How Responsive Multimodal Transportation Management Linked To IVHS Can Improve Environmental Quality

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CONTENTS

EXHIBITS

1. INTRODUCTION

1.1 Purpose

This paper has the following four objectives:

- To review Multimodal Transportation Management Strategies Linked to IVHS

- To review the potential of various strategies and technologies to improve environmental quality

- To discuss a process by which IVHS can be involved in environmental evaluations

- To outline concerns that should be addressed to improve the Multimodal IVHS Environmental Quality Process

1.2 Background

Responsive Multimodal Transportation Management Strategies include those actions which involve more than one mode of transportation, provide real or semi-real time information to users of IVHS technology, and achieve the following goals and objectives established by the Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA):

1) Improve the market share and operations of high occupancy vehicles (HOV), ridesharing and mass transit;
2) Provide for more efficient use of existing transportation facilities and resources:
3) Provide for more efficient use of energy sources:
4) Enhance the efficiency of urban goods movement:
5) Improve the usefulness of existing TSM strategies:
6) Improve air quality:

7) Improve transportation safety:
8) Improve the economic efficiency of transit and paratransit operations:
9) Improve the mobility of the elderly, handicapped, and the transportation disadvantaged; and
10) Improve mobility in rural areas.

This paper presents findings related to conceptual evaluations of scenarios from a two year FHWA/FTA project conducted by a team led by Bellomo-McGee, Inc. (BMI). The objectives of the research study were to:

1) Identify candidate real or semi-real time multimodal transportation management scenarios which use new and emerging IVHS technologies;
2) Determine their usefulness and feasibility;
3) Develop additional innovative concepts;
4) Evaluate the potential utility and cost of each scenario; and
5) Provide recommendations for additional research, development, and operational tests.

A framework for evaluating the potential benefits and costs of multimodal functional scenarios was successfully applied to a conceptual evaluation of some 27 scenarios involving mass transit, paratransit/ridesharing, general highway multimodal, airports, and commercial ports/intermodal facilities. This conceptual evaluation addressed environmental effects and can also be transferrable to the IVHS America mode-specific 27 user groups identified as part of the United States Department of Transportation (USDOT)/IVHS Strategic Program Plan Draft (l).

The conceptual evaluation of environmental effects focused on the physical and socio-economic environment and was based on studies and research to date. Physical environmental effects covered potential impacts on traffic (improved HOV, rideshare, and mass transit, better use of existing facilities) traffic safety, air quality (reduced emissions) and energy (efficiency improvements). Socio-economic areas effects included improved mobility for the elderly, handicapped and transportation disadvantaged, improved rural area mobility, and potential human factors effects. It should be noted, however, that the precise environmental effects of many of these technological advances will not be known until proper evaluations are made during operational tests, data is gathered, and improvements in models are completed.

Before proceeding with the paper, it is important to overview the assumptions and scenarios used in the research.

Assumptions

The scenarios presented in this paper were developed for a mature IVHS environment that is assumed will exist at some time in the future. The following assumptions have been made about the expected level of IVHS maturity in the urbanized areas and in major rural highway corridors under implementation consideration for this study:

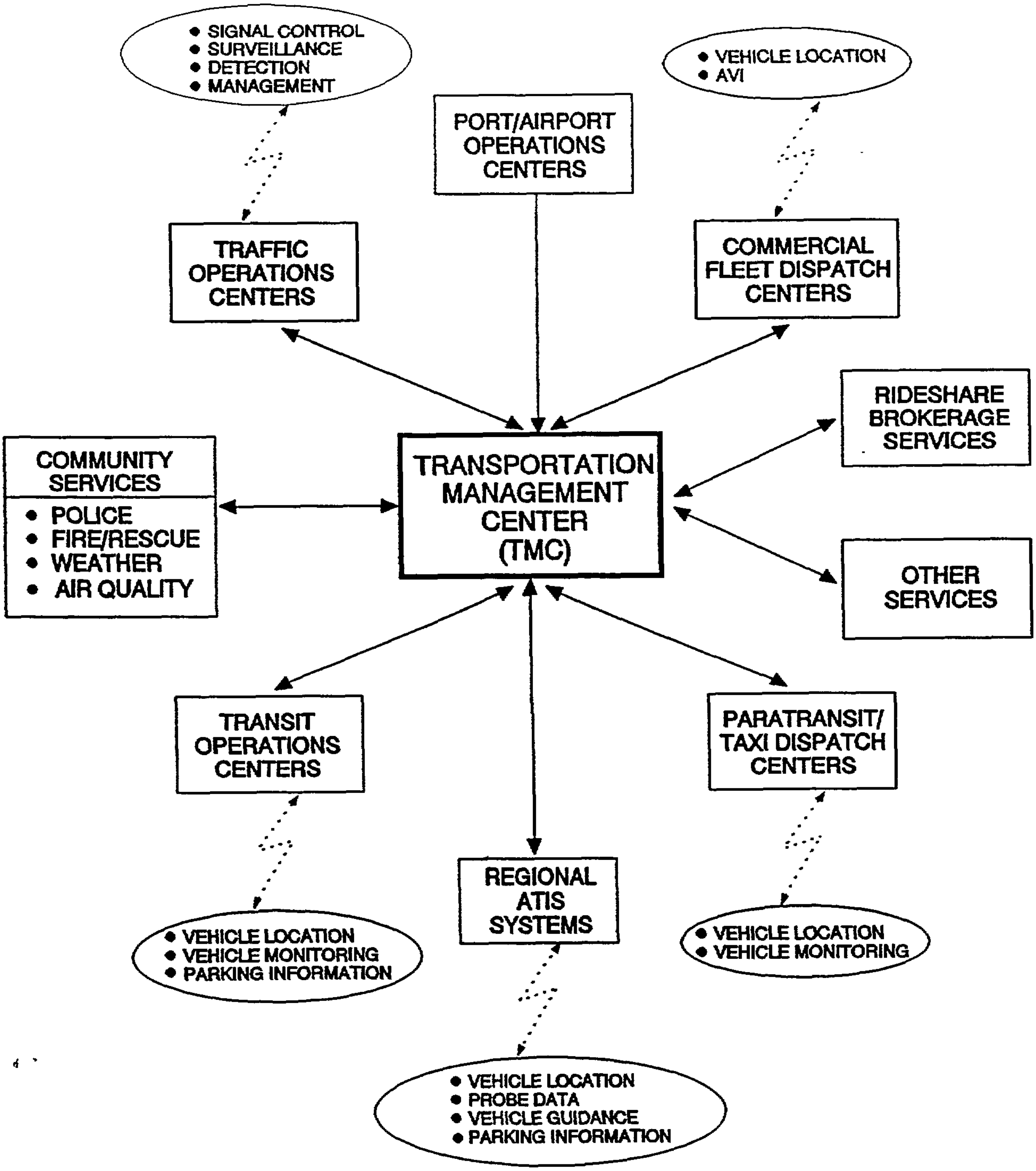
- Traffic signal control, freeway management, and transit fleet management systems have been deployed throughout most of the area.

- The systems are physically/electronically linked.

- Each location has a Transportation Management Center (TMC), similar to Exhibit 1, where information is received, fused, and disseminated to travelers.

- Commercial vehicles are linked to fleet management centers which provide them with traffic and route information.

- There is a large market penetration of in-vehicle navigation devices whereby the above information is provided to passenger car, transit vehicle, and commercial vehicle drivers and recommended routing is



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Transportation Management Center Concept

Exhibit 1

provided based on real-time information.

- Reduced scale in-vehicle systems which provide continuous traffic information on selected corridors are also available. They are less sophisticated and less costly than the fully functional ATIS devices described above.

- Traffic information centers and systems, similar to those described above, exist in major rural highway corridors and areas. However, these systems are not deployed throughout the entirety of the rural networks.

These functional requirements were taken as given during the development and evaluation of the candidate scenarios. Exhibit 2 presents selected criteria used for the evaluation of the multimodal transportation management strategies linked to IVHS. This study was not concerned with the practicality of these requirements or whether or not they are attainable, rather the focus was on how the candidate scenarios would perform given this assumed operating environment.

Scenarios

The 27 candidate multimodal scenarios are discussed here. Although all scenarios have multimodal applications, they are presented according to their major modal applications:

- Mass Transit (10)
- Paratransit/Ridesharing (5)
- General Highway/Multimodal (7)
- Airports (1)
- Commercial Ports/Intermodal Facilities (4)

1. Applicability to Multi-Modal Transportation Management - Criteria include:

- HOV/Ridesharing utilization
- Coordination with mass transit
- Applications to goods movement
- Compliance with Clean Air Act Amendments '90
- Compliance with the Americans with Disabilities Act

2. Technical Feasibility - Screening criteria include:

- Feasibility (need for new technology)
- Flexibility (alternate technologies)
- Reliability
- Expandability & upgradability

3. Potential Benefits - Criteria include:

- Reduced Single Occupant Vehicles
- Congestion reduction & avoidance
- Improve commercial vehicle productivity
- Pollution reduction
- Improved transit/rideshare operations
- Improved safety
- Energy savings

4. Potential Costs - Criteria include:

- Implementation costs
- Operation & Maintenance costs
- Out of pocket user costs
- Non-monetary costs

5. Institutional and Legal Issues - Criteria include:

- Passenger security/safety
- Operator/manufacturer liability
- Need for inter-jurisdictional/inter-agency cooperation
- Opportunity for public/private cooperation
- Legal and regulatory restrictions

6. Financial Feasibility - Criteria include:

- Need for government subsidies
- Potential for commercialization
- User willingness to pay
- Applicability to existing funding programs

7. Attractiveness to Users, Operators, and Society - Criteria include:

- Acceptability to management
- Ease of learning system (users & providers)
- User and provider convenience
- Provision of incentives
- impacts on non-users

8. Human Factors - Criteria include:

- Target audience
- Ability to gain larger user population
- Ease of use for all user populations
- Effectiveness in addressing human concerns

9. Potential for Success - Criteria include:

- Potential market penetration
- Long-term viability
- Integratability with other scenarios

10. Implementation Potential - Criteria include:

- Barriers to deployment
- Compatibility with existing systems/modes
- Implementation sequence
- Areas of greatest potential impact (e.g. urban CBD, urban non-CBD, suburban, high activity centers, etc.)

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Selected Evaluation Criteria

Exhibit 2

Mass Transit Scenarios have been designed to increase transit usage, enhance the efficiency of transit operations, ease transit use, and improve the overall quality of mass transit services. The scenarios include applications to route deviation service, transit management information, smartcards, and automatic vehicle location systems.

