a capacity enhancement project. This finding refutes the often repeated but unsupported notion that additions to roadway capacity are quickly and completely absorbed by additional traffic. Thus, capacity expansion can improve the level of service on the expanded facility; this improved level of service will be realized shortly after

---

[41] Ibid.

[42] IVHS America, *Strategic Plan for Intelligent-Vehicle Systems in the U.S.*, May 1992.

[43] Steven E. Shladover, *Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

[44] Institute of Transportation Studies, University of California at Berkeley, *The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Impacts*, April 1993.

the project is finalized and is likely to continue for many years. Increased roadway capacity is not likely to result in a system with equal congestion and more vehicles.

The ITS study found that the estimated demand-capacity elasticity four years after a capacity expansion ranges from under 0.1 to over 0.3; ten years after completion the range becomes 0.2 to 0.4. Therefore, a 10 percent increase in capacity is expected to result in a 1 to 3 percent increase in traffic four years after the capacity enhancement project is completed. Similarly, this 10 percent increase in capacity is expected to result in a 2 to 4 percent increase in traffic ten years after project completion. Sixteen years after project completion, the demand-capacity elasticity range is estimated to be 0.22 to 0.55. Although capacity-demand elasticity depends on the specific project under consideration, the magnitude of the induced traffic effect resulting from capacity enhancement projects is relatively low, since traffic will not expand to fill capacity until twenty or more years *after* the capacity enhancement project has been completed.

Similarly, results from the ITS study also indicate that road expansion generates traffic at the regional level. The study estimates a 0.5 intraregional elasticity and a 0.2 interregional elasticity of vehicle miles traveled on California highways with respect to changes in capacity (lane-miles) in urban regions. However, other factors such as population and income have a larger effect on the generation of traffic than does road expansion. The study indicates that population elasticities range from 0.7 to 0.8, while income elasticities are in the range of 0.4 to 0.9.

Since the capacity elasticities are less than unity, highway expansion is also expected to lead to reduced congestion at the regional level. Moreover, the study finds that as a result of larger population elasticities and faster population growth, population contributed considerably more than lane-mile growth to the vehicle miles traveled increases of the past two decades in the study region (California).

Although the focus of the ITS study is on lane-mile additions, many of the results are likely to apply to other types of capacity enhancements as well, including those brought about by

IVHS. Implementation of the systems in the specific IVHS technology bundles that may influence roadway capacity probably will not occur until the long term. Even if these systems lead to induced traffic, the ITS report shows that capacity expansion reduces volume-capacity ratios, thereby increasing roadway level of service over an extended period of time. Therefore, the notion that IVHS will result in a system of equal congestion and more vehicles is not supportable. Moreover, satisfaction of latent travel demand also benefits society by providing increased mobility and by contributing to increased economic activity.

In the long term, the implementation of automated vehicle control systems may generate new land use patterns that can lead to increased tripmaking and trip distances. If the effective speed on an automated corridor is twice the speed of that on the existing congested corridor, people may locate up to twice as far from workplaces without increasing the duration of their commute.[45] The emission effects of longer trips that may result from changes in land use are difficult to assess and will vary by road type. For example, if the longer trip takes place on a freely flowing highway, trip emissions could decrease, while longer trips on more congested roads will cause increased emissions. However, the emission performance of the in-use vehicle fleet are likely to change over time in ways that reduce the emissions impact of expanded capacity. Detrimental emission consequences associated with land use patterns that increase trip distance and tripmaking are likely to be reduced sharply as fuel specifications change, better emissions control strategies are introduced, and off-cycle emissions are controlled.

3.5 COMMERCIAL VEHICLE INSPECTION SYSTEMS

System Definitions

Commercial vehicle inspection systems have been conceptualized and designed to increase the productivity of those vehicles engaged in the movement of goods and services, and to

---

[45] Steven E. Shladover, *Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

simplify the regulation of commercial vehicles operating on intrastate and interstate highways. Strategies used in defining this technology bundle appear in appendix A. As discussed in section 2, it is not evident that productivity effects associated with automatic credentials checking, electronic permitting and payment, electronic recordkeeping, automated driver data processing, and traffic data collection systems will necessarily translate into significant emission effects.[46] As a result, these systems are not discussed in this subsection. Of the various commercial vehicle inspection systems, only weigh-in-motion and automated safety inspection systems are expected to have an impact on vehicle emissions by reducing congestion at weigh stations and by reducing the number of hot starts.

- *Weigh-in-motion* systems employ sensors that automatically weigh vehicles at mainline speeds. Coverage can be continuous, complete, and does not result in any delays to truckers.

- *Automated safety inspection* systems involve on-board diagnostic systems, scanners, and road-to-highway communication systems situated at safety inspection stations that can interrogate vehicles at mainline speeds for the condition of critical safety systems.

Market Penetration/Travel, Traffic, and Emission Impacts

The potential travel and emission impacts of weigh-in-motion and automated safety inspection systems are presented in table 3-5. Note that these systems may also result in decreased particulate matter emissions from heavy-duty vehicles.

Weigh-in-motion stations have been successfully tested, most notably in the California Heavy Vehicle Electronic License Plate (HELP) Crescent program, and full-scale short-term implementation may be solely constrained by regulatory and institutional barriers. The

---

[46] Conceptually, productivity effects *could* result in fewer truck trips. Electronic recordkeeping systems, for example, could increase average load on less-than-truckload carriers. Average load increase could potentially result in fewer trips.

congestion effects may be limited to corridors where systems may directly influence congestion at weigh stations. These systems may also indirectly influence congestion on the highway in which the weigh station is located by eliminating truck queues that back up onto the highway.

Systems that allow automated safety inspections to be conducted at mainline speeds could also reduce congestion at roadside inspection stations and along the supporting highway. Additional emissions benefits could be gained from reductions in the number of hot starts. Roadside safety inspections must be conducted under engine-off conditions and last an average of 34 minutes,[47] unlike current weight inspections that last only a few minutes once the vehicle reaches the scales, and that do not require engines to be turned off during the inspection. By eliminating the engine-off requirement, automated safety inspection systems can eliminate those emissions associated with hot starts during the inspection process. However, due to differences in the combustion processes experienced by gasoline versus diesel engines, the emission benefits of a potential reduction in the number of hot starts will only be significant for gasoline-powered heavy-duty vehicles. Emissions from a diesel-powered vehicle under hot start conditions are less important.

Table 3-5. Commercial vehicle inspection systems.

	Short-term Impacts		Long-term Impacts	
	Corridor	**Regional**	**Corridor**	**Regional**
Traffic Flow	Positive	Insignificant	Positive	Insignificant
Vehicle Trips	Insignificant	Insignificant	Insignificant	Insignificant
Trip Distance	Insignificant	Insignificant	Insignificant	Insignificant
Mode Shifts	Insignificant	Insignificant	Insignificant	Insignificant
HC Emissions	Positive	Insignificant	Positive	Insignificant
CO Emissions	Positive	Insignificant	Positive	Insignificant
NO_x Emissions	Positive	Insignificant	Positive	Insignificant

---

[47] Jack Faucett Associates, *Relative Effectiveness of Level I, II, and III Roadside Inspections*, November 1992.

3.6 TRIP GUIDANCE AND PUBLIC TRANSPORTATION SYSTEMS

System Definitions

Trip guidance and public transportation systems encourage the use of transit and rideshare facilities by increasing the attractiveness and accessibility to travelers. The systems included in this technology bundle increase the efficiency of high-occupancy modes of travel, thereby reducing operational costs while offering higher levels of service to the public. As shown in table 2-1, this technology bundle is composed of the following IVHS products and user services:

- *Ridesharing information systems* including online computers in business centers, shopping malls, homes, or smart kiosks that tie into a real time central data base where ridesharing matches can be identified.

- *Traveler information and service systems* including techniques to provide travelers with real time schedule and fare information, pretrip planning information, trip reservation and payment services, and rideshare participant selection and location information.

- *Traffic management systems*, as they relate to this technology bundle, are designed to give priority to high-occupancy vehicles through traffic signal priority, dedicated highway lanes, ramp controls, and toll strategies.

- *Transit and fleet management systems* are designed to better track transit vehicles during service and, thereby, improve scheduling, ticketing, and planning operations.

Market Penetration

From a technological perspective, the operational reliability of these systems is virtually assured, given that current communications and computer systems are well suited to handle the interface between centralized information clearinghouses and travelers (particularly for work-related trips). Moreover, the implementation of the systems may be accelerated by the 1990 Clean Air Act Amendments, which emphasize transportation control measures, such as ridesharing, as a means to reduce the air quality impact of transportation activities.

Market penetration of these systems will depend on the applicability and reliability of automatic vehicle identification, automatic vehicle location, automatic vehicle classification, and automated vehicle monitoring technologies. As discussed in appendix A, these enabling technologies are the building blocks of many IVHS products and user services. Their effectiveness has been proven by demonstration projects such as the HELP Crescent program.

The short-term implementation of traffic management systems does not appear to be constrained by technology. For example, experimental transit preferential signal priority schemes have been installed in Kent, Ohio, Louisville, Kentucky, and Washington, D.C. These schemes employ automatic vehicle identification technology to identify transit or other types of high-occupancy vehicles when approaching the specially equipped intersection.

Travel, Traffic, and Emission Impacts

Possible travel and emission implications of the implementation of trip guidance and public transportation systems are summarized in table 3-6. Under a scenario of full system implementation, the potential traffic operation impacts of this technology bundle may translate into reduced CO, HC, and NO_X emissions at both the corridor and regional levels. Although improvements in level of service may increase average speeds and thereby increase NO_X emission rates, *total* NO_X emission levels may be reduced as vehicle miles traveled and the number of vehicle trips fall. However, the effect on NO_X emissions will depend on the types of systems and the extent of their implementation. Thus, the impacts of this bundle on NO_X emissions are uncertain. These emission impacts can be realized in the short term, since the penetration of these systems is virtually unconstrained by technical factors.

The travel impacts of trip guidance and public transportation systems may include fewer vehicle trips and vehicle miles traveled as a result of person trip shifts from single-occupancy vehicle modes to high-occupancy vehicle modes. Although the number of person trips may not decrease, reductions in the total number of vehicle trips and total vehicle miles traveled will result in overall reduced congestion and improved level of service, at both the corridor and network levels. Trip guidance systems are also capable of influencing the temporal distribution of trips. Real time information on traffic conditions at the route level can induce motorists to delay trips to those times when congestion levels are low.

Table 3-6. Trip guidance and public transportation systems.

	Short-term Impacts		**Long-term Impacts**	
	Corridor	**Regional**	**Corridor**	**Regional**
Traffic Flow	Positive	Positive	Positive	Positive
Vehicle Trips	Positive	Positive	Positive	Positive
Trip Distance	Insignificant	Insignificant	Insignificant	Insignificant
Mode Shifts	Positive	Positive	Positive	Positive
HC Emissions	Positive	Positive	Positive	Positive
CO Emissions	Positive	Positive	Positive	Positive
NO_x Emissions	Uncertain	Uncertain	Uncertain	Uncertain

3.7 ENABLING TECHNOLOGIES FOR TRAVEL FEES

System Definitions

As shown in table 2-1, examples of IVHS enabling technologies for road pricing programs include automatic vehicle identification, location, and classification technologies, electronic toll collection, and smart cards. These are briefly described below.

- *Automatic vehicle identification* technologies use transponders, roadside readers, and computers that automatically and uniquely identify vehicles as they pass through specially equipped points on the system network, thereby making it possible to collect information and conduct transactions without requiring vehicles to suspend operation.

- *Automatic vehicle location* technologies provide vehicle location information to a control center by means of on-board computers or sensors. Using these technologies, traffic control centers will be able to monitor, on a real time basis, the location and movement of specific vehicles operating in the network.

- *Automatic vehicle classification systems* classify vehicles according to type, gross vehicle weight designation, or other attributes.

- *Electronic toll collection* streamlines the toll collection process by allowing for toll collection without vehicle stops.

- *Smart cards* involve a computer chip embedded in a credit card sized tag that stores personalized identification codes linked to centralized data bases.

Market Penetration

Conventional road pricing strategies can be implemented in the short term without the support of IVHS. Implementation barriers are political rather than technological, due to the difficulty of gaining public acceptance.

Given the political sensitivity of road pricing strategies and the potentially regressive nature of most programs, "smart cards" can be instrumental in the implementation of strategies that provide differential pricing based on income. The stigma associated with poverty and programs that alleviate it (such as food stamp programs) can be minimized through the use of smart cards.[48] Similarly, advanced vehicle classification technologies differentiate price based on vehicle type. For example, it may be economically more efficient and equitable if

---

[48] Lamont C. Hempel, National IVHS/Air Quality Workshop, March 1993.

user charges differ for passenger vehicles and heavy-duty trucks. Finally, automatic vehicle identification technologies will be integral to any system that attempts to implement and administer road pricing schemes.

Travel, Traffic, and Emission Impacts

The potential short term and long term corridor and regional impacts of this technology bundle on travel and emissions are provided in table 3-7. The short-term corridor-level impact on mode shift may be positive due to the use of high-occupancy vehicle buy-in lanes. On a per vehicle basis, NO_X emissions may increase as reduced congestion facilitates faster travel speeds. However, it is difficult to determine how overall NO_X emissions will change in the short term, since travel fees may have the effect of reducing the total number of vehicle trips. In the long term, significant changes in the number of vehicle trips may decrease total NO_X emissions at both the corridor and regional levels.

The impact of travel fees on travel demand, mode shifts, trip distance, and emissions will vary depending on the type of pricing program and the price level. Programs that attempt to increase travel cost to levels that reflect the entire social cost of using roadways may reduce significantly the number of vehicle trips during peak periods on the affected corridors, depending on the sensitivity of motorists to increases in trip costs. Travelers may use alternative routes, possibly increasing congestion on roadways not designed to support high volumes of traffic, or they may satisfy travel needs by using high-occupancy modes of travel. Under congestion pricing programs, trips may also be delayed to off-peak periods, during which the congestion externalities associated with an individual's travel demand are minimal.

The enabling technologies included in this IVHS bundle can increase the effectiveness of roadway pricing by minimizing the substitution of local streets and roads for high-capacity facilities. Automatic vehicle identification and location systems may facilitate the implementation of comprehensive roadway pricing at the regional level, so that travelers are charged appropriate travel fees for using any portion of the transportation network. In this way, the substitution on the part of travelers away from mainlines to local roads that may not be equipped for high traffic volumes can be minimized, so that the increase in travel cost at the network level tends to shift trips to alternative modes or delay trips to off-peak periods.

However, these strategies are likely to be unavailable in the short term, as technological, institutional, legal, ethical, and political barriers inhibit the implementation of local or regional schemes. In the short term, those urban areas that do implement road pricing programs are likely to do so only on selected high-capacity facilities. As a result, the short-term travel and emission effects of corridor-level projects are uncertain when considered from the perspective of the entire region or transportation network. In the long term, however, the *potential* does exist for significant travel and emission effects at both the corridor and regional levels.