Paratransit and Ridesharing Scenarios were designed to increase the use of HOV and ridesharing, enhance the operations of paratransit services, and generally improve personal mobility in both urban and rural environments. The scenarios include real-time ridesharing, improved paratransit dispatching, rural ATIS systems, and using courier vehicles to move people on HOV facilities.

General Highway/Multimodal Scenarios were designed to improve travel on the transportation system and encourage the awareness and use of alternate modes of travel. The scenarios included providing travel information in homes and workplaces, using IVHS to reduce travel demand during air quality alerts, using ATIS to monitor parking availability, and developing a hand-held portable ATIS unit.

The Airport Scenario was designed to improve travel and traffic flow at airports.

Ports/Intermodal Facilities Scenarios were designed to improve the operation and efficiency of intermodal port and rail facilities. The scenarios provide for improved truck access to ports and rail facilities, improved vehicle processing at ports, and coordination of river and drawbridge traffic.

13 Organization

The paper is organized into five sections. Section 2 presents the multimodal transportation management scenarios and environmental concerns identified during the conduct of workshops. Section 3 highlights at a conceptual level broad, potential environmental effects. Section 4 discusses how multimodal transportation management can be related to the environmental processes. Section 5 presents concerns that need to be addressed and Section 6 presents conclusions.

2. MULTIMODAL TRANSPORTATION MANAGEMENT SCENARIOS

The study developed 27 conceptual IVHS scenarios covering a wide range of modes, user services, and areas of applicability. Exhibit 3 presents a sample scenario, "Air Quality Alert." Its purpose is to assist transportation managers in air quality non-attainment areas to manage travel during air quality alerts. Exhibit 4 presents a summary evaluation of this scenario based on each of the evaluation criteria identified in Exhibit 2 (more detailed evaluations were also performed and included as an appendix to the Final Report).

2.1 Modal and Ares Applicability

Exhibit 5 presents a correlation of the 27 scenarios to their various modes. While all of the scenarios are multimodal in scope, they are grouped according to their primary mode of application. In developing these scenarios, an attempt was made to consider all modes, and not just the traditional highway modes.

2.2 Linkage to IVHS

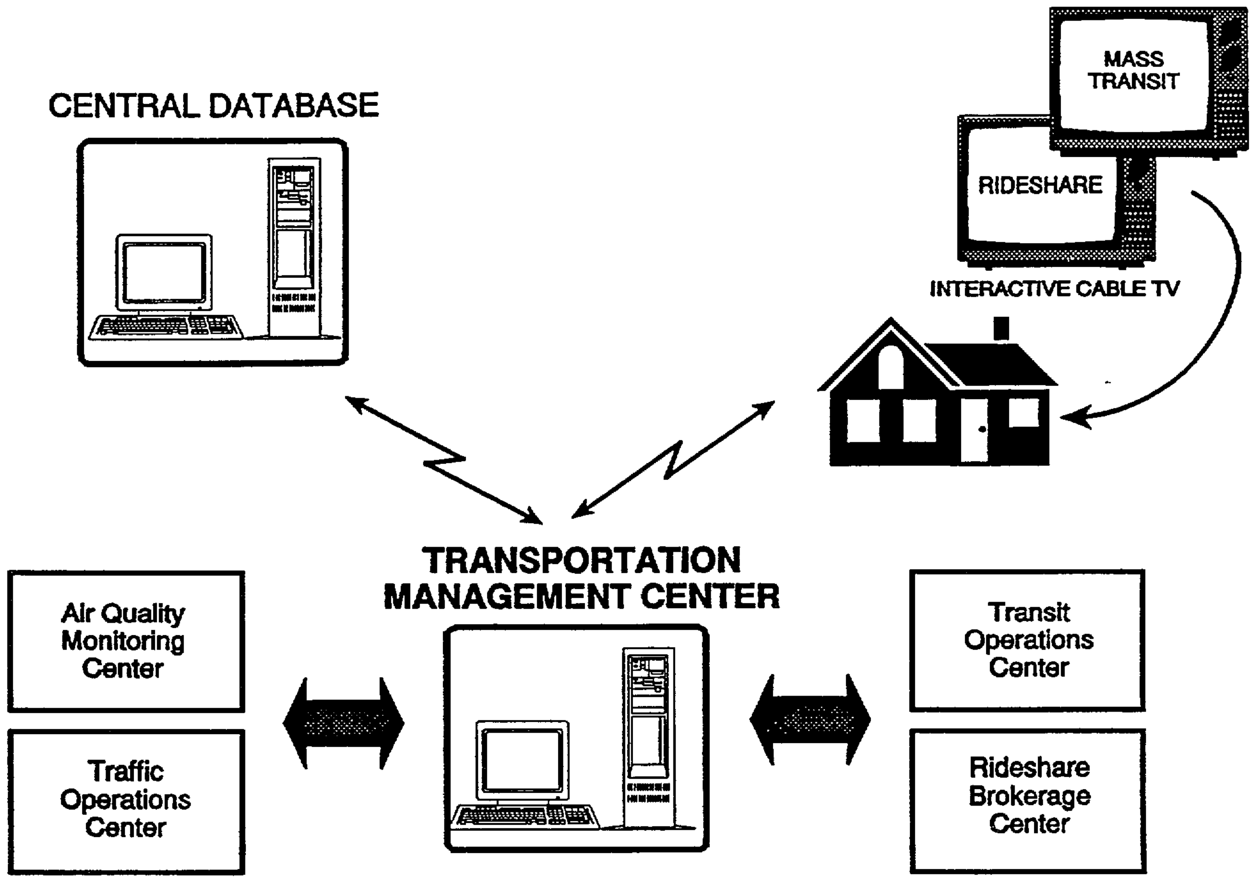
Exhibit 6 correlates each of the scenarios with the relevant IVHS technology areas (ATMS, ATIS, CVO, APTS, and AVCS) and areas of applicability. It can be seen that many of the scenarios have correlations to several IVHS technology areas.

It should be noted that although each scenario is listed individually, the scenarios can be combined in "packages" which might yield greater benefits than what could be obtained from the scenarios individually. For instance, scenario 18 "Air Pollution Alert," scenario 11 "Real Time Ridesharing," and scenario 4 "Transit Park & Ride Information" could be combined for use during air quality alerts or special events to encourage travelers to use Carpools or transit. Together, they would likely encourage greater use of alternate modes than any one scenario would on its own.

Not all scenarios, however, could be combined with positive results. While some combinations would enhance the overall benefits, others may prove counterproductive. Exhibit 7 presents the interrelationship between multimodal

SCENARIO NO. 18
AIR POLLUTION ALERT

GOAL: Reduce mobile source emissions and encourage use of alternate modes during non-attainment periods.



SCENARIO

1. Air Quality monitoring center identifies non-attainment areas or forecasts potential air quality problems.
2. Persons within these areas are notified and presented with alternate travel modes.
3. Road pricing policies could be implemented using AVI equipment on cars.
4. Real-time travel data allows cities to adjust management strategies once they have been implemented.

SCENARIO: 18. AIR QUALITY ALERT

Summary Evaluation

Criteria Category	Summary Rating/Comment	Comments
1. Applicable to MM Transportation Management?	YES	Would Permit implementation of multi-modal transportation controls to meet air quality attainment goals
2. Technically Feasible?	YES	Would largely use other IVHS systems to gain and disseminate information.
3. Potential Benefits	HIGH	Could help reduce mobile emissions and facilitate use of other modes.
4. Potential costs	MODERATE	If system uses existing IVHS infrastructure additional costs should be moderate.
5. institutional/Legal Barriers	MODERATE	Will require regional (multi-jurisdictional) pollution control authority to coordinate mitigation measures.
6. Financially Feasible?	YES	Services could be provided through other IVHS systems. Would not need to dedicate an entire system solely to this purpose.
7. Attractiveness to Users, Operators and Society	MODERATE	While mitigation measures themselves may be seen as unattractive, this system should be useful for users and operators during alerts.
8. Human Factors Effectineness	HIGH	Will increase information available to travelers during alerts. Information will need to be accurate, timely, and accessible.
9. Potential for Success	HIGH	Should be a useful element of regional air quality plans. Could help to significantly reduce mobile source emissions.
10. Implementation Potential	HIGH	The CAAA 90 set out federal mandates to address air quality problems. This will be a major concern for non-attainment areas.

SCENARIO	MODE										
	PERSONS								GOODS		
	AUTO	HOV	TAXI	BUS	RAIL	AIR	BIKE	PED	TRUCK	PORT	RAIL
MASS TRANSIT											
1. Transit Route Deviation				X	X			X			
2. Real-Time Bus Location Information				X				X			
3. Timed Transfer Management				X	X						
4. Transit Park-Ride Information	X	X		X	X						
5. Smartcard Fare Collection				X	X						
6. Transit Priority on Signalized Networks	X	X	X	X	X	X	X	X			
7. In-Vehicle Information Displays				X	X						
8. Transit Schedule Reliability				X	X						
9. Improved Transit Management Info.				X	X						
10. Accident Data Recording	X	X	X	X	X				X		X
PARATRANSIT & RIDESHARING											
11. Real-Time Ridesharing		X		X					X		
12. Paratransit Dispatching		X		X							
13. Taxi Management w/ Smartcard		X		X							
14. Urban Goods/Passenger Movement		X							X		
15. Rural ATIS/Route Guidance	X	X	X	X					X		
GENERAL HIGHWAY											
16. Real-Time Transportation Information	X	X		X	X						
17. Needs Scheduling	X			X	X						
18. Air Quality Alert	X	X		X	X		X	X	X		
19. Weather/Roadway Condition Monitoring	X	X	X	X					X		
20. ATIS - Parking Availability	X	X	X						X		
21. Personal ATIS System				X	X		X	X			
22. Traffic Management at Parks/Monument	X	X		X	X	X					
AIRPORTS AND PORTS											
23. Airport Access - Passenger Pick-Up	X	X				X					
24. Truck Access to Ports/Rail									X	X	X
25. Vehicle Processing at Ports/Rail									X	X	X
26. River and Drawbridge Coordination	X			X					X	X	
27. Moving Urban Goods on Ferries									X	X	

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Scenarios and Modal Applicability