Table 3-7. Enabling technologies for travel fees.

	Short-term Impacts		Long-term Impacts	
	Corridor	**Regional**	**Corridor**	**Regional**
Traffic Flow	Positive	Uncertain	Positive	Positive
Vehicle Trips	Positive	Uncertain	Positive	Positive
Trip Distance	Insignificant	Uncertain	Positive	Positive
Mode Shifts	Positive	Uncertain	Positive	Positive
HC Emissions	Positive	Uncertain	Positive	Positive
CO Emissions	Positive	Uncertain	Positive	Positive
NO_x Emissions	Uncertain	Uncertain	Positive	Positive

3.8 EMISSION CONTROL ENABLING TECHNOLOGIES

System Definitions

This technology bundle includes those devices and systems that have the potential to mitigate mobile source emissions directly by complementing conventional emission control strategies, such as inspection and maintenance programs. This bundle includes remote sensing devices and vehicle condition warning systems, briefly defined below.

- *Remote sensing devices* measure the concentration of pollutants in the exhaust plume of vehicles as they pass a roadside monitoring station. These devices involve an infrared beam that crosses the exhaust plume and a signal receiving detector that can communicate with an emissions diagnostic computer. The computer then calculates exhaust gas concentrations. Emission readings are superimposed on a freeze frame video-picture of the vehicle's license plate, which allows authorities to identify potential gross-emitters. Emission concentrations are converted to emission rate estimates using an assumed fuel consumption rate.[49]

- *Vehicle condition warning systems* include vehicle diagnostic mechanisms that monitor the fuel consumption and exhaust emissions of vehicles and advise drivers on appropriate maintenance practices.

Market Penetration

Remote sensing devices are available for short-term implementation. Although their accuracy in measuring emission concentrations has been well established, various problems must still be resolved if these devices are to have a significant impact as a complementary control strategy to conventional inspection and maintenance programs. For example, instantaneous measurements of emissions vary dramatically with transient mode operations, such as enrichment processes or hot versus cold start operational conditions, resulting in incorrect identification of gross-emitters. However, remote sensing devices can still be effective in identifying *candidate* gross-emitting vehicles[50] when deployed at specified points in the network infrastructure, such as intersections or freeway ramps.

---

[49] Lamont C. Hempel, *Exploring the Transportation-Environmental Nexus: The Role of IVHS in Reducing Urban Air Pollution Caused by Congestion and Super-Emitting Vehicles*, March 1993.

[50] Ibid.

Vehicle condition warning systems can also be applied in the short term. Since 1981, manufacturers of motor vehicles have installed an on-board computer and memory system on many models which is used to monitor and control engine systems. The computer is also used for on-board diagnostic of performance-related components. This on-board system can be expanded to include the diagnostic of in-use emission control component malfunctions. Section 205 of the 1990 Clean Air Act Amendments promulgates regulations requiring manufacturers of light-duty vehicles and light-duty trucks to install emission diagnostic systems beginning in model year 1994. The California Air Resources Board has promulgated similar regulations that require vehicle manufacturers to install on-board diagnostic devices that monitor the performance of catalytic converters. Therefore, the short-term penetration of on-board emission diagnostic systems may be accelerated by these regulations, and penetration rates may only be constrained by vehicle turnover rates.

Travel, Traffic, and Emission Impacts

The potential effects of this technology bundle are summarized in table 3-8. Remote sensing devices and on-board diagnostic systems are not expected to impact traffic operations or the number of vehicle trips at either the corridor or regional levels. Rather, the utilization of these devices and systems is expected to improve current processes that attempt to mitigate emissions from in-use vehicles. An integrated emissions identification, inspection, and maintenance approach may significantly reduce in-use emissions from motor vehicles. In the short term, benefits may be constrained by vehicle turnover rates and operational deficiencies. In the long term, the impact of this technology bundle on in-use emissions will be more significant, as all in-use motor vehicles begin to employ on-board emission diagnostic systems and the operational reliability of remote sensing devices is improved. When fully implemented, remote sensing devices and on-board diagnostic systems can help urban areas reduce air pollution and help them attain National Ambient Air Quality Standards.

The effectiveness of remote sensing devices and on-board diagnostic systems in reducing emissions from motor vehicles will also depend on the reliability of these systems and the manner in which they are combined with conventional approaches, especially inspection and maintenance programs. For example, the use of remote sensing devices as an alternative to scheduled, periodic inspection and maintenance programs has several major shortcomings related to the inability of remote sensing devices to obtain readings on all vehicles; to measure evaporative, crankcase, and NO_x emissions; to detect problems with systems designed to control emissions during engine warm-up operation; and to distinguish vehicles with moderately high HC and CO emissions from those that are free from defects.

However, as a supplement to conventional inspection and maintenance programs, remote sensing offers two potential advantages by:

- Providing a deterrent to the tampering or maladjustment of emission control devices by a vehicle owner that might occur after successful completion of a periodic inspection and maintenance test; and

- Allowing for early detection of emissions related vehicular defects unrelated to tampering that can occur between periodic inspections.

Similarly, the penetration of on-board emission diagnostic systems has the potential to improve the identification, by vehicle owners, of emission control system malfunctions. Whether or not vehicle owners that are alerted to malfunctions will repair their vehicles in a timely fashion depends on many factors unrelated to the reliability of on-board diagnostic systems. It is important to combine strategies that facilitate the identification of system malfunctions, such as on-board diagnostic systems, with those that accelerate repair practices and deter tampering of emission control devices, such as remote sensing devices and inspection maintenance programs.

Table 3-8. Emission control enabling technologies.

	Short-term Impacts		Long-term Impacts	
	Corridor	Regional	Corridor	Regional
Traffic Flow	Insignificant	Insignificant	Insignificant	Insignificant
Vehicle Trips	Insignificant	Insignificant	Insignificant	Insignificant
Trip Distance	Insignificant	Insignificant	Insignificant	Insignificant
Mode Shifts	Insignificant	Insignificant	Insignificant	Insignificant
HC Emissions	Positive	Positive	Positive	Positive
CO Emissions	Positive	Positive	Positive	Positive
NO_x Emissions	Positive	Positive	Positive	Positive

3.9 A SUMMARY OF THE POTENTIAL EMISSION IMPACTS OF IVHS

The impact of IVHS on emissions is directly a function of the staged implementation of technologies and systems and the resulting travel and traffic repercussions. Most technologies and systems will lead to improvements in level of service at both the corridor and network levels. These improvements are likely to be measured in small percentage terms, rather than in orders of magnitude, and level of service improvements are not expected to induce significant amounts of travel. Some IVHS strategies can potentially decrease emissions by improving traffic flow, while others can reduce the number of vehicle trips (and cold and hot starts) by promoting travel on high-occupancy vehicles and public transit systems.

Although better control of off-cycle emissions will reduce the magnitude of the emission benefits that result from improved traffic flow, the emission impacts of most IVHS actions may still be positive. When combined with remote sensing devices, on-board diagnostic systems, and travel fees, IVHS strategies that improve traffic flow and the level of service on roadways have the potential to alleviate air quality problems associated with congestion, poor vehicle maintenance, and wasted travel.

Vehicle control systems have the potential to induce traffic as a result of significant increases in roadway capacity, yet it is unlikely that the induced traffic generated by these systems will result in a transportation system characterized by the same level of congestion and more vehicles. Moreover, the implementation of those vehicle control systems that can significantly increase capacity, such as automated highways, may not occur until the long term. In that time frame, emissions from motor vehicles may be much lower than current levels, as fuel specifications change (e.g., reformulated fuels), and advanced emission control technologies (e.g., electrically heated catalysts) become feasible.

The following section discusses the research and data collection efforts that will be necessary to quantify the travel and emission impacts of the products, user services, and technologies that comprise IVHS.

4. NECESSARY RESEARCH AND DATA COLLECTION EFFORT

Quantitatively estimating IVHS effects on motor vehicle emissions will require extensive research and data collection efforts in the areas of mobile source emissions modeling, travel demand modeling, traffic simulation modeling, travel behavior analysis, and the interface of models for use in an IVHS assessment framework. The task is complicated by the uncertainty surrounding the qualitative estimates that have been presented in section 3. More thorough understanding of the fundamental relationships between motor vehicle operations and emissions, economic incentives and travel behavior, and road capacity improvements and induced travel demand (to name a few) is crucial to an accurate and representative assessment of the likely emission repercussions of IVHS deployment in regions across the country, especially in nonattainment areas. Models that describe these relationships and that interface with one another are necessary tools for IVHS evaluation efforts. Integration of these models will allow for an assessment framework that accounts for the dynamic relationships between the factors that influence the levels of mobile source emissions.

The development of a research and data collection agenda to better understand and model the fundamental relationships that are referenced above was the focus of both the National IVHS/Air Quality Workshop held recently in Diamond Bar, California and the Video-Conference on IVHS and Air Quality held in Washington, D.C. and San Francisco. It is clear from these "meetings of minds" among experts in the study of mobile source emissions, travel demand, travel behavior, IVHS, and public policy that although advances have taken place in mobile source, travel demand, and traffic simulation modeling during the past two decades, many currently available tools are inappropriate if applied to an IVHS emissions assessment framework. This section provides a detailed accounting of the research and data collection issues that were prioritized in these conferences, as well as other issues that need to be more fully addressed.

4.1 MOBILE SOURCE EMISSIONS MODELING

Light-duty Vehicle Emissions

Current versions of the U.S. Environmental Protection Agency's MOBILE and the California Air Resources Board's EMFAC emission factor models cannot incorporate accurately the likely emission effects of IVHS actions that improve traffic flow and increase average speeds. Traffic and incident management systems, route guidance systems, and accident reduction systems are expected to improve traffic flow on mainlines, arterial corridors, and intersections during peak travel periods. Because vehicle emission rates directly vary with speed, acceleration, and deceleration, smoother traffic flows will change the emission rates of vehicles. By reducing acceleration and deceleration components of a vehicle trip, inertial energy losses are minimized, and emissions associated with these modes of activity are also avoided.[51]

Changes in the speed profiles of vehicle trips cannot be accounted for accurately in current versions of MOBILE and EMFAC. The baseline exhaust emissions data contained in both models are based on a standardized driving cycle that was originally developed to duplicate the speed-time profile of a road route in the Los Angeles metropolitan area in the late 1960s. This driving pattern was then incorporated into the testing process employed by automobile manufacturers for emissions certification, called the federal test procedure (FTP).[52]

The drive cycle used in the FTP simulates a trip distance of about 7.5 miles at an average speed of 19.6 miles per hour. It does not allow for travel speeds above 57 miles per hour, for accelerations greater than 3.3 miles per hour per second, nor for sharp decelerations. The relationship between speed and automobile emission rates follows a parabola-type curve in which rates are minimized at travel speeds roughly between 20 and 60 miles per hour and sharply increase at speeds below 20 miles per hour and above 60 miles per hour. Relation-

---

[51] Daniel Sperling, Randall Guensler, Dorriah Page, and Simon Washington, *Air Quality Impact of IVHS: An Initial Review*, 1992.

[52] Sierra Research, Inc., *Evaluation of "MOBILE" Vehicle Emissions Model*, April 1993.

ships between speed and emissions, such as this one, have been derived from drive cycles that employ average speeds, but none of the test cycles are characterized by flows at close to constant speed, or extremely smooth flows.[53]

Emission consequences of IVHS actions like ramp metering and advanced vehicle control systems cannot be currently modeled because EMFAC and MOBILE do not model sharp acceleration and deceleration events nor high-speed travel. As mentioned in section 2, the National Research Council concluded that motor vehicles emit two to four times as much hydrocarbon and carbon monoxide pollutants as that estimated by the U.S. Environmental Protection Agency and the California Air Resources Board using MOBILE and EMFAC. Much of this estimation shortfall has been blamed on the federal test procedure and its inability to duplicate real world urban driving patterns. Driving characteristics are situation-specific, and variations in speed, acceleration, and deceleration can have significant effects on emission rates. In order to quantify accurately the effects of smoother traffic flows brought about by IVHS technology bundles like traffic and incident management systems or route guidance systems, drive cycles need to be constructed to represent a wide variety of functional class roadways and driving situations.[54] Both the U.S. Environmental Protection Agency and the California Air Resources Board have begun efforts to better characterize real world driving behavior and driving patterns.

Heavy-duty Vehicle Emissions

As is the case with various aspects of emissions modeling for light-duty vehicles, neither MOBILE nor EMFAC accurately model heavy-duty vehicle emissions. This is largely due to the lack of data on heavy-duty vehicle emission rates and to methodological uncertainties in modeling algorithms.

---

[53] Daniel Sperling, Randall Guensler, Dorriah Page and Simon Washington, *Air Quality Impact of IVHS: An Initial Review*, 1992.

[54] Burton Stephens and Charles Goodman, *Summary Conclusions: Video-Conference on IVHS and Air Quality*, March 1993.

As with light-duty vehicles, baseline in-use vehicle emission rates for heavy-duty diesel and gasoline vehicles are determined through laboratory testing using the methods and procedures developed by the U.S. Environmental Protection Agency and the California Air Resources Board. However, heavy-duty vehicle emissions testing differs from light-duty vehicle emissions testing, since the testing of heavy-duty vehicles is conducted on an engine dynamometer as opposed to a chassis dynamometer. Uncertainty is introduced into heavy-duty emissions testing through the necessary use of conversion factors to prepare grams per mile emission rates for use in mobile source emission models and analyses. For example, MOBILE uses a conversion factor routine to translate emission factors from grams per brake-horsepower-hour to grams per mile. This routine is based on fuel data — specifically, fuel density, brake-specific fuel consumption, and fuel economy. For 1988 and later model year heavy-duty vehicles, fuel economy is projected using technology penetration scenarios (e.g., weight efficiency improvements, drag reduction technologies, etc.), while fuel economy estimates for pre-1988 model year heavy-duty vehicles are derived from survey data — DOT's Truck Inventory and Use Survey (TIUS). Although the conversion factors are likely to reflect accurate fuel density and brake-specific fuel consumption data, the representativeness of fuel economy data is questionable. Measures to overcome data constraints on in-use heavy-duty vehicle emission factors, such as the conversion process described above, lead to uncertain estimates.[55]

In addition, current heavy-duty vehicle emission modeling routines are based on drive cycles (a federal test procedure and a 13-mode steady-state test) that may not reflect actual heavy-duty vehicle driving patterns in many urban areas. As with light-duty emission rate results, uncertainty exists from the outset as a function of the precision and accuracy associated with the individual sampling and test methods.[56] The U.S. Environmental Protection Agency's heavy duty drive cycles are based on data gathered from instrumented heavy-duty vehicles operating in New York and Los Angeles during the mid-1970s. The testing procedure uses an estimated cycle speed of 19.45 miles per hour and an approximate trip length of

---

[55] Telephone conversation with Phil Heirigs of Sierra Research Inc., April 1993.