Exhibit **5**

SCENARIO	IVHS FUNCTIONAL AREA					URBAN AREA			RURAL
	ATMS	ATIS	APTS	CVO	AVCS	REGION	SUB-AREA	FACILITY	
<u>MASS TRANSIT</u>									
1. Transit Route Deviation	X	X	X			X	X	X	X
2. Real-Time Bus Location Information	X	X	X			X	X	X	X
3. Timed Transfer Management	X	X	X					X	
4. Transit Park-Ride Information	X	X	X			X	X		X
5. Smartcard Fare Collection	X		X				X	X	X
6. Transit Priority on Signalized Networks	X		X			X	X		
7. In-Vehicle Information Displays		X	X				X	X	X
8. Transit Schedule Reliability	X	X	X					X	X
9. Improved Transit Management Info.		X	X		X	X	X	X	X
10. Accident Data Recording		X	X	X	X				
<u>PARATRANSIT & RIDESHARING</u>									
11. Real-Time Ridesharing	X	X	X			X	X		X
12. Paratransit Dispatching	X	X	X			X	X		X
13. Taxi Management w/ Smartcard		X	X	X			X		X
14. Urban Goods/Passenger Movement		X	X	X			X		X
15. Rural ATIS/Route Guidance	X	X	X	X					X
<u>GENERAL HIGHWAY</u>									
16. Real-Time Transportation Information	X	X	X	X		X	X		X
17. Needs Scheduling	X	X	X			X	X		X
18. Air Quality Alert	X	X	X	X		X	X	X	X
19. Weather/Roadway Condition Monitoring	X	X		X	X	X	X	X	X
20. ATIS - Parking Availability	X	X		X			X	X	
21. Personal ATIS System	X	X	X			X	X		X
22. Traffic Management at Parks/Monument	X	X	X					X	
<u>AIRPORTS AND PORTS</u>									
23. Airport Access - Passenger Pick-Up	X	X						X	
24. Truck Access to Ports/Rail	X	X		X				X	X
25. Vehicle Processing at Ports/Rail	X	X		X				X	X
26. River and Drawbridge Coordination	X	X		X			X	X	
27. Moving Urban Goods on Ferries	X	X		X		X	X	X	

IVHS Action Groups

	Increase Carpool	Increase Walk & Bike	Improve Paratransit & Goods Movement	Restricted Traffic	Pricing Measures	Parking Management
Increase Transit	C	A	A	A	A	A
Increase Carpool		I	I	C	A	A
Increase Walk & Bicycle			I	A	I	I
Improve Paratransit & Goods Movement				C	I	I
Restricted Traffic					C	C
Pricing Measures						A

A - Action Groups assist each other.
I - Action Groups are independent of each other.
C - Action Groups are counterproductive to each other.

transportation action groups. It can be seen that some action groups assist one another, some are independent of one another, and others are counterproductive. Before operational testing or implementation, careful consideration will need to be given to how an IVHS scenario will interact with other transportation management measures already in place in an area.

23 Environmental Concerns

As part of the study, a series of eight workshops were held at sites across the country. The one-day workshops were attended by transportation professionals from Federal, State, and local highway and transit agencies, representatives from airport and port authorities, and transportation planners from State planning agencies and MPOs. At the workshops, various participants discussed their concerns for IVHS and the environment. Some of the key points are summarized in Exhibit 8.

2.4 Relationship to Operational Tests

A final task of the study was to correlate the 27 scenarios with on-going or planned IVHS operational tests. This helped to identify potential test sites where each of the scenarios could be tied into ongoing tests. The correlation identified all ongoing and planned IVHS operational tests in the U.S. and determined whether they could provide a useful basis for testing any of the candidate scenarios. Exhibit 9 presents a sample correlation of a candidate scenario ("Transit Route Deviation") with ongoing operational tests. These correlations were useful not only for identifying sites where the candidate scenarios could be tested, but also for identifying areas where there is currently not enough IVHS research being done. The areas where there was a lack of current activity included air quality, enviromnental concerns, and intermodal ports and terminal facility operations. None of the IVHS operational tests currently being conducted in the U.S. has as one of its primary goals the reduction of air emissions or the improvement of environmental quality.

- For IVHS to be effective in reducing air quality there is a need to focus on parking availability and price. Volunteer efforts are ineffective during air quality episodes.

- Integrated Smart Cards covering mass transit, tolls, parking, congestion, pricing, etc. are needed to address reductions in emissions through SOV trip and VMT reduction. This will require a concerted partnership among the institutions.

- For mass transit to be effective in reducing SOV's, VMT, and emissions, there is a need to make it more customer oriented through improved mobility management (APTS) and driver training. AVL and AVI systems have been found to be effective in our management efforts.

- Nonrecurring congestion on freeways and arterials is a big part of the problem resulting in idling, emissions and wasted fuel. There is a need to develop ATMS, ATIS and other IVHS infrastructure to address the problem. However, it (IVHS) will not work unless there are alternative routes with capacity to choose from.

- Since many of the environmental benefits of IVHS are subjects of various demonstrations and are uncertain, how can these projects be considered in LRTP, TIP and SIP developments at the State and Local level?

- For IVHS to be effective in improving environmental quality, IVHS related projects need to be integrated into plans and programs with conventional highway, transit, airport/port, ground access and other projects. It took us 8 years to get a signal implemented, how do we get our board to act on items in the research/demonstration stage?

- When you look at the environment, think beyond the physical impacts (air quality, energy, congestion, traffic safety, etc.) to human factor effects (reduced anxiety and stress, improved driver/vehicle navigation, etc.). As IVHS makes better use of intrastructure, we have to account for new demands created, human factors, and socio-economic effects.

- We have trouble getting travel and environmental models (emissions, fuel consumption, etc.) to work with conventional plan and project evaluation. How do you get environmental models to work for real and semi-real time evaluations?

- Is there a clearinghouse to go to for reliable evaluation data and findings related to IVHS demonstrations and case studies? This is a particular concern for intermodal/multimodal projects.

APPLICABLE OPERATIONAL TEST SITES		COULD BE TESTED SOON (FULLY)	COULD BE TESTED SOON PARTIALLY	MAY NEED NEW INFRA-STRUCTURE	NOTES/ COMMENTS
Number	Description				
C-I-11	Fredericksburg ARTIS (VIRGINIA)		X	X	Needs to relate to VDOT.
A-II-4	Advance (Illinois)	X			NHTSA is cooperating.
A-II-5	Fast Trac (Michigan)			X*	NHTSA is cooperating.
C-I-5	TravLink (Minnesota)		X		Need outputs on initial project.
C-II-15	Portland SmartBus (Oregon)		X	X	Future Smart Vehicle projects could benefit.
C-II-16	Denver SmartBus Stage I (Colorado)		X	X	Future Smart Vehicle projects could benefit.
C-II-17	Baltimore SmartBus (Maryland)		X	X	Future Smart Vehicle project could benefit.
C-III-19	Ann Arbor Smart Intermodal (Michigan)		X	X	Future Smart Vehicle project could benefit.
C-III-20	Chicago Smart Intermodal (Illinois)		X	X	Future Smart Vehicle project could benefit.
C-I-12	Winston Salem Mobility Manager (N.C.)		X	X	
C-I-13	Delaware County Mobility Manager (Pennsylvania)		X	X	

COMMENTS

Presently only area where this is being done is C-I-11. There is not a lot going on in this area. Need to be more pro-active in promoting this scenario.

Modal administrations interested include FTA, FHWA, and NHTSA. The agencies are participating in the operational tests noted above.

*only arterial and collectors can be displayed in Fast Trac. Display and navigation for residential streets is required for this scenario.

A - PRESENT OPERATIONAL TESTS (FHWA)
B - PLANNED OPERATIONAL TESTS
C - APTS PROGRAM (FTA)
D - TRANSIT OPERATIONS OPERATING/PROCURING AVL SYSTEMS

CORRELATION OF SITES WITH SCENARIO I.

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Scenario Relationship to Operational Tests

Exhibit 9

Environmental concerns are often being addressed only as secondary impacts of IVHS research, not as primary goals. Secondly, the lack of operational test activities means a corresponding lack of available operational test data on which future evaluations of IVHS environmental impacts could be based. There is currently very little data on the potential environmental effects of IVHS.

3. POTENTIAL ENVIRONMENTAL EFFECTS OF SCENARIOS

3.1 Range of Environmental Effects

Intelligent Vehicle Highway Systems have the potential to create positive environmental effects in a number of areas, including reductions in congestion and vehicle emissions, reduced VMT, improved safety, and improved economic efficiency. Exhibit 10 presents a list of environmental elements and potential IVHS effects. It should be noted that the magnitude of these potential impacts remains to be determined through modeling and operational testing.

3.2 Analytic Uncertainties

There are inherent uncertainties in trying to assess the potential impacts of IVHS scenarios. Current models are not necessarily accurate and may not consider the full range of IVHS impacts. This problem was discussed by Brand in a paper describing criteria and methods for evaluating IVHS plans and operational tests. In the past, techniques for evaluating IVHS scenarios and operational tests have tended to underestimate the mobility and personal benefits of new technology and have not taken into account the time frame for impacts or the differences between supply and demand impacts. With IVHS, evaluations must be based not just on the use of infrastructure, but on the use of information as well.‘“’ Traditional evaluation methods may therefore not provide accurate estimates of potential benefits and costs.

There are similar uncertainties with the existing models used to project impacts of IVHS scenarios, particularly as they relate to air quality. Current emission models have high levels of uncertainty and may not yield accurate forecasts. Combined with

Traffic: . Safety . VMT • Speed Congestion	 . Reduced Accident Potential • Reduced Trip Ends, VMT • Reduced Idling, Improved Speeds, Managed Congestion
Physical: • Cultural Resources • Air Quality • Noise & Vibration • Biota • Energy	 • Reduced Tourist Anxiety • Improved Pretrip Planning • Reduced Emissions, Concentrations Better Information During Episodes • Reduced Truck Speeds • Less Construction. More Efficient Use of Facilities. • Improved Speeds, Reduced Fuel Consumption.
Social: • Community Cohesion • Accessibility of Facilities and Services • Displacement	 • Less Time in Traffic Jams. More time with community. • Better Real Time Responses for Police, Fire, Ambulance, and Other Services. • Minimal Land Requirements.
Economic: • Employment, Income • Business Activity • Residential Effects • Property Tax • Resources	 • New Technology and New Jobs. • More Predictable Passenger and Freight Movements. increased Productivity. • Minimal • Unknown . More efficient Use of Resources.

* Impression subject to verification and validation using demonstrative test results and acceptable environmental assessment models/procedures.

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Potential Environmental Effects of Scenarios

Exhibit **10**

the uncertainties associated with the impacts of IVHS on VMT, travel patterns, and transit/HOV use, the magnitude of potential environmental impacts are unclear.