[56] Randall Guensler, Daniel Sperling, and Paul Jovanis, *Uncertainty in the Emissions Inventory for Heavy-Duty Diesel-Powered Trucks*, June 1991.

6.4 miles, and it includes 36 percent idle operation. Tests are run in both hot start and cold start modes, with test results weighted one-seventh cold starts and six-sevenths hot starts. These splits probably do not represent actual vehicle operations.[57] The overall certification procedure needs to be evaluated to assure that current drive cycles and assumptions replicate real world heavy-duty vehicle driving patterns.

Furthermore, emission factors currently employed by MOBILE for heavy-duty diesel vehicles are based on only a sample of 30 in-use vehicles tested in 1983/84 by the U.S. Environmental Protection Agency and the Engine Manufacturers Association. The final in-use heavy-duty diesel engine emission factors are based on test results from 22 of the 30 engines that were tested.[58] Therefore, this sample must be expanded to include more heavy-duty vehicle configurations, model years, and engine types.

4.2 TRAVEL DEMAND MODELING

Transportation forecasting, originally designed to estimate changes in transportation demand in response to changes in capacity, includes these four general steps: 1) trip generation, 2) trip distribution, 3) mode choice, and 4) network assignment. Trip generation models relate land use and transportation demand by estimating the number of trips that result from a set of land use and activity configuration parameters. Given the number of trips that the system must absorb, trip distribution models describe the spatial and temporal characteristics of trips. Mode choice models are then used to determine the modal share of trips between various origins and destinations (e.g., percent of trips between an origin and destination that are taken by car, bus, train, etc.). Finally, network assignment models allocate, by mode and time of day, among different routes connecting each origin and destination.

Several improvements must be made to these series of travel demand models in order to quantify the emission effects of IVHS deployment. The need to improve their sophistication

---

[57] Ibid.

[58] Ibid.

to better account for demographic, geographic, economic, and political realities is widely recognized by transportation planners and policy makers.[59] Activity has already begun to develop a new generation of models that better characterizes the effects of transportation demand management strategies, capacity improvements, land use policies, and other relevant issues. While much of this activity complements the model changes that are necessary to quantify the emission effects of IVHS deployment, additional efforts are necessary to address this goal. The following discussion has been tailored to those research topics especially relevant to IVHS and travel demand modeling.

For travel forecasting models to accurately represent the tripmaking impacts of IVHS, various issues need to be researched and incorporated into a travel demand modeling framework. One is the relationship between accessibility and location decisions, and the accessibility impacts of advanced transportation technologies like IVHS. Historically, improved accessibility has resulted in shifts in land use patterns from the central district (or city) to surrounding areas (or suburbs). From an emissions perspective, different land use policies and location decisions result in differences in trip starts and trip distances. Long-term IVHS strategies, such as vehicle control systems, may affect land use patterns as system capacity improvements induce new land developments and household locations farther away from employment centers. As a result, the relationship among trip distance, trip duration, and household location needs to be better understood. This is mostly relevant to work trips, although other trip types are also influenced by household location.

Another important issue is the development of activity-based trip generation models necessary to characterize trip chaining accurately. Once this has been accomplished, it will be necessary to formalize the relationship between improved information, such as that available from IVHS deployment, and trip chaining. Current trip generation models are not sensitive to trip chaining. In many metropolitan areas across the U.S. the share of work trips relative to non-work trips has decreased. This can be partially attributed to trip chaining, or the

---

[59] An evaluation of transportation models from the perspective of air quality is provided in the following studies: Greig Harvey and Elizabeth Deakin, *A Manual of MPO Practice in Transportation Modeling for Air Quality Planning*, November 1992.
Greig Harvey and Elizabeth Deakin, *Toward Improved Regional Transportation Modeling Practice*, 1992.

linking of one trip to another (e.g., home to day care to work, or work to day care to home). Trip chaining may significantly alter the emissions profile of trips by decreasing the fraction of trips undertaken in a cold start mode, thereby reducing emissions by converting potential cold starts into hot starts. IVHS technologies that improve the quality and completeness of travel information, such as trip guidance and public transportation systems, may directly affect the timing and methods employed by travelers to satisfy a set of activities. Travelers may be more inclined to link many activities during trips, as they can better plan a trip given improved, real time information on traffic conditions, route choice, and public transit opportunities. Therefore, IVHS could facilitate trip chaining directly by improving the efficiency of the transportation network and providing travelers with more complete information about possible destinations where their needs and activities can be readily satisfied, the proximity of those places to other destinations, and the modes available to reach them.

Induced travel demand effects of IVHS deployment also need to be better understood and modeled in the trip generation framework. Currently, the induced effects of new capacity are not modeled correctly.[60] Although most IVHS actions will not have significant induced travel demand effects, there is debate about how extensively automated highway systems will lead to induced travel in the long term through their effects on highway capacity. Travel demand experts that attended the Video-Conference on IVHS and Air Quality generally agreed that the induced travel potential of IVHS strategies is likely to be minimal. However, others argue that technologies which facilitate motorized travel will lead to significant increases in travel demand beyond increases attributable to demographic factors.[61]

Trip distribution models must accurately mimic changes in temporal trip distributions that are brought about by IVHS. One important potential contribution of IVHS, specifically trip guidance systems, relates to changes in the temporal distribution of trips. Improved travel information may induce motorists to delay trips to off-peak periods or to forgo trips

---

[60] Fred Ducca, National IVHS and Air Quality Workshop, March 1993.

[61] Jon Kessler, National IVHS and Air Quality Workshop, March 1993.

altogether. Current trip distribution models often assume the distribution of trips by time of day to be fixed, ignoring the effects of traffic congestion and demographic factors that affect departure time choice. In particular, the current modeling regime typically lacks feedback loops between modeling subroutines. Departure time choice models that can be integrated into the trip generation and distribution frameworks need to be developed. In this manner, trip estimates can be generated separately by time of day. But to incorporate IVHS into the modeling framework, more must be known about the relationships among reduced congestion, improved travel and route information, improvements in level of service, increased capacity, and the temporal distribution of trips by trip type.

Travel demand impacts of transportation demand management strategies (such as high-occupancy vehicle lanes, road pricing, ridesharing, car pooling, etc.) also need to be more fully incorporated into the modeling framework. Models that are sensitive to transportation control measures need to be developed to test the travel demand effects of various strategies. IVHS technologies can play an integral role in the application of road pricing programs. The effect of such transportation control measures on travel demand and peak period congestion needs further research. Activity-based transportation demand models that replicate household travel behavior on a 24-hour basis may best serve this need.

4.3 TRAFFIC SIMULATION MODELS

Traffic simulation models will be essential for evaluating operational tests of traffic and incident management systems, route guidance systems, and accident reduction systems. Implementation of these IVHS technology bundles is expected to result in more efficient traffic operations. Unlike travel demand models that focus on regional-level tripmaking, spatial and temporal trip distribution, mode shares, and network assignment, traffic simulation models focus on the movement of vehicles along a specific corridor and may directly include the effects of lane capacity, level of service, road geometry, and signalization on traffic operations.

Computerized traffic simulation models will play a major role in the design, analysis, and evaluation of traffic and incident management systems, route guidance systems, and other actions that affect traffic operations. Advanced traffic signalization systems will be a basic element of IVHS, contributing significantly to overall system efficiencies and reducing congestion at the corridor level. IVHS components such as electronic route guidance and surveillance systems and fully adaptive traffic signalization systems need to be linked with simulation models for an accurate assessment and evaluation of traffic and incident management systems and route guidance systems.

The vision of IVHS planners is to develop a traffic environment characterized by integrated networks of highways, freeways, and urban roads. Models that simulate traffic flow under an integrated system, rather than current models that simulate traffic at the corridor level, will be required to accomplish this. New models must be able to accept and interpret real time traffic data received from surveillance points along the network and to represent real time demand and supply conditions along a corridor or over the entire regional network. In this manner, interactive signal coordination systems can be tested and eventually deployed, and the full efficiency effects and corresponding emission impacts of traffic and incident management systems and route guidance systems can be better assessed.

From the point of view of emissions modeling, traffic simulation models that mimic vehicle operating conditions on various roadway types and at specific points along the network can help resolve the problems associated with emissions testing and certification under the federal test procedure. The testing of drive cycles produced by these microscopic models should be initiated as early as possible in order to improve modeling capabilities for assisting with IVHS deployment decisions. Current models that could be modified to achieve this goal include TRAF-NETSIM and FRESIM.[62]

The need to better understand traffic operations and flow characteristics is increasing the level of attention to and reliance upon traffic simulation models. This perspective should not

---

[62] Burton Stephens and Charles Goodman, *Summary Conclusions: Video-Conference on IVHS and Air Quality*, March 1993.

replace the four-step travel forecasting model, but rather should probably be linked to it. Future research should address this linkage and the linkage of travel models with mobile source emission models.[63] In fact, work has already begun on an integrated modeling framework that addresses both the macroscopic and microscopic aspects of travel demand and traffic operations, as well as the emissions profile of various trip types. For example, Ruyichi Kitamura of the Institute for Transportation Studies, University of California at Davis is currently in the process of developing an activity-based travel demand model that overcomes the deficiencies of conventional transportation planning systems by replicating the causal dynamics underlying the travel behavior of households across an explicit temporal dimension on a 24-hour continuous time basis. The outputs of this model are envisioned to include the following: trips and trip chaining, travel times and routes, vehicle occupancy, travel modes and destinations, departure and arrival times, and the number of cold and hot vehicle starts. The interface requirements for an emissions module that uses as inputs the outputs of the activity-based travel model are also being evaluated. The expected results of this integrated framework include improved forecasts of link volumes, vehicle operating conditions, and emissions.

4.4 TRAVEL BEHAVIOR ANALYSIS

The effectiveness of IVHS in reducing congestion, promoting high-occupancy vehicle travel, improving safety, and increasing the overall efficiency of the movement of people and goods on the surface transportation system largely depends on the effect that advanced technologies, products, and services have on user behavior. Technology bundles such as route guidance systems, trip guidance and public transportation systems, and certain traffic and incident management systems are predicated upon the assumption that increased and more reliable information on travel conditions will be used effectively by the traveling public. While it is evident that imperfect information on traffic conditions has contributed to the congestion problems currently faced by many metropolitan areas across the country, the degree to which travelers will make effective use of improved travel information for their trip, route, and mode decisions is not well understood. A better understanding of the willingness of different

---

[63] Ibid.

segments of the population to use such information is necessary for an appropriate assessment of the travel impacts of IVHS.[64]

An important aspect of IVHS implementation is the ability of trip guidance and advanced public transportation systems to promote trip shifts from single occupancy vehicles to high-occupancy vehicles. However, the effects of these systems on the underlying variables that drive preferences between single-occupancy vehicle and high-occupancy vehicle travel need to be investigated. It is possible that advanced, more user friendly public transportation systems may not induce a significant number of travelers to shift from single occupancy vehicles to public transit or ridesharing. Convenience, time, independence, cost, and many other tangible and intangible factors determine the preference of travelers for single occupancy and high-occupancy vehicle travel modes. It is important to better understand, within the context of IVHS, the theoretical and empirical relationships between such factors and mode choices so that trip guidance and public transportation systems are designed and implemented in a way that will benefit current users of high-occupancy vehicle modes *and* shift traveler preferences toward these more efficient forms of travel.

Travel cost is likely to impact travel behavior, including mode choice. It is this expectation that has focused the attention of analysts and policy makers toward road pricing programs for reducing both congestion and mobile source emissions. As discussed in earlier sections of this report, various IVHS technologies, products, and user services can be employed to enable corridor or regional pricing strategies. However, many fundamental questions have yet to be answered regarding the relationship between travel demand, mode choice, and travel cost. If road user charges are invoked, for example, their effectiveness in managing travel demand or inducing shifts to more efficient modes will depend greatly on the sensitivity of motorists to increased travel cost. This sensitivity is a function of many variables, including trip duration, trip distance, trip type, trip price of competing modes, income, demographic and geographic factors, and many other factors that directly or indirectly affect travel demand.

---

[64] Ibid.

Extensive research efforts are required to better understand the effectiveness of different pricing strategies (e.g., congestion pricing, road pricing such as high-occupancy vehicle lane buy-in, emission taxes, etc.) in affecting travel behavior and reducing tripmaking, vehicle miles traveled, vehicle hours traveled, and emissions. Researchers should also investigate political and institutional constraints to the implementation of road pricing programs, given that voter acceptance of such programs is questionable. The focus should be on assessing the most effective program types, determining their likely political and institutional feasibility, determining potential equity impacts, and developing strategies that will sway public opinion toward their implementation. Clearly, without a comprehensive understanding of these issues, the effect of road pricing programs on emissions reduction cannot be accurately quantified.

Large-scale surveys can be conducted to determine the response and acceptability of motorists to road pricing. Longitudinal surveys also need to be designed and conducted to statistically characterize travel behavior and the effect of other transportation control measures on travel demand.

In order to estimate travel behavior changes resulting from route guidance systems, vehicle control systems, and accidental reduction systems, research is needed on the likely penetration of these technologies into the in-use vehicle fleet. Expected technology penetration rates can then be employed in an IVHS modeling framework. Surveys could determine the marketability of on-board technologies and devices, such as on-board navigation systems. As mentioned previously, many on-board technologies are expected to be expensive when first introduced. Full implementation may not occur until the long run, when prices fall to more acceptable levels and the systems are offered as standard equipment on new vehicles.

4.5 OPERATIONAL FIELD TESTS

Operational field tests currently underway will help to determine the operational reliability of IVHS technologies, the scope and timing of their implementation, and their likely impacts on traffic operations. However, these operational field tests do not directly assess the environmental effects of the relevant system being tested. This fact follows from the secondary role that energy consumption and vehicle emissions have taken to system development in the conceptualization of IVHS strategies. Future operational field tests should be tailored not only to determine the technical feasibility of IVHS technologies, but also their environmental consequences. The incorporation of emissions and air quality into testing programs can eventually result in the development and implementation of advanced transportation technologies that improve air quality at both regional and local levels.

This change in approach was a central theme during both the National IVHS/Air Quality Workshop and the Video-Conference on IVHS and Air Quality. A demonstration project was recommended by participants at the video-conference to assess the effective interface between on-board diagnostic systems and queries from the highway system, as well as the use of remote sensing devices to accommodate data needs associated with in-use vehicle emissions. Similarly, participants at the national workshop stressed the need for operational tests specifically designed to apply mechanisms to improve air quality.

APPENDIX A: IVHS TECHNOLOGIES, PRODUCTS, AND SERVICES

IVHS America divides IVHS into the six functional areas that are briefly described in section 2, and the literature follows this taxonomy when describing the systems that are included within each functional area. This appendix also follows this taxonomy in describing the systems, products, and user services that are included in each functional area. While all attempts have been made to assure that most of the individual systems are included in this study, the lack of detail in much of the literature with respect to individual system identification and definition may have resulted in the exclusion of certain products or services. However, the specific systems defined below span the full array of the technologies that comprise IVHS (i.e., information processing, communications, computer hardware and software, detection, control, and electronics).

Embedded in many of the products and user services that constitute IVHS are *automatic vehicle identification* and *automatic vehicle location*. Because of their important role and applicability to different products and services, these technologies are described first.

Automatic Vehicle Identification makes possible the collection of information and the performance of transactions (e.g., toll collection) without requiring vehicles to stop, by automatically and uniquely identifying vehicles as they pass through specific points on the system network. Automatic vehicle identification systems have three functional elements:

- Vehicle mounted *transponders* or identification tags;
- *Roadside readers* with associated communication antennas; and
- A linked *computer system* with data processing, storing, and transmission capabilities.

Automatic vehicle identification is a proven technology that must often be applied in each of the six functional areas that comprise IVHS, and in many cases represents the foundation for a system's effectiveness. Moreover, this technology is integral in *enabling* the implementation of transportation demand management strategies, such travel fees. Without automatic vehicle identification, many IVHS actions will remain in the conceptual rather than implementation stage — for example, electronic toll collection. At present, automatic vehicle identification is being used in the Heavy Vehicle Electronic License Plate (HELP) Crescent project on the North Dallas Tollway and on the Coronado Bridge.

Automatic Vehicle Location systems provide vehicle location information to a control center through on-board computers. Similar to on-board navigation systems, first generation automatic vehicle location systems employ dead reckoning, beacon proximity, or radio determination as location technologies. Future systems will employ satellite systems conceptually similar to global positioning satellites, with the difference being that the location determination will occur at a stationary site rather than at the vehicle itself — an example of these satellite technologies is the radio determination satellite services. As such, automatic vehicle location may play an important role in real time electronically linked route guidance systems, as traffic control centers will be able to monitor, on a real time basis, the location and movement of specific vehicles in the network. Similarly, short-run applications of automatic vehicle location will be used primarily in commercial vehicles to improve carrier tracking efficiencies in the movement of freight and to reduce empty backhauls. Automatic vehicle location is already widely employed by police vehicles, public transit, and emergency vehicles.

A number of technologies (not further described in this report) are currently available or under development to facilitate automatic vehicle location. These include global positioning satellites, LORAN-C transmitters, and proprietary satellites.

A.1 ADVANCED TRAFFIC MANAGEMENT SYSTEMS

Traffic management systems strive to achieve the following goals: smoother traffic flows, shorter trip durations, fuel savings, emission reductions, and generally reduced congestion.

Advanced traffic management systems encompass technologies that integrate current and new surface transportation management and control systems to allow control centers to respond to real time traffic conditions on a defined network while servicing motorized modes of surface transportation. The foundation of advanced traffic management systems is a surveillance system that detects traffic conditions over a wide geographic area and transmits dynamic information to traffic management centers. These systems are geared to minimize the externalities associated with both recurrent and nonrecurrent congestion by providing real time information to traffic management centers on the time and location of congestion and incidents. Communication between the road and the control center will enable traffic managers to react to changes in traffic flow with a combination of control strategies, such as signal timing, ramp metering, rapid incident response, and responsive demand management concepts (e.g., road pricing). In addition, advanced traffic management systems can be applied specifically to gear the transportation system towards high-occupancy vehicles by giving them priority in the network.

The specific systems that comprise this functional area can be divided into four categories, each addressing a particular aspect of traffic management: traffic signalization, electronic toll collection, incident detection, and freeway and corridor control. The following are brief describes each of these categories and the systems they include.

Traffic Signalization Systems are an essential component of advanced traffic management systems. Improvements in traffic flow will be directly related to advances in traffic signalization that incorporate real time data on network capacity and demand. In order to implement the more advanced traffic signalization systems, new traffic models will need to be created, including real time traffic assignment models and real time traffic simulation models. However, various techniques already exist for optimal signal control at isolated intersections and in fixed-time coordinated networks. It is worthwhile to not only describe the more advanced traffic signalization systems, but also to describe the first (or earlier) generation systems that make up this category of advanced traffic management systems.

- *Optimized vehicle actuation.* Isolated intersections may be operated with fixed-time, semiactuated, or full (optimized) vehicle actuation. Optimized vehicle actuation can be considered as a first generation advanced traffic signalization system that can be fully implemented in the short term. It calculates signal timings at isolated intersections according to a predetermined performance measure using computer optimization techniques. Optimized vehicle actuation will reduce unnecessary stops and delays at isolated intersections. Isolated control will remain predominant in all areas where signal density is low, since linking the network in such areas would not be a viable option. As a result, full implementation of optimized vehicle actuation may have efficiency effects in terms of capacity improvements and corresponding reduced travel times, fuel efficiency gains, and emissions reduction.

- *Fixed-time coordination* functions at the network level through network optimization techniques. These techniques have been developed through various generations of macroscopic traffic models, such as the Traffic Network Study Tool (TRANSYT) program that models traffic behavior, carries out an optimization process, and calculates the best signal settings for an entire network. The TRANSYT program also provides information on the network's performance, generating data on estimated delays, stops, speeds, and fuel consumption. Signal plans, based on simulation of the network, are developed and implemented in the fixed-time coordination routine. These plans are not based on real time network conditions. Rather, they reflect modeling approximations of the network's performance under various conditions including the diurnal patterns of travel demand that the network must satisfy. As a result, the benefits offered by fixed-time signal plans will depreciate over time as traffic conditions change in the network and must be updated periodically to reflect demand changes over the network, changes in link flows, or physical or regulatory changes to the network infrastructure.

Fixed-time coordination provides a viable short-term option to alleviate congestion, travel times, stops, and associated delays.

- *Partially adaptive coordination.* In contrast to fixed-time coordination schemes, traffic-adaptive control systems react to real time network conditions. Detection devices allow these systems to adapt themselves to traffic patterns and respond to traffic demands as they occur. First and second generation traffic-adaptive control systems include partially adaptive coordination systems that involve automatic signal plan selection. Under first generation partially adaptive coordinations, data transmitted from roadside detectors, situated along predetermined positions on the network deemed to be critical, are employed to select the most effective signal control plan from a predetermined library of plans. While most first generation systems still require the development of off-line signal plans based on traffic simulation models, some of these systems can store 60 to 100 alternative signal plans and can instantaneously implement the closest match. As a result, the benefits of first generation partially adaptive coordination systems may exceed the benefits of fixed-time coordination systems.

  Second generation partially adaptive coordination systems involve real time, online systems that compute and implement signal timing plans based on surveillance data and predicted changes in traffic patterns and flows. Early second generation partially adaptive coordination systems have proven to be less effective than first generation systems and have actually resulted in system degradation.[65] This degradation resulted from too many signal plan changes during a given period of time that led to transition delays, inadequate prediction of traffic variations, slow response times to unexpected events, and faulty detector data. Infrared and machine vision systems could remedy those problems associated with detectors or roadside sensors.

---

[65] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, December 1991.

- *Fully adaptive coordination.* Third and fourth generations of traffic-adaptive control systems include fully adaptive coordination schemes. These systems are more advanced than partially adaptive coordination schemes since their adaptation to real time traffic conditions is not based on predetermined sets of signal plans. Third generation systems, such as the Split, Cycle and Offset Optimization Technique (SCOOT) react automatically to changes in traffic flow, adjusting the cycle time, the splits, and the offsets in accordance with an on-line optimization process such as techniques used to enable partially adaptive coordination. Inductive loop detectors are used as sensors to provide real time information on traffic flows.

  Fourth generation traffic adaptive systems need to be developed to overcome some of the problems associated with the third-generation fully adaptive coordinations — for example, the limited information on network traffic conditions that is provided by third generation loop detectors. In this respect, externally linked electronic route guidance systems offer much greater feedback on signal plan performance in the form of actual trip times and delays as they occur. In any event, fully adaptive coordination schemes are probably not a short-term solution to the congestion problems that are caused by inefficient traffic signalization.

- *Interactive signal coordination* systems go beyond adaptive signal control systems by integrating signalization control with real time traffic monitoring, short-term travel demand forecasting, and electronic route guidance.

Electronic Toll Collection systems attempt to minimize recurrent congestion at toll plazas and increase the efficiency of toll procedures by streamlining the collection process. Electronic toll collection involves complementary technologies like automatic vehicle identification and vehicle transponders that allow toll collection without vehicle stops. Sensors built into designated toll roads would serve as toll gates through which vehicles would pass. Automatic vehicle identification computer chips would then identify the vehicle and an on-board transponder would relay information to a centralized processing unit for billing purposes. Billing could be structured as prepaid accounts or end-of-month invoices. In this manner, electronic toll collection would streamline the collection process and reduce recurrent congestion on toll roads. Examples of locations where electronic toll collection systems have been implemented are the North Dallas Tollway and the Coronado Bridge.

Incident Detection Systems are designed not only to minimize the delays and network inefficiencies caused by nonrecurrent congestion, but also to detect dangerous road conditions and advise travelers accordingly. The first type of incident detection system typically consists of a small computer or distributed microprocessor system that automatically monitors signals from vehicle detectors spaced along a given highway. Incidents are then detected by observed breaks in traffic control patterns using specially designed algorithms that detect disturbances.

The second type of incident detection system includes devices for detecting adverse environmental conditions — such as rain, fog, ice, snow, or other climatic conditions. For example, electronic roadside sensors can be deployed that automatically detect pavement slickness due to rain, snow, ice, sleet, or spillages from commercial carriers. Through variable message roadside signs, information can be provided to travelers about road conditions and appropriate travel speeds.

Radios and cellular telephones also have incident detection applications, and can be considered as first generation advanced traffic management systems. For example, police in southern California receive accident reports from motorists through mobile telephones and immediately respond (first call) to the reported accident. This substantially decreases incident response times and helps to reduce the congestion associated with traffic accidents.[66]

Freeway and Corridor Control Systems include capacity management strategies that reduce the occurrence of congestion through systems that maximize vehicle throughput and improve

---

[66] Elizabeth Deakin, Video-Conference on IVHS and Air Quality, March 1993.

level of service.[67] Various types of capacity management systems have been deployed throughout the world. These include ramp metering, express lanes (e.g., high-occupancy vehicles lanes), variable speed control, and corridor control.

- *Ramp metering systems* use standard traffic signals to control the influx of vehicles onto a freeway. Systems used in the U.S. usually release either one or two vehicles per green light, thereby staggering the rate at which vehicles enter the mainline. Ramp signals are varied according to the expected traffic flow in the freeway. First generation ramp metering systems vary according to a preset timing routine by time of day based on the expected mainline flow determined through simulation models. Later generation ramp signals vary continuously as measured ramp and freeway flows are monitored in real time. These later generation systems have been deployed in Chicago, where they have resulted in a 60 percent reduction in peak period congestion and an 18 percent reduction in freeway accidents on affected freeways.[68]

- *Express lanes* and lane reversal during peak periods have been implemented in many countries. In the U.S., high-occupancy vehicle lanes and reversible lanes are indicated by permanent signs and lane markings which travelers are legally required to follow by observing the corresponding time of day lane limitations. Other more advanced systems include variable signs that change according to current traffic flow. These systems are designed for permanent flow control to better react to real time conditions during both peak and off-peak periods.

- *Variable speed control.* The control of freeway speeds using variable message signs has been widely incorporated in many cities across the U.S. These systems are designed to improve freeway traffic flow by managing the speed at which

---

[67] Although the literature often includes demand management techniques - such as, congestion pricing, ridesharing, improved public transit, and other transportation control measures - under the umbrella of freeway and corridor control systems, these have been treated separately in earlier sections of this report.

[68] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, December 1991.

vehicles operate during high congestion periods. Unfortunately, drivers commonly ignore advisory speed limits.

- *Corridor control* is a strategy that encompasses many different types of systems, including traffic signalization, variable message signs, ramp metering, and other concepts related to traffic management. It treats urban freeways and arterial roads as a single system, and optimizes capacity by diverting traffic from overloaded links to those with excess capacity. The key to its deployment centers on real time information-gathering on traffic conditions by the traffic control center, and the use of this information to manage the network with the objective of increasing the efficiency of motorized travel.

A.2 ADVANCED TRAVELER INFORMATION SYSTEMS

Advanced traveler information systems provide detailed trip-related information to users of the transportation system. Imperfect information is currently partly responsible for wasteful vehicle miles traveled and tripmaking, contributing to system inefficiencies, increased air pollution, and increased energy use. As a result, strategies that serve users of the transportation infrastructure can lead to substantial improvements in each of these areas. Advanced traveler information systems address those inefficiencies resulting from imperfect information by assisting motorists in their decision-making processes regarding trip route, trip mode, trip time, and other aspects of tripmaking.

These systems can be conceptualized as an information link between advanced traffic management systems, advanced public transportation systems, and equipment that is either portable or permanently located in vehicles, homes, offices, or sidewalk kiosks, to give transportation users information about traffic conditions, parking, routes, and transit schedules. The objective of this link is to assure that users of the transportation system make trip decisions that are based on real time data specific to origin-destination mobility (or accessibility).[69]

---

[69] *Accessibility* is a term that stresses the need to evaluate IVHS from the context of accessibility to goods, services, and activities, rather than from the context of mobility between an origin and destination.

Advanced traveler information systems can divert traffic from congested links to links with excess capacity by providing real time information to motorists regarding alternative routes during a trip, mode choice before a trip, optimal trip departure time, and/or the potential for trip chaining.

While advanced traffic management systems are directed at the operation of a traffic network, advanced traveler information systems focus on the individual traveler, providing assistance with planning, analysis, and tripmaking. An on-board computer is crucial for system effectiveness, since it can receive, process, store, and collect data which are then communicated to the traveler. By providing accurate routing information these computers can serve as navigation devices, reducing excess vehicle miles traveled that often occur as a result of navigation errors.

Systems included in this functional area are not limited to the motor vehicle, however. Televisions, information consoles, and personal computers can be used by travelers in the planning stage of a trip. By learning about travel conditions and areas of congestion, travelers can make informed decisions on both mode and route choice. Ridesharing information received at home or at work can have beneficial environmental effects by reducing the number of trips taken by single occupancy vehicles.

Specific systems included in this functional area include electronic route planning and information systems, radio data systems, on-board navigation systems, externally linked route guidance systems, real time changeable message road sign display systems, and ridesharing information systems. In addition, advanced traveler information systems incorporate emergency mayday systems as well as vehicle condition warning systems that give motorists information about the mechanical condition of the vehicle being used.