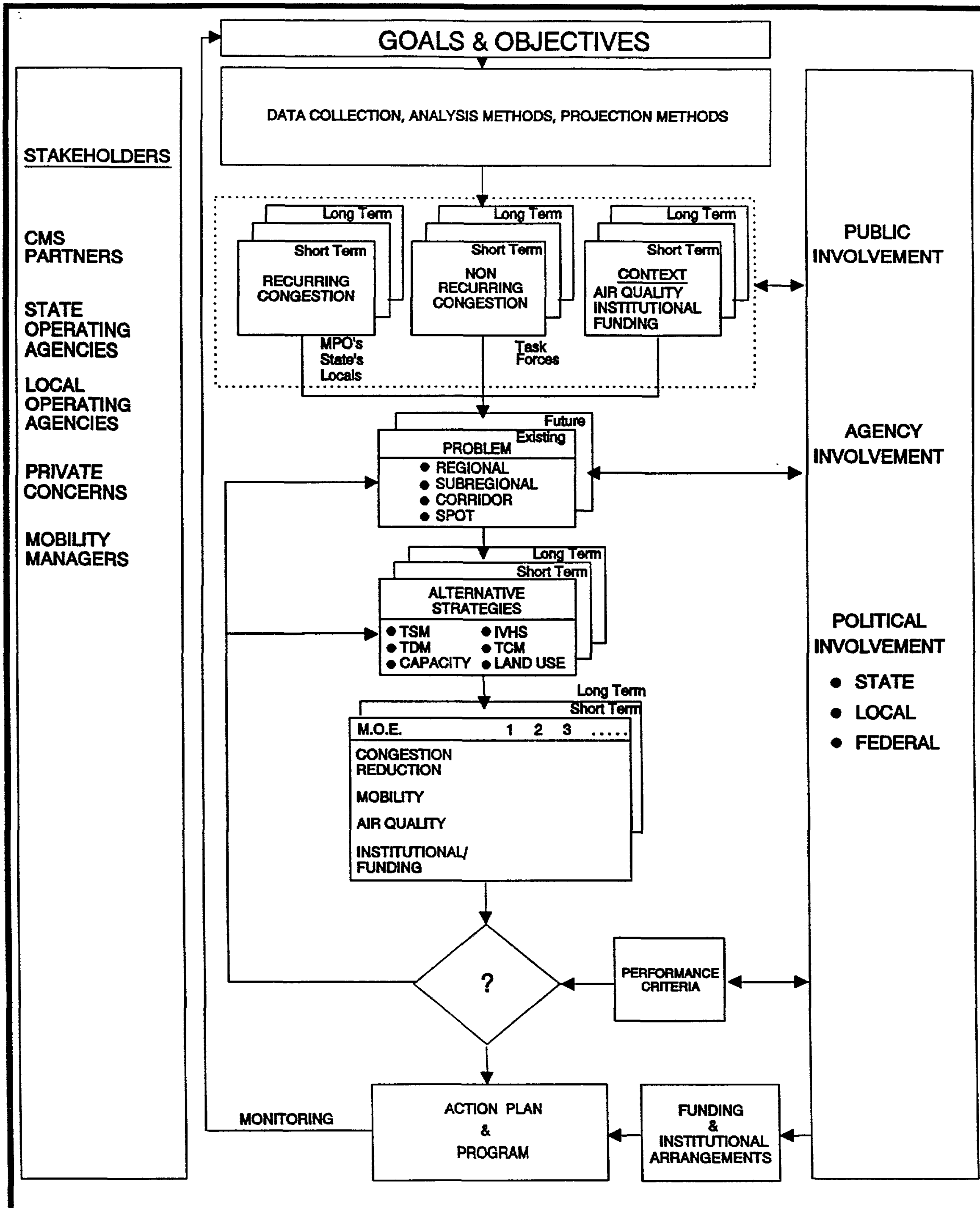
4. RELATING MULTIMODAL WI-IS TO ENVIRONMENTAL PROCESSES

The previous sections have highlighted the multimodal IVHS scenarios and potential environmental effects as well as uncertainties. For IVHS to be fully integrated and implemented, it will need to be incorporated into ISTEA, CAAA, management systems, planning activities, and the NEPA process.

4.1 Congestion Management and Air Quality

Multimodal transportation management strategies linked to IVHS have potential impacts on ISTEA's management system requirements, particularly the Congestion Management System (CMS), which is one of the six major management systems. Other management systems that could benefit from IVHS advanced technologies could include: Intermodal, Public Transportation, Highway Safety, Highway Pavement and Bridge Management Systems.

Exhibit 11 illustrates a general CMS process for addressing recurring congestion, non-recurring congestion, and air quality. As indicated, multimodal and mode specific actions incorporating IVHS technologies should be considered and evaluated with respect to their effectiveness along with other actions. It will be important to know the effects for existing, short term, and long term conditions. The challenge of examining IVHS will be to evaluate the use of information (not just infrastructure) on a real time basis. Presently, our analytic procedures and data are not providing practitioners what is needed for definitive evaluation. If IVHS is to be implemented, it will need to address state of the art improvement and present the relevant costs and environmental effects to the decision makers. Principles related to this new evaluation process where highlighted by Brand at TRB (').



BMI Congestion Management, Air Quality, and IVHS

Exhibit 11

4.2 State and Local IVHS Strategic Plans

Incorporation of environmental quality concerns should be an integral part of IVHS Strategic Plans under development and refinement by State and Local governments. Most plans today highlight current and planned demonstrations of transportation - IVHS applications with a focus on the technical feasibility of the technology. Often times, many of the demonstrations give a cursory view of the evaluation activities rather than making it a formal activity upfront. This environmental evaluation will need to be done using best available data and models. As noted at the National IVHS and Air Quality Workshop (3) there needs to be a stepped up effort in micro and macro scale models and data in order to achieve this improvement with respect to the IVHS Strategic Planning process.

43 State and Local LRTP's and SIP's

To increase the implementation of multimodal transportation management, IVHS will require incorporation of these actions into State and Local Long Range Transportation Plan (LRTP's) and State Implementation Plan (SIP's). A key problem here is evaluation methodology and clear communications on the costs and environmental benefits, particular details on how the transportation/IVHS action contributes to the reduction of emissions and achievement of air quality standards.

In conducting the multimodal IVHS workshop, a clear theme was the importance of showing the decision makers the environmental benefits in terms understandable for that region or area.

- Will arterial and freeway volumes and speed change? If so, by how much?
- Will HC, NO and CO emissions change?
- Will fuel consumption decrease?
- Will the quality of flow be improved?
- What are the socio-economic benefits?

Without definitive information, IVHS implementation can be stalled. The TSC is undertaking development of integrated models to assess IVHS impacts for Advanced Traffic Management Systems (ATMS), Advanced Traveller Information Systems (ATIS), and Advanced Public Transportation Systems (APTS) (3'. There is a need to include other technology groups such as CVO, ARTS, and AVCS in the model development process.

4.4 EIS, EA's Under NEPA

How Multimodal-IVHS projects are examined under the NEPA environmental process is unclear. However, IVHS has been included for site access EIS's/EA's and at the corridor level associated with other transportation actions. At the site level, multimodal-IVHS actions can aide TDM, TSM, and TCM actions which can reduce SOV use, thereby improving air quality, reducing energy consumption, and providing benefits. At the corridor level, IVHS can assist multimodal HOV actions organized to increase auto occupancy in the corridor.

The decision of whether or how to include IVHS in the environmental process is largely an administrative decision based on the lead and cooperating agencies involved.

5. CONCERNS TO BE ADDRESSED

The study and workshops have identified a number of concerns that need to be addressed before more meaningful evaluations can be made of IVHS's potential to improve the environment.

5.1 Comprehensive Evaluation Framework

There needs to be a comprehensive framework for evaluating IVHS projects that includes environmental considerations. Too often, environmental impacts are given only secondary consideration when evaluating potential IVHS benefits. A comprehensive framework of the type shown **in** Exhibit 2 that includes benefits (and costs) to air quality, the environment, the economy, and to society should be developed.

5.2 Reliable Data Sources

There is a need for more reliable data sources than are currently available. IVHS will be hard to sell at the state and local levels if there is not data to justify large expenditures on IVHS infrastructure and communication systems. Data from programs across the nation need to be consolidated and made available through a clearinghouse so that IVHS planners may have accurate data on which to base projections of benefits and costs.

53 Improved Modeling

The current models used to project impacts on air quality and the environment need to be updated to provide more accurate estimates of IVHS impacts. New models which take into account the wide range of potential IVHS impacts should also be developed.

5.4 Improved Operational Test Evaluations

There is a need for operational test data which can be used to assess the environmental effects of IVHS scenarios. Future operational tests must have evaluation programs that will yield reliable data. Appropriate measures of effectiveness should be developed to ensure that the data generated is meaningful and useful to transportation planners and engineers.

6. CONCLUSIONS

- IVHS Actions have potential positive environmental quality effects.

- When assessing environmental effects of IVHS, there needs to be a broad outlook to include social and economic effects in addition to traffic, air quality, energy and physical environmental effects.

- IVHS actions need to be incorporated into CMS, LRTP,TIP, and other processes where enviromnental concerns are addressed. It is difficult to assess IVHS as a stand alone action.

- A number of concerns need to be addressed including a data/finding clearinghouse function, better data, and better models.

- Priority needs to be given to scenarios with obvious environmental benefits including air quality alert, port/airport intermodal facilities, etc.