Electronic Route Planning and Information Systems link minimum path computer algorithms — which may be based on trip length, trip time, or trip cost — to surface transportation network data bases. *Prior to a trip*, travelers access route planning computers, often through a telephone line, to determine the best route between an origin and destination based on the three criteria described above. In the U.S., electronic route planning and information systems have been used by rental car companies to provide consumers with route guidance.

Radio Data Systems use a radio frequency to broadcast traffic information to motorists. Short-range traveler information stations, often referred to as highway advisory radio, have been in service in the United States since 1977. At present, transmissions are limited to AM stations with a frequency of 530kHz or 1610kHz, which most standard car radios can receive. In some cases, alternative routes can be suggested to motorists. Because police and highway agencies often provide this information, there can be a minor delay between when an incident occurs and when the consumer receives relevant incident-related information. Automatic detection equipment could remedy this problem as could information provided from cellular phones. All travelers could potentially benefit from radio data systems, resulting in shorter travel times and reduced congestion.

On-Board Navigation Systems provide travelers with information on location and its relevance to destination. Information is extracted from an on-board computer that does not interface with a traffic control center, but rather uses software contained within the computer's memory — much like current personal computers. The lack of interface with traffic centers makes on-board navigation systems entirely static and nonresponsive to real time traffic conditions. Even so, on-board navigation systems may reduce inefficiencies related to navigation errors or route choice — navigational errors have been estimated to account for approximately 6 to 20 percent of the distance traveled by motor vehicles.[70]

On-board navigation systems are usually separated into three types:

- *Directional aids.* On-board equipment for directional aids consists of a computer (or central processing unit), a keyboard, and a video-display monitor. The traveler inputs the coordinates for the trip's origin and destination, and the system then employs dead reckoning to provide navigational information. Dead

---

[70] Steven E. Shladover, *Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

reckoning is a technique that calculates the current location of a moving object by measuring the distance and direction of motion since departure.

- *Location displays*. Unlike directional aides, location displays show the entire road network to the motorist, as well as the vehicle's current position in the network. However, location displays only show the vehicle's location relative to a predisposed destination. As a result, these systems cannot provide best route information to travelers.

- *Self-contained guidance systems*. The most advanced types of on-board navigation systems include self-contained guidance systems which actually provide best route information to travelers based on trip length. As with the other types of on-board navigation systems, this system also relies on information stored in the on-board microcomputer — albeit a more comprehensive and detailed description of the network with an algorithm that calculates the shortest path from an origin (or location) to a destination.

Externally Linked Route Guidance Systems are more advanced than both electronic route planning and on-board navigation systems, since they provide real time information on traffic conditions and suggest alternative routes to circumvent congested roads. These systems involve communication between an external network management system (e.g., those available through advanced traffic management systems) and on-board guidance equipment. The effectiveness of externally linked route guidance systems depends on the accuracy of sensors used to detect incidents, rather than on proven technology that allows for two-way communication between vehicles and roadways. System tests in Japan have shown that these guidance systems are effective in reducing mean travel times by roughly 11.5 percent.[71] When fully implemented, externally linked route guidance systems are expected to help reduce both recurrent and nonrecurrent congestion.

---

[71] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, December 1991.

Real Time Changeable Message Road Sign Display Systems represent the next generation of current static road signs, providing up-to-date information for travelers using freeways or arterial roadways. First generation systems, currently used in a number of U.S. cities, provide information to motorists following an incident. This information is designed to divert traffic from congested corridors to those with excess capacity. Future generation systems will employ information gathered by advanced traffic management systems to provide real time information on traffic conditions and route guidance services along freeways or heavily traveled arterials during both peak and off-peak periods. Road signs present a viable, though not complete, short-run remedy to the externalities associated with congestion.

Ridesharing Information Systems, or carpooling information systems, are often included in this functional area since advanced traveler information systems as an information enhancement tool for travelers creates ample opportunities to divert trips from single occupancy vehicles to high-occupancy vehicles. The concept is to provide travelers with a mechanism through which ridesharing opportunities can be identified. Terminals can be placed at various business centers, transit locations, or another smart kiosks across a city that tie in to a real time central data base (or clearinghouse) where ridesharing matches can be determined based on destination. Similarly, home computers can be employed to access the data base for those trips originating from the home. This system has been conceptualized to reduce the number of work-related single occupancy vehicles trips, rather than other types of single occupancy vehicles trips. Similar concepts have been developed under advanced public transportation systems, and are discussed later in this appendix.

Vehicle Condition Warning Systems are designed to better inform vehicle owners about the operational and physical condition of their vehicles. First generation devices are available in most current model year vehicles. For example, on-board microcomputers allow for monitoring of engine systems. Future technologies may expand on current systems to allow real time monitoring of fuel consumption rates and exhaust emissions. Vehicle condition warning systems will give motorists real time, detailed information on vehicle conditions to allow for improved maintenance practices. These systems can have secondary effects, though probably small, on nonrecurrent congestion by improving fleet maintenance practices and reducing the likelihood of vehicle breakdown during operation.

Emergency Mayday Systems use cellular telephones or satellite communication links to assist drivers in the case of an emergency during a trip. These systems improve upon current roadside mayday boxes by enabling the driver to call for help from the vehicle. A signal is sent by the on-board communications system to the traffic network, which then processes the information and relays it to appropriate incident clearance crews. Vehicle location is identified, its condition acknowledged, and assistance is provided by the traffic control center. Given that such a system can be implemented using current technology, emergency mayday systems are a short-term strategy for mitigating nonrecurrent congestion.

A.3 COMMERCIAL VEHICLE OPERATIONS

Commercial vehicle systems combine various products, services, and enabling technologies of advanced traffic management systems, advanced traveler information systems, and advanced vehicle control systems to improve the safety and efficiency of commercial vehicle and fleet operations. Examples of commercial vehicle systems include: automated credentials and weight checking systems that automatically check carrier credentials and clear transponder-equipped vehicles through ports of entry and weigh stations, thereby improving traffic flow and eliminating related delays; real time information systems which provide enhanced information to drivers or dispatchers concerning congestion, incidents, and optimum routing; electronic toll collection, already discussed under advanced traffic management systems, which will reduce the burden of highway tolls on a carrier's time; and various other systems that employ enabling technologies such as automatic vehicle identification and automatic vehicle location. Although IVHS America includes trucks, delivery vans, inter-city buses, and emergency vehicles under the umbrella of commercial vehicle operations, most of the systems included in this functional area have to do with vehicles engaged in the movement of goods and services. The discussion presented below focuses on these vehicles.

Many of the systems included in the commercial vehicle operations functional area are currently being investigated in operational field tests, such as Advantage I-75 which extends from Florida to Ontario, and the Crescent project of the Heavy Vehicle Electronic License Plate (HELP) program which covers highways from central Texas to Canada. These field tests will provide insight into how specific systems function at the corridor level and over a large surface transportation network. The Advantage I-75 study will help determine how data is transmitted between states, while the HELP Crescent project will measure the reliability of systems such as weight checking and automated license plate checking. While most of the systems included in commercial vehicle operations are technologically feasible, many institutional barriers preclude their widespread implementation. It is not evident that many systems in this functional area will have any significant impact on urban air quality. Nevertheless, descriptions of the systems included in commercial vehicle operations are provided below.

Automatic Vehicle Identification in Commercial Vehicle Operations involves each truck carrying a transponder that would transmit its identity when interrogated by an automatic vehicle identification system. Such systems can exchange information as simple as a truck ID/registration number or as complex as complete credentials and origin-destination data. Automatic vehicle identification is a currently available, proven technology. It has been tested successfully in numerous toll collection systems, most notably in the HELP Crescent and Advantage I-75 commercial vehicle programs. At present, the major barrier to widespread automatic vehicle identification implementation for commercial vehicles is an institutional one — standardization. For obvious reasons, truckers would like to have a single automatic vehicle identification tag that would work in all areas of the country. Although numerous successful tests of automatic vehicle identification technologies have been conducted, there are as yet no national automatic vehicle identification communication standards. The U.S. Department of Transportation has set a goal to develop national automatic vehicle identification standards by the year 1996.

Automatic Credentials Checking. Truck credentials, which can include vehicle registration, fuel tax information, operating authority, and oversize and hazardous materials permits, are usually inspected only randomly by individual state enforcement agencies. Because almost all verification must be done manually, it is quite expensive and far from comprehensive. Automatic vehicle identification equipment could permit automated credentials checking of all trucks at mainline speeds without any delay to truckers. Automatic credentials checking would improve the efficiency of state monitoring programs and encourage more widespread compliance by making inspections universal. Trucks which do not comply with permit requirements could be flagged and either fined or directed to an inspection center. This type of system would probably require a shared data base so that each state could verify a vehicle's background information.

Electronic Permitting and Payment. Motor carriers face an extremely complex array of registration, insurance, and permitting requirements from each of the individual states. There is convincing evidence that interstate carriers face substantially different circumstances across states in each of these regulatory areas. For example, over half of the states require carriers to obtain trip permits (in lieu of full vehicle registration). These trip permits vary in cost from $4 to $45. They also require carriers to go through the expense (time and money) of obtaining them.

An electronic registering system would allow truckers to obtain necessary permits and registrations for all states at one location. This "one-stop shopping" for permits would be welcome by the industry as a time savings opportunity. Additionally, the industry would benefit from reduced fines for permit violations, since many carriers do not currently obtain the permits because of limited information about the mechanics of obtaining them, as well as an unwillingness to take the time to obtain the permit in the first place. The major barrier to implementing an electronic registering system is the lack of coordination between state agencies and the lack of necessary communication networks. It would require agreements between states on billing and electronic funds transfers and would assume a free exchange of information. In addition, from an institutional standpoint, the deployment of CVO technologies may increase the likelihood that more uniform state-to-state permit requirements will evolve.

Electronic Recordkeeping. Truck operators are required to collect data to demonstrate their compliance with trucking regulations (e.g., fuel tax data). Automating this type of data collection and report generating process could ease some of the cost and burden to the trucking industry and encourage greater compliance. Carriers have estimated that the cost of tax reporting amounts to an average of approximately $170 per vehicle per year (NCHRP/HELP surveys). Transmitting these data/reports to the states electronically could also reduce bookkeeping costs for the regulating agencies.

Weigh-in-Motion. Typically, states perform truck weighing at either permanent weigh stations or using roving weighing crews. At permanent stations, trucks are required to pull off the mainline onto scales, often delaying the driver. Some states cannot afford to staff weigh stations full time and operate them only intermittently. Other states perform weighing by using roving crews that travel throughout the state that operate at temporary sites for a few days each month. Truck weighing is often sporadic and incomplete, and often fails to correct serious compliance problems. Weigh stations can also create traffic hazards and congestion when truck queues back up onto the highway.

Weigh-in-motion sensors can weigh vehicles automatically at mainline speeds. The coverage can be continuous (365 days a year), complete, and does not result in any delays to truckers. Weigh-in-motion stations have been successfully tested, most notably in the California HELP Crescent program.[72] Although the technology is available, the biggest barrier to successful multistate implementation is the difference in weight standards between different states. States will need to bring weight standards in line with one another if a multistate weigh-in-motion system is to be effective.

Automated Safety Inspections. Ensuring that all trucks and drivers comply with safety standards is a difficult task for most states. Safety inspections are conducted manually and often only sporadically. Furthermore, a thorough truck inspection requires an average of 34 minutes to complete, resulting in lost time to the driver.[73] The advent of on-board systems that monitor vehicle performance could lead to the automation of safety inspections. Current systems can

---

[72] IVHS America, *Strategic Plan for IVHS in the United States*, May 1992.

[73] Jack Faucett Associates, *Relative Effectiveness of Level I, II, and III Roadside Inspections*, November 1992.

monitor brake temperature and pressure, steering, and engine performance. Future systems may be able to monitor tire temperature and condition. Although these systems are currently designed for the operator, they could easily be combined with road-highway communication systems. A scanner at a safety inspection station could interrogate each vehicle (at mainline speeds) for the condition of critical safety systems. Vehicles which do not meet standards could be pulled over or automatically fined. As with many commercial vehicle systems, the greatest institutional barrier to the implementation of automated safety inspections may be the lack of national safety standards.

Automated Driver Data Processing. Driver's licenses, records, and performance data could be verified using automatic vehicle identification equipment. Drivers must maintain detailed logs of their driving schedule and are prohibited from driving more than a certain amount of time in a prescribed time period. Driving logs could be maintained automatically by on-board systems and verified at safety checkpoints, easing the burden on truckers while reducing the opportunity for fraud. Highly advanced systems may one day also monitor driver condition.

Traffic Data Collection Systems. Both the states and the trucking industry collect large amounts of data on truck movements, often independently. States collect data for transportation planning and taxation purposes. The trucking industry collects data which allows them to better manage their fleets. Commercial vehicle systems could provide automatically traditional count and vehicle classification data (using automated vehicle classification technology), as well as more sophisticated mileage and origin-destination data. For example, a system that records truck mileage for fuel tax allocation purposes is being developed for testing in Iowa. For such a system to be truly effective, states and the trucking industry would need to standardize the types and format of data being collected. Commercial vehicle traffic data collection systems would probably require a jointly maintained data base and an agreement for the automatic and free exchange of information between all parties.

Advanced Driver Information Systems. Although often overlooked in commercial vehicle operations, truckers may benefit as much from advanced driver information systems as from other commercial vehicle systems. Advanced information systems can automatically notify drivers of height, weight, and hazardous materials restrictions as trucks travel from state to state. These systems could also provide information on traffic and weather conditions and suggest the most efficient routes. A system that provides route guidance to truckers will require cooperation between states so that all parties can agree on route diversion strategies.

Real time information systems could inform drivers on congestion and incidents, and would allow for more effective routing to occur. Both fleet managers and vehicle operators could benefit from information systems, which would require two-way communication between the road and the vehicle. Roadside sensors would record incidents, and inform a control center, which would then send information to both the vehicle and to fleet managers. Many fleet operators are also implementing systems to monitor automatically the positions of their vehicles. This information will enable fleet operators to improve dispatching and fleet management. Such information could be useful for states too, particularly for following the progress of hazardous materials or special permit vehicles. It would require some type of standardized automatic vehicle location system.

SmartRamp Designs automatically detect the size, weight, and speed of trucks as they approach ramps and determine if there is a rollover hazard. Such systems will enhance public safety and benefit the trucking industry. While these systems are usually independent, cooperation among states in their design and implementation can aid in establishing safety standards and reducing development costs.

Hazardous Material Information Systems can be of assistance to regulators by tracking shipments of hazardous material. Detection would occur by means of on-board systems which communicate with roadside units. Should an incident occur, response teams would have data on the contents of the vehicle and its location. Assessments of system reliability are not yet possible. Additional tests and research need to be performed.

Site-Specific Highway Warning Systems for Trucks provide truck operators with advance warnings about highway conditions (e.g., sharp inclines, tight ramps, and intersections). This information would help prevent accidents and could improve safety. Roadside sensors would be set up to advise drivers about potential road hazards. Although the technology currently exists to set up a reliable system using roadway signs, road to vehicle communication requires additional research. Once this technology is implemented, it will enable truck operators to receive information specific to their vehicle; they will not need to rely on generic warnings from road signs.

A.4 ADVANCED VEHICLE CONTROL SYSTEMS

Advanced vehicle control systems have the potential to dramatically improve driver performance, safety, and traffic flows by using sensors and computers to aid drivers. Included in this functional area are technologies which assist with braking, steering, and maintaining a safe distance between vehicles, as well as technologies which take preventive steps to avoid an impending collision. The most advanced vehicle control system involves an automated highway on which all aspects of the vehicle are controlled, including lateral and longitudinal position, steering, braking, merging, and the influx and exit of vehicles onto and out of a freeway. Partial to complete automation will require that vehicles communicate with the road and with other vehicles, using technologies found in advanced traveler information and advanced traffic management systems.

Because many advanced vehicle control systems have yet to be developed and tested, additional research, development, and evaluation is needed for effective full scale system implementation along corridors or over an entire network. Three deployment stages are envisioned for advanced vehicle control systems. First, vehicle-based systems which assist driver performance but do not communicate with the road would be deployed. Second to be deployed would be systems which control a vehicle's position through the use of automated lanes. This second phase could make vehicle platooning possible, because vehicle speed and distance will be held constant along a corridor. The last deployment stage for advanced vehicle control systems involve fully automated highways in which all aspects of vehicle operation are controlled automatically. Such a system relieves the driver of duties related to vehicle operation and control.

In summary, features of advanced vehicle control systems include driver warning systems, driver assistance systems, and full vehicle control systems. With devices that give drivers an enhanced sense of impending collisions, or of the environment in or around the vehicle, and automated controls that are more responsive than human motions, this functional area represents the *smart vehicle* with which the *smart road* will communicate.

In general, the deployment of advanced vehicle control systems is expected to increase roadway capacity or vehicle throughput by a factor of two to three, and to reduce the number of traffic accidents. However, for deployment at any level, advanced vehicle control systems require more research and development than systems in other functional areas. Moreover, since most of the devices will be on-board systems available to consumers, their acceptance into the market is also a concern. Yet, both Europe and Japan have taken significant steps to deploy these systems. In Europe, field tests have been scheduled for 1994, while Japan has drawn up plans for an automated freight lane (on a highway) to be constructed between Tokyo and Osaka. Descriptions of the technologies, products, and services that comprise first and later generation advanced vehicle control systems are provided below.

Antilock Braking Systems, an enabling technology for more advanced vehicle control systems, assume control of a vehicle's braking function during moments of excessive braking or severe cornering.[74] The system differentially pumps the vehicle's brakes to ensure shorter braking distances and nonskid braking. Antilock braking systems have been successfully marketed in many recent and current year models as either standard or optional equipment. The attractiveness of antilock braking systems centers on safety gains, as drivers remain in full control of the vehicle under slick road conditions and during moments where emergency braking is required. It has been estimated that over seven percent of all highway accidents may have been prevented if these systems had been deployed in every in-use vehicle.[75]

---

[74] In 1991, IVHS America's Advanced Vehicle Control Systems Committee decided that antilock braking systems should not be considered as part of this functional area if used independently.

[75] NCHRP Report 340, *Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*, December 1991.

Radar Braking Systems are designed to brake vehicles automatically when predetermined speed and distance relationships are violated. Once radar heads, fitted to the front of a vehicle, detect obstacles (such as vehicles traveling directly in front), the distance and relative velocity is calculated between the vehicle and the obstacle. If the preset speed distance relationship is violated, then the radar braking system is activated and the vehicle's brakes are automatically applied.

As with many advanced vehicle control systems, radar braking is a technology that can potentially yield substantial safety and congestion benefits (through the reduction of delays associated with nonrecurrent congestion), but it requires additional testing. One major problem associated with radar braking is that false alarms may be caused by objects that do not pose any potential danger to the vehicle and passengers, such as trees, road signs, vehicles traveling in adjacent lanes, parked cars, and other obstacles particular to corners or bends along a roadway.

Vehicle Speed Control Systems can reduce traffic accidents and alleviate congestion, both recurrent and nonrecurrent. The effect of these systems on traffic accidents is obvious, as speed control will reduce the probability of high-speed collisions. The impact of speed control systems on congestion is more indirect and has to do with improving traffic flow on a particular mainline.

Three generations of speed control systems have been conceptualized. The first two of these have already experienced wide-scale deployment in recent and current model year vehicles. These systems include cruise control, speed governors, and variable (or adaptive) speed control.

- *Conventional cruise control systems* are common in many in-use vehicles operating in the U.S. They operate by maintaining driver specified vehicle speed constant (at cruise) until a driver imposed acceleration event takes place or until the driver depresses the brake pedal. Cruise control can also permit controlled acceleration/deceleration, and through memory can resume the speed prior to a braking event.

- *Speed governors* prevent vehicles from exceeding a predetermined speed. Most applications have occurred on heavy duty trucks, although implementation is also possible on passenger vehicles. The system is installed into the vehicle with a preset speed limit. Should the vehicle exceed the preset limit, sensors actuate the fuel injection pump to prevent further acceleration, thus limiting speed.

- *Variable speed control systems,* often referred to as adaptive cruise control, are designed to reduce speed differentials and minimize the frequency of vehicle stops. These systems may have significant impacts on the minimization or elimination of stop-and-go phenomena so commonly experienced on freeways and arterial roads during heavy congestion periods.[76] Two types of variable speed control systems are currently being investigated: 1) conventional cruise controls or speed governors with fixed speed limits unique to different road types or sections of highways, and 2) variable-message speed control road signs that are linked through automatic vehicle identification to an on-board variable speed control system.

Automatic Headway Control Systems, similar in concept to radar braking systems, employ vehicle sensors to maintain constant distances between vehicles traveling on a particular lane of a roadway. For effective automatic headway control operation, distance monitoring is combined with brake and speed control. Vehicle speed is adjusted based on the distance between vehicles, thereby potentially preventing collisions that commonly occur when vehicles operate at unsafe distances from each other (tailgate). Automatic headway control systems are intended to control daily traffic flows, particularly during heavily traveled peak periods, and have the potential to significantly increase vehicle throughput and system capacity. A secondary effect often ignored in the literature is fuel efficiency improvements — and related emission decreases — associated with reduced aerodynamic drag. In Europe, the PROMETHEUS program is considering ways to improve upon current technologies for automatic headway control systems, including advances in radar sensors to improve their reliability. In the U.S., testing by the California Partners for

---

[76] Steven E. Shladover, *Potential Contributions of IVHS to Reducing Transportation's Greenhouse Gas Production*, May 1993.

Advanced Transit and Highways (PATH) program is also expected to generate results on the effectiveness and reliability of automatic headway control systems.

Automatic Steering Control Systems are designed to allow vehicles to follow a predetermined path along dedicated highway lanes. As with automatic headway control systems, the objective of automatic steering control is to increase throughput and road capacity by narrowing lane widths, as well as to provide a more direct interface between the vehicle and the road by eliminating (or minimizing) the role of the driver in vehicle operation. The effective operation of automatic steering control systems depends on road to vehicle communication and a vehicle steering control system. Integral to the system are road sensors, which provide information on the lateral location of the vehicle during motion. This information is then processed by the automatic steering control system, and adjustments are made to assure that the predetermined path is followed. Automatic steering control must, therefore, include the following systems for effective operation:

- A *roadway reference system* whose signals are detected by a vehicle to determine its lateral position;

- *On-board sensors* that measure the lateral position and that can calculate appropriate corrective actions; and,

- An *automatic steering control system* that acts on command signals from the on-board sensors or computers.

Together with automatic headway control systems, automatic steering control technologies represent the communications interface between the road and the vehicle. PATH tests will hopefully provide detailed data on the operational effectiveness and reliability of both of these advanced vehicle control systems.

Intersection Hazard Warning Systems are designed to prevent accidents which occur when a vehicle enters an intersection and collides with cross traffic that was not visible to the driver of the vehicle. On-board sensors check the intersection for approaching vehicles. Once an approaching vehicle, not visible to the driver, has been detected by the on-board sensors, signals can be displayed to the driver, radar braking can be deployed automatically, or automatic steering control systems can be deployed to steer the vehicle away from the expected collision. Intersection hazard warning systems would probably have to rely on wayside and on-board sensors.

Collision Avoidance Systems build on technologies that warn drivers of impending collisions. Necessary collision avoidance actions are taken by the vehicle automatically using on-board systems, such as microprocessing units and sensors to detect approaching objects. These systems are virtually identical conceptually to intersection hazard warning systems, with the only difference being that collision avoidance systems are not limited to intersection collision avoidance. Both collision avoidance and intersection hazard warning systems incorporate technologies and products, such as radar braking and automatic steering control, that are the basis of advanced vehicle control systems.

Automated Highway Systems. This long-term IVHS concept involves the automated control of vehicle steering and vehicle traveling distances using automatic steering control and automatic headway control. Vehicles would essentially drive themselves, without the need for driver intervention.

A.5 ADVANCED PUBLIC TRANSPORTATION SYSTEMS

A major goal of IVHS is to reduce the detrimental externalities that are directly associated with urban traffic congestion. Given that the level of congestion is inevitably related to the number of vehicles competing for space on the scarce highway network system, reducing this number will relieve urban congestion. Advanced public transportation systems involve strategies to increase the efficiency of surface transportation by offering the potential to move an increased proportion of travelers in fewer motorized vehicles. Currently, most commuters' travel needs are satisfied by passenger cars, and a high proportion of urban travel is done in single or low occupancy vehicles.[77] Advanced public transportation systems enable transportation agencies to provide timely transit information to passengers and to improve the convenience, reliability, and safety of public transportation service so that more trips can be undertaken in high-occupancy vehicles.[78] Shifting person trips from single occupancy vehicles to high-occupancy vehicles has the potential of not only alleviating congestion, but also of decreasing the consumption of petroleum products by the transportation sector and reducing the emission contributions of mobile sources in a given region.

This functional area specifically encompasses the application of electronic technologies for more effective deployment and operation of high-occupancy, shared-ride vehicles, including buses, rail vehicles, and paratransit vehicles. For example, by providing real time information to commuters about arrival times, advanced public transportation systems could reduce the number of single occupancy vehicle trips and encourage alternative modes of transportation. In addition, ridesharing information can provide a mechanism to pretrip planning improvements on the part of commuters. In contrast to the other components of IVHS, advanced public transportation systems are designed to influence mode choice, and will likely have a disproportionate effect on work-related trips. Many of the services that are planned have been conceptualized as derivatives of advanced traffic management and advanced traveler information systems, and are often enabled by technologies like automatic vehicle identification and automatic vehicle location. With this in mind, the products, user services, and technologies that comprise advanced public transportation systems are described below.

Smart Cards. Smart card technology is an enabling technology which will allow for the implementation of many public transportation services. A smart card, which is the same size and shape as a conventional credit card, uses microprocessors and memory storage that allow for the implementation of trip reservation and payment and road pricing strategies. In essence, this technology involves a computer chip embedded in a credit card-sized tag that stores

---

[77] IVHS America cites estimates that attribute an annual savings of $30 billion in congestion costs from a 20% shift of single vehicle occupancy trips to alternative modes.

[78] Federal Transit Administration, *Technical Assistance Brief 1: Advanced Public Transportation Systems*, Spring 1993.

personalized identification codes and that can be linked to data bases in the same manner as credit cards. Many advanced public transportation systems depend on the use of smart cards to transmit passenger information to a transit or high-occupancy vehicle and to the transit control center.

Traveler Information and Service Systems provide transit and rideshare information to the traveler. These services are intended to enhance both the accessibility and attractiveness of transit systems by using both current and imminently available technology. Included in this category are the following services: real time trip planning information, schedule and fare information, ticket purchase and seat information, and rideshare participant selection and location. In order to achieve system efficiency, some of these services often use a combination of different enabling IVHS technologies. For example, real time passenger information systems could use automatic vehicle monitoring technology to track vehicles to provide this information to travelers.

Advanced traveler information and service systems are often grouped as follows.

- *Pretrip planning information* allows prospective travelers to obtain information before making a trip. Information about real time travel conditions and ridesharing opportunities is provided. Real time information on traffic conditions can allow travelers to avoid a certain route or use alternative modes, including public transit or ridesharing. In applications of these systems, the traveler receives information from either a telephone, television, or facsimile machine. In first generation telephone information systems, information is relayed manually by a service operative. Second generation systems would use touch tone phones, while third generation systems would be voice activated. Televisions (e.g., a dedicated cable TV channel) can also be used to provide information to travelers through the use of a teletext. Facsimile machines, which are a widely used technology and, like the telephone, are interactive, could offer particular benefits to the hearing-impaired by producing visual copies of transit and traffic related information. In addition, activity centers, such as shopping malls and business parks, could provide this information at kiosks.

- *Trip reservation and payment.* Many of the technologies described for trip planning could also be used to enable travelers to automatically reserve and pay for transit services with conventional credit card procedures. For example, telephone systems could be implemented to enable travelers to make reservations by entering a PIN number and credit card number. Future systems could be voice activated, providing increased security to the traveler. Prepayment would also be possible. A smart card could have a predetermined number of units which are then debited by the on-board computer in the transit vehicle that communicates with a central dispatcher. This service could eliminate the need for exact change when boarding buses, and could thus reduce delays which occur at passenger pickup/dropoff locations. More advanced systems could use automatic personal identification, which is similar to automatic vehicle identification in that a microwave or radio frequency tag is carried by the traveler. With automatic personal identification, travelers are automatically identified as they enter and exit the vehicle. A bill could then be sent to the passenger in the same way as electronic billing systems currently operate.

- *In-terminal information* provides information to travelers at transit departure and arrival terminals. Many of the technologies discussed under pretrip planning could also be used, although systems installed in transit locations could be more elaborate due to the high volume of passengers at a given terminal. First generation systems which use monitors to display real time information on arrival and departure times have already been widely implemented. More advanced systems include interactive services in which a traveler enters a desired service or destination and receives information on optimum routes. Ridesharing information could also be received at parking lots or collection points. Upon arrival, participants could enter their destination information by using automatic vehicle identification, automatic personal identification, or smart card technology.

A computerized ride allocation system would then match travelers based on their destination. Such a process could enhance the efficiency of existing systems by eliminating the need for fixed-time schedules.