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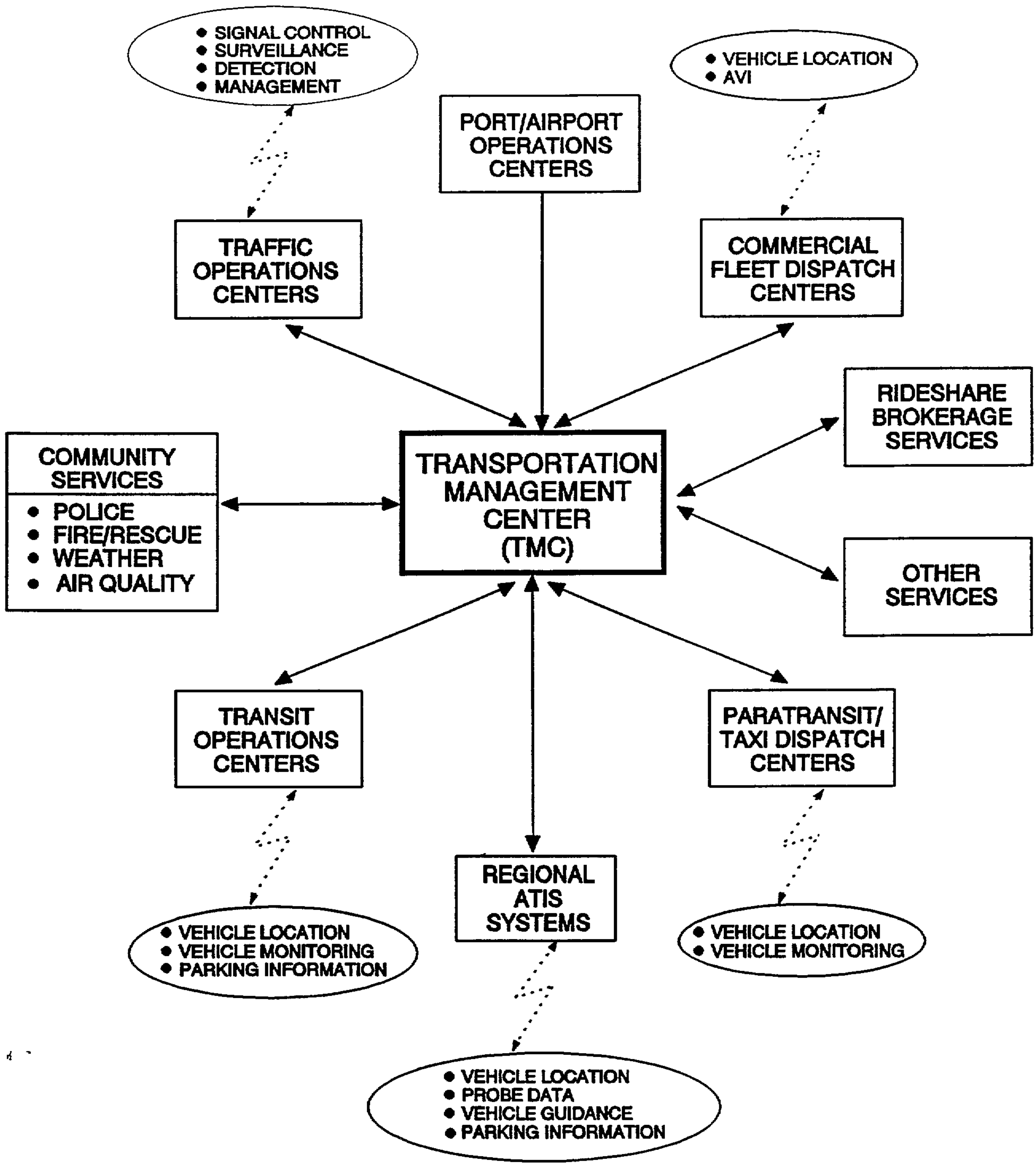

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Transportation Management Center Concept

Exhibit 1

1. Applicability to Multi-Modal Transportation Management - Criteria include:

- HOV/Ridesharing utilization
- Coordination with mass transit
- Applications to goods movement
- Compliance with Clean Air Act Amendments '90
- Compliance with the Americans with Disabilities Act

2. Technical Feasibility - Screening criteria include:

- Feasibility (need for new technology)
- Flexibility (alternate technologies)
- Reliability
- Expandability & upgradability

3. Potential Benefits - Criteria include:

- Reduced Single Occupant Vehicles
- Congestion reduction & avoidance
- Improve commercial vehicle productivity
- Pollution reduction
- Improved transit/rideshare operations
- Improved safety
- Energy savings

4. Potential Costs - Criteria include:

- Implementation costs
- Operation & Maintenance costs
- Out of pocket user costs
- Non-monetary costs

5. Institutional and Legal Issues - Criteria include:

- Passenger security/safety
- Operator/manufacturer liability
- Need for inter-jurisdictional/inter-agency cooperation
- Opportunity for public/private cooperation
- Legal and regulatory restrictions

6. Financial Feasibility - Criteria include:

- Need for government subsidies
- Potential for commercialization
- User willingness to pay
- Applicability to existing funding programs

7. Attractiveness to Users, Operators, and Society - Criteria include:

- Acceptability to management
- Ease of learning system (users & providers)
- User and provider convenience
- Provision of incentives
- Impacts on non-users

8. Human Factors - Criteria include:

- Target audience
- Ability to gain larger user population
- Ease of use for all user populations
- Effectiveness in addressing human concerns

9. Potential for Success - Criteria include:

- Potential market penetration
- Long-term viability
- Integratability with other scenarios

10. Implementation Potential - Criteria include:

- Barriers to deployment
- Compatibility with existing systems/modes
- Implementation sequence
- Areas of greatest potential impact (e.g. urban CBD, urban non-CBD, suburban, high activity centers, etc.)

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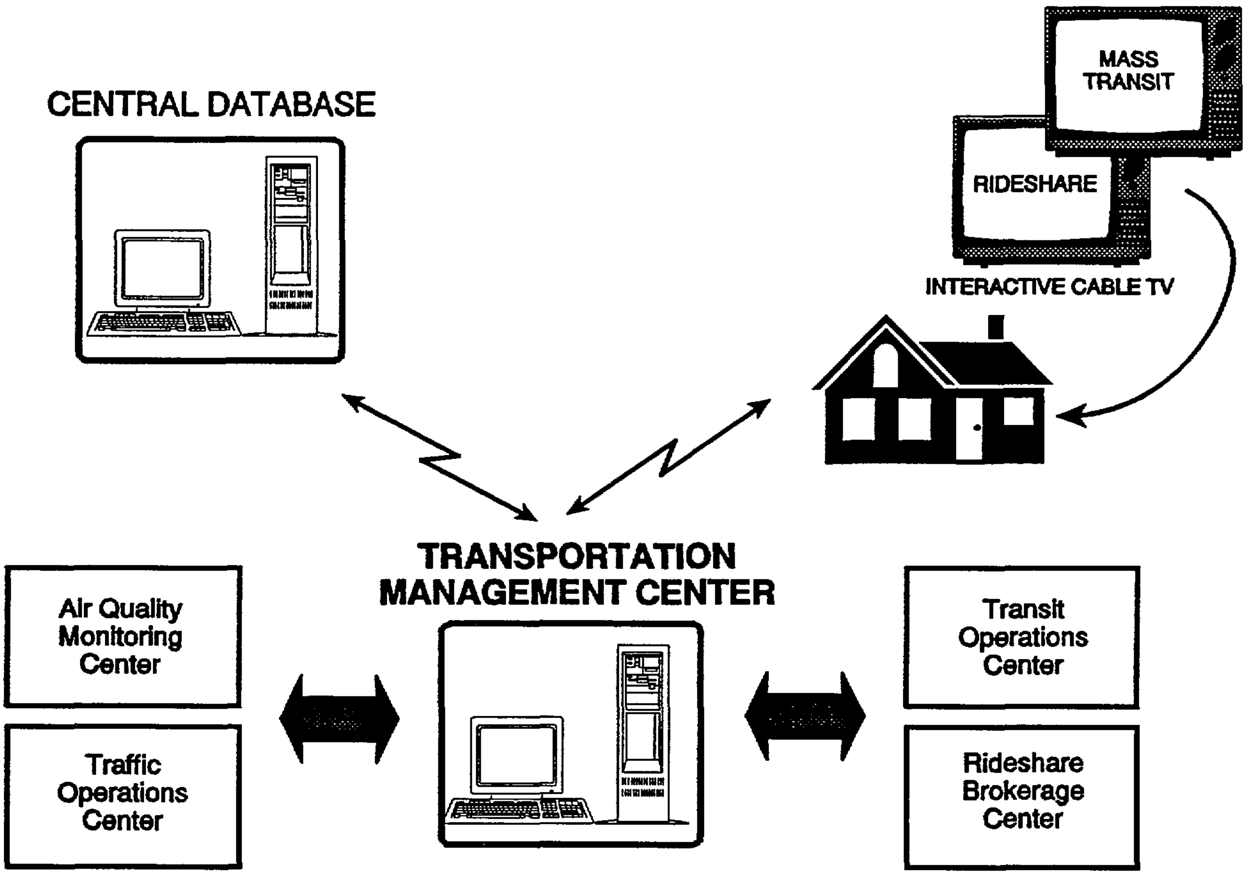
Selected Evaluation Criteria

Exhibit **2**

SCENARIO NO. 18
AIR POLLUTION ALERT

GOAL: Reduce mobile source emissions and encourage use of alternate modes during non-attainment periods.



SCENARIO

1. Air Quality monitoring center identifies non-attainment areas or forecasts potential air quality problems.
2. Persons within these areas are notified and presented with alternate travel modes.
3. Road pricing policies could be implemented using AVI equipment on cars.
4. Real-time travel data allows cities to adjust management strategies once they have been implemented.

SCENARIO: 18. AIR QUALITY ALERT

Summary Evaluation

Criteria Category	Summary Rating/Comment	Comments
1. Applicable to MM Transportation Management?	YES	Would permit implementation of multi-modal transportation controls to meet air quality attainment goals
2. Technically Feasible?	YES	Would largely use other IVHS systems to gain and disseminate information.
3. Potential Benefits	HIGH	Could help reduce mobile emissions and facilitate use of other modes.
4. Potential Costs	MODERATE	If system uses existing IVHS infrastructure, additional costs should be moderate.
5. Institutional/Legal Barriers	MODERATE	Will require regional (multi-jurisdictional) pollution control authority to coordinate mitigation measures.
6. Financially Feasible?	YES	Services could be provided through other IVHS systems. Would not need to dedicate an entire system solely to this purpose.
7. Attractiveness to Users, Operators, and Society	MODERATE	While mitigation measures themselves may be seen as unattractive, this system should be useful for users and operators during alerts.
8. Human Factors Effectiveness	HIGH	Will increase information available to travelers during alerts. Information will need to be accurate, timely, and accessible.
9. Potential for Success	HIGH	Should be a useful element of regional air quality plans Could help to significantly reduce mobile source emissions.
10. Implementation Potential	HIGH	The CAAA '90 set out federal mandates to address air quality problems This will be a major concern for non-attainment areas.

SCENARIO	MODE										
	PERSONS								GOODS		
	AUTO	HOV	TAXI	BUS	RAIL	AIR	BIKE	PED	TRUCK	PORT	RAIL
MASS TRANSIT											
1. Transit Route Deviation				X	X			X			
2. Real-Time Bus Location Information				X				X			
3. Timed Transfer Management				X	X						
4. Transit Park-Ride Information	X	X		X	X						
5. Smartcard Fare Collection				X	X						
6. Transit Priority on Signalized Networks	X	X	X	X	X	X	X	X			
7. In-Vehicle Information Displays				X	X						
8. Transit Schedule Reliability				X	X						
9. Improved Transit Management Info.				X	X						
10. Accident Data Recording	X	X	X	X	X				X		X
PARATRANSIT & RIDESHARING											
11. Real-Time Ridesharing		X		X					X		
12. Paratransit Dispatching		X		X							
13. Taxi Management w/ Smartcard		X		X							
14. Urban Goods/Passenger Movement		X							X		
15. Rural ATIS/Route Guidance	X	X	X	X					X		
GENERAL HIGHWAY											
16. Real-Time Transportation Information	X	X		X	X						
17. Needs Scheduling	X			X	X						
18. Air Quality Alert	X	X		X	X		X	X	X		
19. Weather/Roadway Condition Monitoring	X	X	X	X					X		
20. ATIS - Parking Availability	X	X	X						X		
21. Personal ATIS System				X	X		X	X			
22. Traffic Management at Parks/Monument	X	X		X	X	X					
AIRPORTS AND PORTS											
23. Airport Access - Passenger Pick-Up	X	X				X					
24. Truck Access to Ports/Rail									X	X	X
25. Vehicle Processing at Ports/Rail									X	X	X
26. River and Drawbridge Coordination	X			X					X	X	
27. Moving Urban Goods on Ferries									X	X	

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Scenarios and Modal Applicability

Exhibit **5**

SCENARIO	IVHS FUNCTIONAL AREA					URBAN AREA			
	ATMS	ATIS	APTS	CVO	AVCS	REGION	SUB-AREA	FACILITY	RURAL
MASS TRANSIT									
1. Transit Route Deviation	X	X	X			X	X	X	X
2. Real-Time Bus Location Information	X	X	X			X	X	X	X
3. Timed Transfer Management	X	X	X					X	
4. Transit Park-Ride Information	X	X	X			X	X		X
5. Smartcard Fare Collection	X		X				X	X	X
6. Transit Priority on Signalized Networks	X		X			X	X		
7. In-Vehicle Information Displays		X	X				X	X	X
8. Transit Schedule Reliability	X	X	X					X	X
9. Improved Transit Management Info.		X	X		X	X	X	X	X
10. Accident Data Recording		X	X	X	X				
PARATRANSIT & RIDESHARING									
11. Real-Time Ridesharing	X	X	X			X	X		X
12. Paratransit Dispatching	X	X	X			X	X		X
13. Taxi Management w/ Smartcard		X	X	X			X		X
14. Urban Goods/Passenger Movement		X	X	X			X		X
15. Rural ATIS/Route Guidance	X	X	X	X					X
GENERAL HIGHWAY									
16. Real-Time Transportation Information	X	X	X	X		X	X		X
17. Needs Scheduling	X	X	X			X	X		X
18. Air Quality Alert	X	X	X	X		X	X	X	X
19. Weather/Roadway Condition Monitoring	X	X		X	X	X	X	X	X
20. ATIS - Parking Availability	X	X		X			X	X	
21. Personal ATIS System	X	X	X			X	X		X
22. Traffic Management at Parks/Monument	X	X	X					X	
AIRPORTS AND PORTS									
23. Airport Access - Passenger Pick-Up	X	X						X	
24. Truck Access to Ports/Rail	X	X		X				X	X
25. Vehicle Processing at Ports/Rail	X	X		X				X	X
26. River and Drawbridge Coordination	X	X		X			X	X	
27. Moving Urban Goods on Ferries	X	X		X		X	X	X	

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Scenarios and IVHS/Area Applicability

Exhibit 6

IVHS Action Groups

	Increase Carpool	Increase Walk & Bike	Improve Paratransit & Goods Movement	Restricted Traffic	Pricing Measures	Parking Management
Increase Transit	C	A	A	A	A	A
Increase Carpool		I	I	C	A	A
Increase Walk & Bicycle			I	A	I	I
Improve Paratransit & Goods Movement				C	I	I
Restricted Traffic					C	C
Pricing Measures						A

A - Action Groups assist each other.
I - Action Groups are independent of each other.
C - Action Groups are counterproductive to each other.

BMI Interrelationships Between Multimodal Action Groups

Exhibit 7

- For IVHS to be effective in reducing air quality there is a need to focus on parking availability and price. Volunteer efforts are ineffective during air quality episodes.

- Integrated Smart Cards covering mass transit, tolls, parking, congestion, pricing, etc. are needed to address reductions in emissions through SOV trip and VMT reduction. This will require a concerted partnership among the institutions.

- For mass transit to be effective in reducing SOV's, VMT, and emissions, there is a need to make it more customer oriented through improved mobility management (APTS) and driver training. AVL and AVI systems have been found to be effective in our management efforts.

- Nonrecurring congestion on freeways and arterials is a big part of the problem resulting in idling, emissions and wasted fuel. There is a need to develop ATMS, ATIS and other IVHS infrastructure to address the problem. However, it (IVHS) will not work unless there are alternative routes with capacity to choose from.

- Since many of the environmental benefits of IVHS are subjects of various demonstrations and are uncertain, how can these projects be considered in LRTP, TIP and SIP developments at the State and Local level?

- For IVHS to be effective in improving environmental quality, IVHS related projects need to be integrated into plans and programs with conventional highway, transit, airport/port, ground access and other projects. It took us 8 years to get a signal implemented, how do we get our board to act on items in the research/demonstration stage?

- When you look at the environment, think beyond the physical impacts (air quality, energy, congestion, traffic safety, etc.) to human factor effects (reduced anxiety and stress, improved driver/vehicle navigation, etc.). As IVHS makes better use of intrastructure, we have to account for new demands created, human factors, and socio-economic effects.

- We have trouble getting travel and environmental models (emissions, fuel consumption, etc.) to work with conventional plan and project evaluation. How do you get environmental models to work for real and semi-real time evaluations?

- Is there a clearinghouse to go to for reliable evaluation data and findings related to IVHS demonstrations and case studies? This is a particular concern for intermodal/multimodal projects.

APPLICABLE OPERATIONAL TEST SITES		COULD BE TESTED SOON (FULLY)	COULD BE TESTED SOON PARTIALLY	MAY NEED NEW INFRA-STRUCTURE	NOTES/ COMMENTS
Number	Description				
C-I-11	Fredericksburg ARTIS (VIRGINIA)		X	X	Needs to relate to VDOT.
A-II-4	Advance (Illinois)	X			NHTSA is cooperating.
A-II-5	Fast Trac (Michigan)			X*	NHTSA is cooperating.
C-I-5	TravLink (Minnesota)		X		Need outputs on initial project.
C-II-15	Portland SmartBus (Oregon)		X	X	Future Smart Vehicle projects could benefit.
C-II-16	Denver SmartBus Stage I (Colorado)		X	X	Future Smart Vehicle projects could benefit.
C-II-17	Baltimore SmartBus (Maryland)		X	X	Future Smart Vehicle project could benefit.
C-III-19	Ann Arbor Smart Intermodal (Michigan)		X	X	Future Smart Vehicle project could benefit.
C-III-20	Chicago Smart Intermodal (Illinois)		X	X	Future Smart Vehicle project could benefit.
C-I-12	Winston Salem Mobility Manager (N.C.)		X	X	
C-I-13	Delaware County Mobility Manager (Pennsylvania)		X	X	

COMMENTS

Presently only area where this is being done is C-I-11. There is not a lot going on in this area. Need to be more pro-active in promoting this scenario.

Modal administrations interested include FTA, FHWA and NHTSA.The agencies are participating in the operational tests noted above.

*only arterial and collectors can be displayed in Fast Trac Display and navigation for residential streets is required for this scenario.

A - PRESENT OPERATIONAL TESTS (FHWA) C - APTS PROGRAM (FTA)
B - PLANNED OPERATIONAL TESTS D- TRANSIT OPERATIONS OPERATING/PROCURING AVL SYSTEMS

CORRELATION OF SITES WITH SCENARIO L

BMI

Scenario Relationship to Operational Tests

Exhibit 9

Traffic: • Safety • VMT • Speed Congestion	• Reduced Accident Potential • Reduced Trip Ends, VMT • Reduced Idling, Improved Speeds, Managed Congestion
Physical: • Cultural Resources	• Reduced Tourist Anxiety • Improved Pretrip Planning
• Air Quality	• Reduced Emissions, Concentrations Better Information During Episodes
• Noise & Vibration	• Reduced Truck Speeds
• Biota	• Less Construction, More Efficient Use of Facilities.
• Energy	• Improved Speeds, Reduced Fuel Consumption.
Social: • Community Cohesion	• Less Time in Traffic Jams. More time with community.
• Accessibility of Facilities and Services	• Better Real Time Responses for Police, Fire, Ambulance, and Other Services.
• Displacement	• Minimal Land Requirements.
Economic: • Employment, Income	a New Technology and New Jobs.
• Business Activity	• More Predictable Passenger and Freight Movements. Increased Productivity.
• Residential Effects	• Minimal
• Property Tax	• Unknown
• Resources	• More Efficient Use of Resources.

Impression subject to verification and validation using demonstrative test results and acceptable environmental assessment models/procedures.