- *On-board vehicle information systems* are intended to provide information to travelers in the transit vehicle. Upon entering the transit vehicle, passengers could receive information about available seating. After having been seated, the passenger would then learn about current location, distance, and expected arrival time from video display monitors. Real time information could also be valuable to travelers using connecting services. USAir has already equipped some of their 757s with these information systems.

Traffic Management Systems. With respect to public transportation, traffic management is designed to give priority to selected vehicle types. These systems can have two principal effects on a traffic network. The first effect is a reduction in the fluctuations of transit and high-occupancy vehicle travel times as a result of priority measures for these vehicles. Such benefits serve to enhance the attractiveness of these alternative modes. The second effect relates to how nonpriority vehicles will be affected by these schemes. In particular, these vehicles could have less access to freer flowing high-occupancy vehicle lanes. As a result, these travelers may turn to transit or rideshare schemes as substitutes for single occupancy vehicle travel.

Four applications are discussed below:

1. *Traffic signal priority* can be used to give priority to transit and rideshare vehicles. First generation systems would operate at isolated intersections, while more advanced systems would include partially and fully adaptive systems which link intersections together. Automatic vehicle classification could be used to identify vehicles as they approach the intersection, while more advanced systems could use automatic vehicle identification. As vehicles approach the intersection, signal timings would adjust in order to give priority to high-occupancy vehicles. First generation systems have already been implemented at locations such as fire

stations to give priority to emergency vehicles entering and leaving the fire station.

2. *Dedicated highway lanes* involve the reservation of certain lanes for high-occupancy vehicles and other transit vehicles. Different schemes have already been implemented in the U.S. to achieve this purpose (e.g., I-66 in northern Virginia). Advanced technologies could improve on existing systems by providing more effective control and enforcement.

3. *Ramp controls*. Priority can be given to high-occupancy and transit vehicles by implementing bypass lanes at metered ramps. Access to these lanes would be restricted to compliant vehicles. Automatic vehicle classification or automatic vehicle identification could enable road-to-vehicle-to-control center communication allowing officials to monitor vehicles using the bypass lane. This automated system would eliminate the need for physical barriers.

4. *Toll highways*. By using automatic vehicle identification, automated toll lanes could be established to give preference to high-occupancy vehicles. In addition, lower fees could be set for high-occupancy vehicles. Toll pricing strategies could give travelers an incentive to choose alternative modes of transportation, such as ridesharing. Road-to-vehicle-to-control center communication would identify noncompliant vehicles.

<u>Transit and Fleet Management Systems</u> include technologies which have already been discussed under the category of commercial vehicle operations. This discussion deals with the application of systems for rideshare and transit vehicles. Transit and fleet management systems are intended to improve the efficiency and operation of vehicle fleets. Implementing these systems can enhance network and operations planning, vehicle and crew scheduling, and vehicle tracking. Examples of the services and technologies included in this category are described below.

- *Transit operations software* involves the use of computer software for transit operations and planning. In particular, these on-line, interactive systems can be used to develop new or revised routes based on travel demands. Network-based programs can make possible the scheduling of complete networks, while other software can allow the user to define a target number of vehicles. At present, demand responsive jitney services can be provided using this software.

- *Electronic ticketing systems* can record detailed information on transit transactions as passengers enter transit vehicles and pay their fares. Data that could be collected include revenue information disaggregated by route, by ticket type, by passenger type, and by time of day. These systems would improve on conventional ticket machines which provide only a revenue summary and passenger count. Electronic ticketing systems represent an important reliable source of data for transportation planners measuring the use of transit vehicles. As such, these systems have the potential to increase the productivity of transit services and reduce costs.

- *Automatic vehicle monitoring* systems use both automatic vehicle identification and automatic vehicle location to integrate identification and location information. Automatic vehicle monitoring could also monitor passenger counts, fare information, vehicle condition data, and emergency status messages. In addition, automatic vehicle monitoring could be valuable to transit planners for the efficient operation of a network. On-board computers could measure the number of travelers on a transit vehicle, and then transmit this information to a control center via roadside beacons.

A.6 ADVANCED RURAL TRANSPORTATION SYSTEMS (ARTS)

IVHS America recently added this functional area to the conceptual definition of IVHS to include those products and services which have the explicit intent of representing the needs of the rural transportation community. The advanced rural transportation systems IVHS America committee, founded in 1992, will help prepare an action agenda for these systems. Unlike the products and services that comprise the other five functional areas of IVHS, and that focus on many different factors including increased mobility, reduced environmental impact, and reduced congestion, the products and services included under advanced rural transportation systems focus primarily on safety, advisory information, and emergency services. This emphasis on safety is due to the high incidence of accidents in rural areas.

Addressing rural needs within the context of IVHS is an important step in recognizing the significance of the rural transportation community. Travel on rural roads accounts for approximately 80 percent of vehicle miles traveled in the United States. One major goal of this functional area is to solicit the involvement of local governments, which are often not included in the development process of IVHS services.

APPENDIX B: NATIONAL IVHS/AIR QUALITY WORKSHOP

The National IVHS/Air Quality Workshop was held on March 29-30, 1993 at the South Coast Air Quality Management District in southern California. The format of the invitation-only workshop was highly interactive, with focus on producing research recommendations in the areas of modeling development, field testing, and linkages between IVHS and other clean air strategies. Overviews on major studies regarding IVHS and air quality, such as those being conducted by the Volpe National Transportation Systems Center, were presented. However, the main thrust of the workshop was to solicit ideas from nationally recognized experts on research priorities for ensuring an environmentally sound transportation technology program.

The list of workshop participants and the workshop's final agenda are presented below.

NATIONAL IVHS/AIR QUALITY WORKSHOP

LIST OF ATTENDEES

Aladdin Barawi
Federal Highway Administration

Matthew Barth
University of California, Riverside
Center for Environmental Research & Technology

Kenneth Baxter
California Highway Patrol

Bob Behnke
Aegis Transportation Information Systems

Paul Benson
CALTRANS

David Bernstein
MIT
Department of Civil & Environmental Engineering

Mike Bogdanoff
South Coast AQMD

Margo Bowers
Bowers Research

Sadler Bridges
Texas Transport Institute
Texas A&M University

Joon Byun
Federal Highway Administration

Kan Chen
University of Michigan
IVHS

David Clawson
American Association of State Highways

Stephen Crosby
Smartroute Systems

Frederick Ducca
Federal Highway Administration
Office of Environment and Planning

Ronald Fisher
Federal Transit Administration

Anne Geraghty
California Air Resources Board

John German
U.S. Environmental Protection Agency

Charles Goodman
Federal Highway Administration
Office of Policy Development

Deborah Gordon
Union of Concerned Scientists

Lamont Hempel
Claremont Graduate School
Center for Politics and Policy

Thomas Horan
George Mason University
Institute of Public Policy

Mark Howard
National Association of Regional Councils

Nan Humphrey
Transportation Research Council

Jon Kessler
U.S. Environmental Protection Agency

Brian Ketcham
Konheim & Ketcham

Larry Klein
Hughes Aircraft Co.

Andy Kuchta
Michael Baker, Jr. Inc.

Jeffrey Lindley
Federal Highway Administration
Region 9

Cheryl Little
Volpe National Transportation Systems Center

Alan Lloyd
South Coast AQMD

Wesley Lum
CALTRANS
Office of Advanced Systems Integration & Implementation

Mike McGurrin
The MITRE Corporation
IVHS

Mark Miller
PATH
University of California
Richmond Field Station

Lee Munich, Jr.
Hubert H. Humphrey Institute of Public Affairs

Donald Orne
PATH
University of California
Richmond Field Station

Sergio Ostria
Jack Faucett Associates, Inc.

Nan Powers
California Energy Commission

Charles Purvis
Metropolitan Transportation Commission

Bob Ratcliff
CALTRANS

Michael Replogle
Environmental Defense Fund

Bob Ricci
Volpe National Transportation Systems Center

Craig Roberts
IVHS AMERICA

Norman Roy
CALTRANS
Office of Traffic Improvement

Dick Schoeneberg
Federal Highway Administration

John Shiller
Ford Motor Co.

Steve Shladover
PATH
University of California
Richmond Field Station

Philip Shucet
Michael Baker, Jr. Inc.

Mark Simons
U.S. Environmental Protection Agency

Burt Stephens
Federal Highway Administration
Office of Traffic Management and IVHS

Roger Stough
George Mason University
Institute of Public Policy

Steve Underwood
University of Michigan
IVHS Program

Jerry Ward
Consultant

NATIONAL IVHS AND AIR QUALITY WORKSHOP

South Coast Air Quality Management District Headquarters
Diamond Bar, California
March 29-30, 1993

AGENDA

Monday, March 29

8:00 AM **BREAKFAST AND REGISTRATION**

Introduction - Phil Shucet, Workshop Chair

8:30 AM **OPENING SESSION**

1. Welcoming and Opening Comments
    Alan Lloyd - SCAQMD
    Wes Lum - CALTRANS
    Jeff Lindley - FHWA

2. Keynote Address
    Don Orne - PATH

9:00 AM **GENERAL SESSION I: Roundtable Discussion of IVHS and Air Quality**

Moderator: Tom Horan - George Mason University

1. Overview of IVHS Strategies and Technologies
    Craig Roberts - IVHS America

2. Perspectives on IVHS/Air Quality Impacts

    Federal Perspectives
    Dick Schoeneberg - FHWA
    Jon Kessler - EPA

    State/MPO Perspectives
    Dave Clawson - AASHTO
    Mark Howard - NARC

    Environmental Perspectives
    Anne Geraghty - CARB
    Deborah Gordon - USCS

3. Discussion

    - How do organizations differ in the views on the potential of IVHS?
    - What technical issues should be addressed during the course of the workshop to ensure priority attention to the impacts of IVHS on air quality?

- What requirements do the Clean Air Act Amendments of 1990 (CAAA) and the Intermodal Surface Transportation Efficiency Act (ISTEA) place on the objectives of IVHS programs?

- Which IVHS strategies seem to have the most promise for improving mobility and, conversely, which areas need to be examined for potentially adverse effects?

10:30 AM **BREAK**

10:45 AM **GENERAL SESSION II: The Impacts of IVHS Strategies on Travel and Traffic**

Moderator: Charles Goodman - FHWA

1. Overview of Current Practice and Research Plans

   Current 4-step demand forecasting process and research/update.
   Fred Ducca - FHWA

   Traffic operations simulation, limitations and planned research.
   David Bernstein - MIT

2. Case Studies in Evaluating IVHS Strategies

   National Field Tests and Evaluations
   Steve Underwood - U. of Michigan

   California Field Tests and Evaluations
   Mark Miller - PATH

3. Discussion

   - What behavioral and system factors could affect traveler response to IVHS strategies?

   - What data collection/model development efforts are needed to improve our ability to evaluate the specific IVHS strategies?

   - What are the tradeoffs of laboratory versus field testing to assess behavioral issues?

   - What data collection activities are needed to improve understanding of the potential for IVHS strategies to "induce" travel?

   - What roles should organizations and interest groups play in this behavioral research?

12:30 PM **LUNCH**

1:30 PM **GENERAL SESSION III: Measuring IVHS Impacts on Air Quality**

Moderator: Paul Benson - CALTRANS

1. Current Practice and Research in determining travel flow/emissions rates for assessing air quality impacts of IVHS
   Robin Miles-McClean - EPA

2. Integrated Models to Assess IVHS Impacts
   Cheryl Little - VNTSC

3. Innovative Measurement and Impact of IVHS Strategies
   Lamont Hempel - CGS

4. Discussion

   - Which IVHS strategies are adequately addressed by current air quality models and which are not?
   - Which strategies require evaluation that is most dependent upon the interface between travel demand, traffic simulation, and emissions models?
   - What data collection/model improvements are needed to improve the ability to assess individual IVHS strategies?
   - What are the most promising opportunities for integrating IVHS systems with related systems for emission monitoring and reduction?

3:00 PM **BREAK**

3:15 PM **CONCURRENT WORKSHOPS I: Topical Issues**

Group A1: IVHS Strategies to Improve Air Quality
Moderator: Mark Simons - EPA

Group A2: IVHS Strategies to Improve Air Quality
Moderator: Ron Fisher - FTA

Groups A1 and A2 will review and pre-screen air quality impacts of specific IVHS strategies. In addition to the workshop presentations, a list prepared by the IVHS America's BEC committee will be transmitted to participants for their consideration. Through independent, small group discussion, both groups will generate issues, additional data needs, as well as needs for future research dealing with specific IVHS strategies.

Group B1: IVHS Data Collection and Model Development Needs
Moderator: Mike Replogle - EDF

Group B2: Data Collection and Model Development Needs
Moderator: Roger Stough - GMU

Workshops B1 and B2 will discuss IVHS impacts and associated limitations in data collection and models for estimating and projecting changes in travel demand, traffic flow, and mobile source emissions associated with them. Discussion will focus on the points of interface between the model elements, compatibility of input data requirements, and sensitivity to operating and policy variables with regard to the individual strategies.

5:30 PM	**RECEPTION**	**At the Diamond Bar Country Club**
6:30 PM	**DINNER**	**On Your Own**

7:00 PM **Workshop Meeting of Moderators**
Facilitator: Burt Stephens - FHWA

Moderators from the general and workshop sessions will meet to develop a preliminary draft listing of research activities associated with individual IVHS strategies resulting from the first day's discussion. This list will be the starting point for discussion on Day 2.

Tuesday, March 30

8:30 AM **GENERAL DISCUSSION I: Summary of Group Discussions from Day 1**

Presentations by workshop moderators, with discussion panel to include all session moderators.

9:30 AM **CONCURRENT WORKSHOPS II: Future Research Needs**

Group C1: Research Agenda on Technical Issues
Moderator: Bob Ricci - VNTSC

Group C2: Research Agenda on Technical Issues
Moderator: Wes Lum - CALTRANS

These workshops will independently address the information and research needs developed by Conference participants and will prepare "strategic plans" for implementing the required data collection and research activities. The groups will focus on individual IVHS strategies in addressing the relative priorities of need, as well as potential participants and sponsors of elements of the required research.

12:30 PM **LUNCH**

1:30 PM **GENERAL DISCUSSION II: Strategic Agenda for Research**
Moderator: Burt Stephens - FHWA

The morning Workshop moderators will present the recommendations of their respective sessions. The Session moderator will direct the entire group to closure on a "consensus" assessment of analytical capabilities to study individual IVHS strategies and a research/data collection improvement program.

Closing Remarks and Next Steps
Tom Horan
Phil Shucet

3:30 PM **ADJOURNMENT**

APPENDIX C: VIDEO-CONFERENCE ON IVHS AND AIR QUALITY

On March 8, 1993 a video-conference was held to discuss the issues that drive the potential relationships between IVHS technology bundles, travel parameters, traffic operations, and emissions. The discussion panel was comprised of experts in the fields of mobile source emissions modeling and analysis, transportation economics, traffic engineering, and IVHS.