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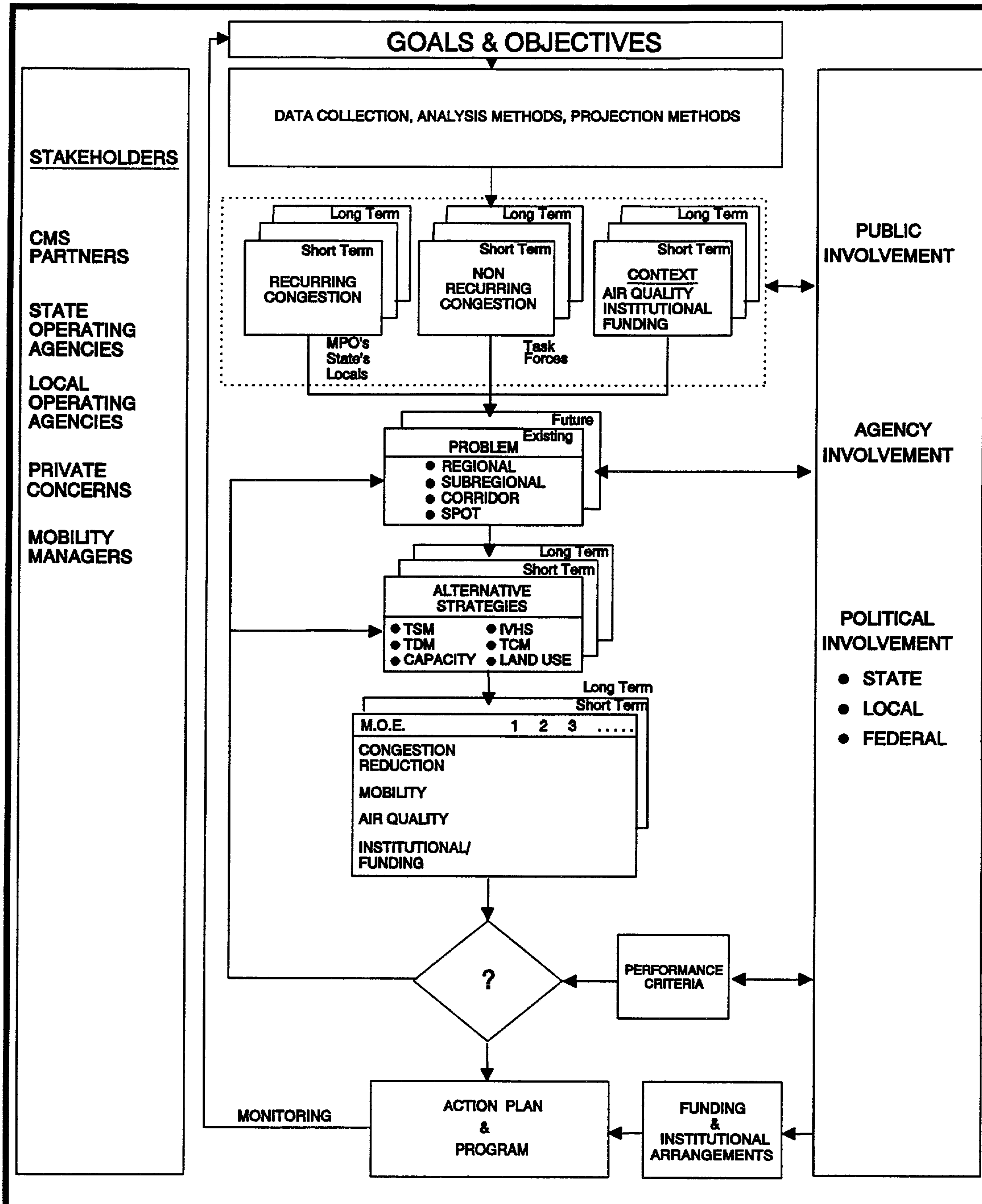
Potential Environmental Effects of Scenarios

Exhibit
10



BMI Congestion Management, Air Quality, and IVHS

Exhibit 11

The Greening of IVHS

Integrating the Goals of Air Quality, Energy Conservation, Mobility and Access in Intelligent Transportation Policy

BY
Lamont C. Hempel
The Claremont Graduate School

IVHS is an amplifier. It amplifies both what is good and what is bad about our transportation system, and extends the consequences to other domains, such as energy, environment, and land use. In some configurations, IVHS technologies promise to boost mobility and safety dramatically, while at the same time inviting increases in vehicular pollution, demand for foreign oil, and inequality in transportation access. Travel safety and capacity enhancement are of course desirable, but what if their achievement comes at the expense of air quality, energy security, and perceived equity?

The answer to this question depends on fundamental assumptions about latent travel demand, modal choice, and the capabilities of vehicles and route guidance systems operating in the future, which in turn involve assumptions about technological innovation, commercialization, and government policy and enforcement with respect to emissions standards, fuel efficiency standards, transit use, and a variety of transportation control measures. Clearly, a doubling of capacity[2] on existing roadways would induce some additional demand, but would the increased number of vehicles emitting pollution and consuming gasoline be more than offset by the emissions savings and fuel savings gained from reduced congestion? And for how long? Would transit applications of MIS compensate for potentially negative energy and environmental consequences of enhanced mobility for automobiles? And assuming that the paramount goal of IVHS advocates is the efficient movement of people, rather than vehicles, how are tradeoffs between access, mobility, air quality, and energy conservation to be decided?

No one should feel confident that these questions can be satisfactorily answered for all regions and circumstances in which IVHS technologies are envisioned. To a large extent, the answers depend on a combination of future behavior changes, market conditions, political leadership and entrepreneurial abilities that can only be dimly discerned today. Moreover, the lack of adequate, tightly coupled, system-wide models of modal choice, trip generation and distribution, on-road driving behavior, vehicle emissions, and pollution dispersion, suggests that no definitive answers will be forthcoming in the near future.

Rather than bemoan the lack of integrated, systemwide models, this paper seeks to refocus attention on the vehicle technology assumptions used by modelers. Recent advances in clean car technology -- e.g., electrically heated catalysts, remote sensing of on-road emissions, reformulated fuels, and ultra efficient, zero- and ultra low-emission "supercars" -- suggest that conventional projections of vehicle fleet characteristics with incremental improvements will overstate future environmental and energy risks of mobility enhancement. In other words, incremental extrapolation of today's vehicle inputs and outputs for purposes of IVHS simulation represents more of a political judgment than one based on technological foresight. The technologies needed for nonincremental change are becoming available with astonishing speed; it is the political will and administrative capacity to employ these green technologies that is, as usual, lagging behind. Even in California, where political mandates for clean car technology are strongest, public acceptance and scattered support from the private sector is wavering. Foremost among the reasons for concern is the huge gap that remains between policy goals and market incentives to develop zero- and ultra low-emission vehicles with ultra high fuel efficiencies.

Viewing IVHS as a potential amplifier of on-road vehicle emissions and fuel consumption implies that the critical factors in determining future impacts are the emissions control capabilities and fuel efficiency ratings of vehicles that are forecast to be on the road during each phase of IVHSimplementation While IVHS also can and should be used to amplify transit use and trip avoidance strategies, the assumption made in this paper is that the impacts of such use, given transportation policies that satisfy near-term conditions of political and economic feasibility, will be small in comparison with the effects of cleaning up single occupancy vehicles (SOVs). For example, removing one vehicle from commuter traffic in 1992 using Southern California's rideshare program (Regulation XV) was estimated to cost nearly $3,000.[3] Investing the same amount of money in remote sensing and related programs for identifying and fixing, or retiring, gross polluting vehicles -- the roughly 10 percent of the vehicle fleet responsible for more than 50 percent of on-road emissions -- would result in emissions reductions that were, according to the author's calculation, at least 14 times greater, and probably much more than that.[4] Similarly, air quality gains from light rail transit compare very unfavorably on an abatement cost basis with clean car programs, and offer little justification by themselves for the enormous subsidies involved in transit ridership -- up to $8,000 per roundtrip passenger per year in Southern California.[5] While many proposed IVHS designs are biased to expand route choices for SOVs without first and foremost increasing modal choices (e.g., enhancing the ***ease*** of choosing existing transit systems), the strong likelihood remains that the negative energy and environmental consequences of this bias will shrink rapidly in the next decade as SOVs become much cleaner and, hopefully, more efficient.

Although transit enhancement, travel safety, and economic stimulation from technology development are all important objectives of IVHS, by far its greatest challenge over the next twenty years will be to double mobility for SOV trips, while enabling pricing strategies (e.g., congestion pricing) and "green" technology applications to achieve net reductions in vehicle emissions and fossil fuel consumption. IVHS by itself is unlikely to contribute greatly to the goals of environmental quality and energy security. It is primarily a bridge to other solutions in these areas, and its potential for ***Indirect*** contributions is what matters most. Accordingly, IVHS should not be thought of as a bundle of end-state products linked to throughput efficiency so much as a set of ***enabling*** technologies for optimizing among the sometimes conflicting goals of efficiency, safety, equity, and sustainability. Given that there are tens- and perhaps hundreds-of-billions of dollars at stake, it is not surprising that the instrumental nature of IVHS has sometimes been lost in the scramble to transform IVHS deployment itself into a national goal. As the remainder of this paper attempts to demonstrate, however, the desirability of IVHS deployment depends heavily on how problems that are external to the transportation system are resolved.

CONSTRAINTS MAPPING

Because thinking about IVHS development and deployment continues to suffer from what Langdon Winner refers to as "reverse adaptation" of ends to means, there is a tendency within the IVHS community to regard issues of social equity and ecological sustainability as constraints rather than goals.[6] Some engineers, for example, may allow their fascination with IVHS as a technological means to shape their vision of social ends -- principally, mobility and safety, if not technological progress, itself The investigation of technical requisites of IVI-IS deployment (e.g., systems architecture) has tended to far outpace investigations of its social, environmental, and institutional implications. As a result, much of the activity surrounding IVHS appears to foster "technology push" rather than "market pull" behavior, and efforts to gauge public acceptance have predictably emphasized consumer issues over those of community and neighborhood livability.

Despite the relatively lavish attention and funding devoted to matters of IVHS technical performance, systems integration, and cost studies, so-called "nontechnical" issues may ultimately play a more influential role in IVHS adoption than straightforward matters of market demand and technological readiness. Grassroots public acceptance and IVHS goal conformity with cross-cutting policies originating outside the transportation sector have already surfaced as pivotal issues in development and implementation. One way to appreciate the nontechnical barriers that stand in the way of rapid deployment of IVHS is to trace systematically the constraints that arise at each stage of implementation -- from conceptual design to full-scale operationalization. An abbreviated constraints map of this sort is presented in Figure (1). Following the conventional view that deployment is the goal, it treats all other variables as either bridges or barriers to that goal. Unlike a critical path diagram or a technology-centered risk assessment, the constraints map attempts to show how limitations in knowledge, finance, hardware, political support, and ecological carrying capacity can influence the strategies of public and private actors and institutions interested in IVHS, and how these strategies are linked to key enabling policies (i.e., ISTEA), which must later be reconciled with other policies (e.g., Clean Air Act Amendments, Energy Policy Act, Americans with Disabilities Act), and made compatible with co-evolving organizational structures and market forces.'