The objectives of the video-conference were as follows: to assure that all possible sources of information were employed in this study; to provide a forum for the exchange of ideas relevant to the debate on the emission and air quality ramifications of IVHS deployment; to derive consensus opinions, where possible, on the likely emission impacts of IVHS technology bundles; and to identify the types of scientific research efforts that are needed to derive quantitative estimates. The list of participants and the video-conference agenda are presented below.

VIDEO-CONFERENCE PARTICIPANTS

WEST-COAST (SAN FRANCISCO) PARTICIPANTS	EAST-COAST (WASHINGTON, D.C.) PARTICIPANTS
Paul Benson — CALTRANS Mobile Source Emissions	Rich Bechtold — EA Engineering Mobile Source Emissions
Elizabeth Deakin — U.C. Berkeley Travel Demand and Traffic Operations	Michael Meyer (Via Telephone) — Georgia Tech. Travel Demand and Traffic Operations
Bob Dulla — Sierra Research Mobile Source Emissions	John Suhrbier — Cambridge Systematics Travel Demand and Traffic Operations
Randall Guensler — U.C. Davis Mobile Source Emissions	Cheryl Little — DOT VNTSC IVHS
Steve Shladover — U.C. Berkeley IVHS (PATH)	
Mike Lawrence — Jack Faucett Associates West Coast Coordinator/Moderator	Joon Byun — DOT FHWA Observer/Participant
Mike Fischer — Jack Faucett Associates Observer/Participant	Fred Ducca — DOT FHWA Observer/Participant
	Charles Goodman — DOT FHWA Observer/Participant
	Burt Stephens — DOT FHWA Observer/Participant
	Sergio Ostria — Jack Faucett Associates East Coast Coordinator

FINAL AGENDA
(EAST COAST TIMES)

MODERATOR: MICHAEL LAWRENCE (JFA)

- *2:00 p.m. to 2:15 p.m.* Introduction and Ground Rules — Mike Lawrence.

- *2:15 p.m. to 2:45 p.m.* What constitutes a small, moderate, or large travel demand, congestion, emissions effect of IVHS technologies?

  - Round-table discussion between travel demand, emissions, IVHS experts.

- *2:45 p.m. to 6:45 p.m.* Discuss/assess the travel demand, congestion, and emissions impacts of IVHS by technology bundle?

  - Traffic and Incident Management Systems — 2:45 to 3:25 (40 minutes)

    * travel demand, congestion effects 2:45 to 3:00 (15 minutes)
    * emission effects 3:00 to 3:15 (15 minutes)
    * IVHS 3:15 to 3:21 (6 minutes)
    * open discussion 3:21 to 3:25 (4 minutes)

  - Route Guidance Systems — 3:25 to 4:05 (40 minutes)

    * travel demand, congestion effects 3:25 to 3:40 (15 minutes)
    * emission effects 3:40 to 3:55 (15 minutes)
    * IVHS 3:55 to 4:01 (6 minutes)
    * open discussion 4:01 to 4:05 (4 minutes)

  - Accident Reduction Systems — 4:05 to 4:45 (40 minutes)

    * travel demand, congestion effects 4:05 to 4:20 (15 minutes)
    * emission effects 4:20 to 4:35 (15 minutes)
    * IVHS 4:35 to 4:41 (6 minutes)
    * open discussion 4:41 to 4:45 (4 minutes)

  - Vehicle Control Systems — 4:45 to 5:25 (40 minutes)

    * travel demand, congestion effects 4:45 to 5:00 (15 minutes)
    * emission effects 5:00 to 5:15 (15 minutes)
    * IVHS 5:15 to 5:21 (6 minutes)
    * open discussion 5:21 to 5:25 (4 minutes)

- Trip Guidance and Public Transportation Systems — 5:25 to 6:05 (40 minutes)

  - * travel demand, congestion effects 5:25 to 5:40 (15 minutes)
  - * emission effects 5:40 to 5:55 (15 minutes)
  - * IVHS 5:55 to 6:01 (6 minutes)
  - * open discussion 6:01 to 6:05 (4 minutes)

- Commercial Vehicle Inspection Systems — 6:05 to 6:25 (20 minutes)

  - * travel demand, congestion effects - 6:05 to 6:13 (8 minutes)
  - * emission effects 6:13 to 6:21 (8 minutes)
  - * IVHS 6:21 to 6:25 (4 minutes)

- Automatic Toll and Road Pricing — 6:25 to 6:45 (20 minutes)

  - * travel demand, congestion effects 6:25 to 6:33 (8 minutes)
  - * emission effects 6:33 to 6:41 (8 minutes)
  - * IVHS 6:41 to 6:45 (4 minutes)

- ● *6:45 p.m. to 7:45 p.m.* Research and modeling needs to quantify effects or reduce uncertainties surrounding qualitative effects.

  - Round-table discussion by area of expertise.

- ● *7:45 p.m. to 8:00 p.m.* Closing remarks — Mike Lawrence.

APPENDIX D: SELECTED LIST OF RELEVANT LITERATURE

1. Behnke, Robert. "Advanced Public Transportation Systems (APTS): Multimodal and Alternative Market Applications of IVHS." *Transportation, Information Technology, and Public Policy*. Proceedings of the Asilomar IVHS Policy Conference, Fairfax, VA. George Mason University, 1992, pp. 81-95.

2. Brand, Daniel. "An IVHS Benefits Assessment Framework: Structuring Travel Demand Models to Forecast IVHS Benefits." Presented at 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., January 10-14, 1993.

3. Chen, Kan and Robert D. Ervin. "Intelligent Vehicle-Highway Systems: U.S. Activities and Policy Issues." *Technological Forecasting and Social Change*, Vol. 38, 1990, pp. 363-374.

4. Chen, Kan and Robert D. Ervin. *Socioeconomic Aspects of Intelligent Vehicle Highway Systems*. Society of Automotive Engineers, Technical Paper Series: Paper No. 901504, August 1990.

5. Cheslow, Melvin. "Energy Estimates for 2000 and 2010." *Surface Trans and the Information Age*. Proceedings of the 1992 IVHS America Annual Meeting, Washington, D.C., 1992, pp. 404-411.

6. Conroy, Patrick. "Transportation's Technology Future: Prospects for Energy and Air Quality Benefits." *TR News*, May-June 1990, pp. 32-37.

7. Deakin, Elizabeth. "Opportunities and Constraints for Advanced Highway Technologies: A Speculative Analysis." University of California at Berkeley, October, 1989.

8. DeCorla-Souza, Patrick. "Travel and Emissions Model Interactions." Presented at the Transportation/Air Quality Conference, Los Angeles, CA, February 4, 1993.

9. Gifford, Jonathan L., Thomas Horan, and Daniel Sperling. "IVHS/RTI Institutional and Environmental Issues: A Strategic Policy Research and Outreach Agenda for the United States." Proceedings, 3rd International Conference on Vehicle Navigation and Information Systems, September 2-4, 1992, Oslo, Norway.

10. Gordon, Deborah. "Intelligent Vehicle/Highway Systems: An Environmental Perspective." *Transportation, Information Technology, and Public Policy*. Proceedings of the Asilomar IVHS Policy Conference, Fairfax, VA: George Mason University, 1992.

11. Guensler, Randall, Daniel Sperling, and Paul Jovanis. "Uncertainty in the Emission Inventory for Heavy-Duty Diesel-Powered Trucks." Institute of Transportation Studies, University of California, Davis, Research Report UCD-ITS-RR-91-02, prepared for the TRED Foundation, June 1991.

12. Guensler, Randall, Daniel Sperling, and Simon Washington. *IVHS Technologies and Motor Vehicle Emissions*. Institute of Transportation Studies, University of California, Davis, 1993.

13. Harvey, Greig and Elizabeth Deakin. "Air Quality and Transportation Planning: An Assessment of Recent Developments." Draft Version, February, 1992.

14. Harvey, Greig and Elizabeth Deakin. "A Manual of MPO Practice in Transportation Modeling for Air Quality Planning." Prepared for the National Association of Regional Councils, November 1992.

15. Harvey, Greig and Elizabeth Deakin. "Toward Improved Regional Transportation Modeling Practice." Prepared for the National Association of Regional Council, 1992.

16. Hempel, Lamont C. "Exploring the Transportation-Environmental Nexus: The Role of IVHS in Reducing Urban Air Pollution Caused by Congestion and Super-Emitting Vehicles." *Transportation, Information Technology, and Public Policy*. Proceedings of the Asilomar IVHS Policy Conference, Fairfax, VA: George Mason University, 1992.

17. Horan, Thomas A. "Evaluating IVHS: Key Issues in Institutional and Environmental Assessments of IVHS Technologies." Prepared for IVHS Policy: A Workshop on Institutional and Environmental Issues, Asilomar Conference Center, Monterey, CA, April 26-28, 1992.

18. Horan, Thomas A. "Toward Adaptive IVHS: The Role of Impact Assessments in Guiding the Development of Advanced Transportation Technologies." Prepared for IVHS National Workshop: Will IVHS Transform Transportation System Effectiveness? San Diego, CA December 1-3, 1992.

19. Horan, Thomas A. and Jonathan L. Gifford. "Determining Congestion and Air Quality Effects: the Need for Field and Forecast Data on IVHS Technologies." *Modeling and Simulation*, Vol. 23, Part II, 1992, pp. 1319-1325.

20. Institute of Transportation Studies, University of California, Berkeley, *The Air Quality Impacts of Urban Highway Capacity Expansion: Traffic Generation and Land-Use Impacts*. Research report (draft) UCB-ITS-RR-93-5, April 1993.

21. IVHS America, *Strategic Plan for Intelligent Vehicle Highway Systems in the United States*. Washington, D.C., May 20, 1992.

22. Jacobson, Leslie N. "Marketing ATMS and Measuring the Benefits," *Surface Transportation and the Information Age*. Proceedings of the 1992 IVHS America Annual Meeting, Washington, D.C., 1992, pp.349-357.

23. Kessler, Jon and William Schroeer. *Meeting Mobility and Air Quality Goals: Strategies That Work*. U.S. Environmental Protection Agency, February 1993.

24. Lockwood, Steven E. *Federal Highway Administration Perspective*. Fourth National High-Occupancy Vehicle (HOV) Facilities Conference, Conference Proceedings, Washington, D.C., April 10-12, 1990.

25. Lund, Scott A. *Intelligent Vehicle/Highway Systems in the U.S. - In Need of a Vision*. Society of Automotive Engineers, Technical Paper Series: Paper no. 910871, 1990.

26. Mahmassani, Hani S. and Peter Shen-Te Chen. "Comparative Assessment of Origin-Based and En Route Real-Time Information Under Alternative User Behavior Rules." *Transportation Research Record* #1306, 1992, pp.69-81.

27. Marans, Robert W. and Cyrus Yoakum. *Assessing the Acceptability of IVHS: Some Preliminary Results*. Society of Automotive Engineers, Technical Paper Series: Paper no. 912811, 1991.

28. Meyer, Michael D. and Catherine Ross. "Transportation and Air Quality Modeling: Fitting a Square Block into A Round Hole." Unpublished.

29. Miller, Mark, Anne Bresnock, Edward Lechner, and Steve Shladover. "Highway Automation: Regional Mobility Impacts Assessment." 72nd Annual Meeting of the Transportation Research Board, Washington, D.C., January 10-14, 1993.

30. Mobility 2000, *Proceedings of a National Workshop on IVHS Sponsored by Mobility 2000*. Dallas, Texas, March 1990.

31. National Cooperative Highway Research Program Report 340, *Assessment of Advanced Technologies for Relieving Urban Traffic Congestion*. Transportation Research Board, National Research Council, Washington, D.C., December 1991.

32. Prendergast, John. "A New Era in Transportation." *Civil Engineering*, Vol. 62, No. 4, April 1992, pp 38-41.

33. Replogle, Michael. "Improving Transportation Modeling for Air Quality and Long-Range Planning." Prepared for presentation to the Transportation Research Board's Annual Meeting, Washington, D.C., 1993.

34. Shladover, Steven E. "Potential Contributions of Intelligent Vehicle/Highway Systems (IVHS) to Reducing Transportation's Greenhouse Gas Production." *Transportation Research*, May 1993.

35. Sierra Research, Inc. *Evaluation of "MOBILE" Vehicle Emission Model.* Prepared for the Volpe National Transportation Systems Center, April 1993.

36. Sperling, Daniel, Randall Guensler, Dorriah Page, and Simon Washington. *Air Quality Impacts of IVHS: An Initial Review, Transportation, Information, Technology, and Public Policy.* Proceedings of the Asilomar IVHS Policy Conference, 1992.

37. Stephens, Burton. "An Overview of Evaluation Plans for Intelligent Vehicle-Highway Systems Operation Tests." *Surface Transportation and the Information Age.* Proceedings of the 1992 IVHS America Annual Meeting, Washington, D.C.: IVHS America, 1992, p. 349-357.

38. Sussman, Joseph M. "Intelligent Vehicle Highway Systems." *OR/MS Today*, December 1992, pp. 18-23.

39. Transportation Research Board. *Advanced Vehicle and Highway Technologies.* National Research Council, Special Report 232, Washington, D.C., 1991.

40. Underwood, Steven E. *Social and Institutional Considerations in Intelligent Vehicle-Highway Systems.* Society of Automotive Engineers, Technical Paper Series: Paper no. 901505, August 1990.

41. Underwood, Steven and Frederick Streff. "Avoiding Delay, Death, and Dirty Air: Framework for Evaluation of Intelligent Vehicle-Highway Systems." *Surface Transportation and the Information Age.* Proceedings of the 1992 IVHS America Annual Meeting, Washington, D.C., pp. 358-381.

42. U.S. Department of Transportation. *Report to Congress on Intelligent Vehicle Highway Systems.* DOT-P-37-90-1, Washington, D.C., March 1990.

43. U.S. Environmental Protection Agency. *Federal Test Procedure Review Project.* Preliminary Report, May 1993.

44. U.S. General Accounting Office. *Smart Highways: An Assessment of Their Potential to Improve Travel.* GAO/PEMD-91-18, Washington, D.C., June 1991.

45. Woods, Jim R. *If Information Technology Could Save Lives, Improve Productivity, Help Clean Up the Environment, and Lower the Budget Deficit, Would We Use It? Should We Use It?* Society of Automotive Engineers, Technical Paper Series: Paper no. 912749, 1991.

46. Zackor, Heinz. *Implementation of New Traffic Control Systems — Problems and Approaches to Solutions.* Society of Automotive Engineers, Technical Paper Series: Paper no. 912863, 1991.

*U.S. GOVERNMENT PRINTING OFFICE: 1995-602-422/20015