The fears and hopes that arise from technological innovation provide the basic driving forces for moving IVHS through the political constraints process that determines the fate of nearly all large-scale policies and projects, especially those that cannot claim national security status or the legitimacy conferred by crisis-driven decision making. These fears and hopes are themselves amplified and sometimes distorted through advocacy coalitions and media coverage. In the case of intelligent transportation systems, most of these fears and hopes are based less on assumptions about human travel behavior than on assumptions about the kind of vehicles and transportation alternatives that will be available in the near- to mid-term.Consider the effects of assumptions about modal choice and vehicle technology on some of the major arguments of IVHS critics and supporters listed below:

Fears of IVHS critics:

- Increases aggregate vehicle emissions and energy consumption due to increased trips and VMT

- Increases travel on arterials by diverted travelers, exposing many neighborhoods to greater smog, air toxics, and noise

- Perpetuates auto dependency -- a “reprieve” for SOVs
  (e.g., Increased auto dependence owing to induced land use patterns that increase average distances traveled by commuters as average travel times decline from congestion relief)

- Imposes large social opportunity costs (IVHS seen as a megaproject that uses up scarce resources needed for achieving other public goals)

- Exacerbates perceived inequalities among travelers (e.g., expense of onboard ATIS may widen gap between information-rich and information-poor travelers)

- Preoccupation with mobility will lead to further neglect of accessibility

- Fosters "dispersed" congestion (as opposed to congestion that is concentrated in CBD)

Hopes of IVHS supporters:

- Improves travel patterns to achieve congestion relief, and thereby reduces emissions and fuel consumption associated with congestion

- ***(Related to*** #I) Smoothes traffic flows, thereby reducing emissions and fuel consumption from repeated acceleration and deceleration

- Serves as a bridge to pricing solutions for use in demand management (e.g., road pricing)

- Enhances attraction of transit and paratransit programs through dissemination of real-time information, etc.

- Encourages ridesharing and trip linking among SOV operators by providing accurate traffic-sensitive and weather-sensitive travel information

THE CAR OF TOMORROW

The single most important factor for deciding whether the critics or supporters have the better case is the predisposition of the participants in the debate toward vehicle technology improvements. In the case of environmentalists, there are two major and competing predispositions: (1) that technology "fixes" have been greatly oversold and will cause more problems than they will solve, and (2) that technological solutions are promising, but unwanted because they undermine more basic environmental arguments for changing human lifestyles. To the first group, the concept of a "green" car is an oxymoron; to the second, it represents a paradoxical improvement and, hence, a bonafide threat to the continuing campaign against the automobile as a symbol of environmental destruction. Having spent more than two decades trying to convince people to break their auto-dependency, the very real prospect of strong, safe, ultra-light, ultra-clean Supercars within ten years* can only be accepted by such groups with a certain amount of ambivalence.

Emissions Control

Since 1961, when California mandated the use of positive crankcase ventilation (PCV) on cars sold within the state beginning in 1963, emissions control for motor vehicles has developed into a major industry. The key advance came during the mid-to-late 1970s with the introduction of the catalytic converter, as well as engine gas recirculation and evaporative recovery systems. This was followed shortly by the improved three-way catalytic converter and by electronic fuel injection, which adjusts the air/fuel mixture to meet the exacting specifications of advanced emissions control systems. These advances made possible a 96 percent reduction in tailpipe emissions of CO and HC, and a 76% reduction in NOx, between 1960 and 1990.[9] During this same period, fuel consumption per mile for new cars dropped nearly 50 percent and accidental deaths per mile declined 65 percent.[10] In short, emissions abatement, fuel efficiency, and auto safety were all major technological success stories during this period, but their achievements were tempered by sheer growth in the number of vehicles, vehicle trips, and vehicle miles traveled. For example, total VMT increased by over 170 percent between 1960 and 1990. While most of this increase can be attributed to the addition of over 250 million new passenger cars registered during this period”, per capita increases in travel and VMT also played a significant role. During the 1980- 1989 period, for example, VMT per vehicle increased 16 percent, contributing to an aggregate increase of 40 percent.[12]

As progress has been achieved in emissions control and automotive engineering, more and more attention has been devoted to emissions caused by cold engines, vehicle acceleration and deceleration, and fuel evaporation. Emissions from what are called “cold starts” and “hot soaks” (emissions that occur at the beginning and at the end of a trip), account for roughly two-thirds of the total emissions from a ten-mile trip under normal driving conditions. If strong acceleration or deceleration occurs, large emission “puffs” will usually be produced as a consequence. Given that it is easier to improve emissions control technology than the driving behavior of tens-of-millions of Americans, potential solutions for cold start and hot soak problems look much more promising than public appeals to step lightly on the accelerator and brake pedals. While IVHS may make its most significant air quality contribution in this latter problem area by smoothing traffic, or providing automatic speed governors,[13] the biggest payoffs are likely to come in the cold start category from the installation of new electrically heated catalyst (EHCs).

Because today’s catalytic converters must reach temperatures of 250-300 °C for optimal performance, the first few minutes of any trip undertaken with a cold engine is a period in which much of the exhaust gas flows through the converter without the catalytic action needed to breakdown harmful emissions. A cold engine typically requires over 100 seconds to heat the catalyst to its start-up temperature.[14] While heated catalysts have been around for many years, the electricity they consumed from the battery made them impractical. Recent advances in EHCs, however, have brought the battery drain down from over 600 amps to about 175 amps (power and energy consumption level of 2 kW and 8 W-hrs. at 15 seconds duration). This is well within the limits of battery and alternator systems, and is sufficient to warm up some catalysts in as little as 5 seconds. Test results of the new EHC systems are summarized in Table 1 and suggest that a significant leap forward in emissions control technology is at hand. Total costs to vehicle manufacturers of producing EHCs (with light-off catalyst, but without precious metal) have been estimated to be $95 per unit, assuming a production volume of 300,000 units. Total cost for a complete alternator-powered EHC system (loaded with precious metal, plus light-off catalyst, plus air injection components, switches, valves, and cables) is estimated to be $165.[15] During the startup phase, costs of these units will of course be higher, perhaps exceeding $400 per vehicle.

Table 1
Emissions Levels of Different EHC Systems
(grams per mile)

Source [16]	***Vehicle Type***	***CO***	***HC***	***NOx***
Coming		0.62	0.02	0.16
SAE	'88 Volvo	0.46	0.06	0.07
ASME	'86 Camry	0.38	0.03	0.25
ASME	'90 Celica	0.40	0.03	0.05
ASME	'90 LeSabre	0.25	0.02	0.18
CARB	'90 LeSabre		0.03	0.27
Average (EHC-equipped vehicles)		0.42	0.03	0.16
1980-1993 Federal Standard		7.00	0.41	2.00
1994-2003 Federal Standard		3.40	0.25	0.40
1997 ULEV Standard (California)		1.70	0.04	0.20

Other advances in emissions control technology will add significantly to the air quality improvements promised by EHCs. They include reformulated gasoline, introduction of electric and compressed natural gas vehicles, and advanced on-board diagnostics systems (OBDs) that provide real-time information about emissions performance, as well as fault tree data that can be downloaded for monitoring and repair purposes. A summary of these and other clean car innovations and policies, along with fuel economy measures, are provided in Table 2.

Fuel Economy

Given the enormous advances in vehicle design and emissions control technology, it seems reasonable to expect that similar advances have occurred in the fuel efficiency area. The fact is, however, that while major efficiency improvements have been achieved with experimental vehicles, the commercial and near-commercial applications of energy-efficiency for automobiles and, especially, trucks, have been disappointing by comparison. Average fuel efficiency of new American cars actually declined by 4 percent from 1988 to 1992.[17] Fuel prices, unlike the price of clean air, have not figured prominently in discussions about vehicle design since the early 1980s, although conflicts like the 1992 Gulf War served to remind many Americans that a fateful link -- oil -- still ties our foreign policy and transportation policy together.

Table 2

Green Car Technologies

Emissions Control *

- electrically heated catalysts
- remote sensing of emissions
- oxygenated fuels
- leak free exhaust/double wall pipes
- improved fuel atomization
- dual oxygen sensor compensation
- paliadium catalysts with cerium washcoats
- on-board diagnostic systems
- reformulated gasoline
- alternative fuels
- sequential fuel injection
- vapor recovery systems
- adaptive transient fuel control

Fuel Economy

- use of composites in body molding
- hybrid electric drives
- advanced radial tires
- recapture of braking energy
- aerodynamic design

*Many of the emissions control technologies may also help to improve fuel economy, just as some of the fuel economy measures may also offer emissions benefits.

The role of IVHS in helping to achieve energy conservation goals is based largely on the premise that smoothing traffic flows, finding the most efficient routes, and eventually providing automated vehicle control systems, will reduce unnecessary VMT and improve actual on-road fuel economy for all classes of vehicles. Initial estimates of energy impacts of IVHS projected 6.5 billion gallons of fuel being conserved by the year 2010, however these estimates have been reduced substantially as additional induced demand factors have been considered.[18] While some advocates of supercars are touting ultra-light hybrids that they claim will travel coast to coast on 8 gallons of gasoline,[19] the apparent demand for such vehicles is low. Since fuel costs represent less than 13 percent of the direct costs of driving, there is little incentive for travelers to make fuel economy a major consideration in their modal choices and vehicle purchases. Absent higher gasoline taxes, efficiency rebates (e.g., California's DRIVE+ program), greater political instability in oil-rich regions, or the imposition of stronger corporate fuel economy standards (CAFE), there is little reason to expect that fuel savings of future fleets will approach their emissions savings.

While several innovative pricing measures, such as pay-at-the-pump auto insurance, might have a significant salutary effect on both fuel economy and vehicle emissions, the political obstacles to such measures have so far been daunting.20

TECHNOLOGY, POLITICS, AND MARKETS

It is customary in papers of this type to pause at this point in order to sharpen the contrast between the promise of new technologies, the dismal impedance of politics, and the redeeming pull of the marketplace. Only the power of the market, many believe, can rescue publicly regulated technoscientific triumphs from the mire of bureaucracy and interest group struggle. A free market, in their view, is the best antidote to the paretic poison of modem politics. It seems to follow that only strong market forces can assure successful navigation of IVHS through the complex corridors of power and channels of public acquiescence. Idealistic environmental, energy, and equity concerns in such a setting are assumed to yield to the logic of the market as marginal costs and benefits -- those that can be easily measured -- are added and compared. Such perspectives lead many to view the implicit demands and constraints placed on IVHS by the Clean Air Act and other policies as excessive, even counterproductive. Why expect IVHS to solve air pollution problems that ought to be tackled by auto manufacturers and by designers of vehicle inspection and maintenance programs?

The above characterization arguably represents the conventional wisdom of many in the IVHS community. It does not, however, do justice to the complexity and significance of public policy making. Politically speaking, IVHS acceptance may ultimately depend less on drawing attention to the problems that it solves than on managing the problems that it amplifies. Americans confronted with a technology or a policy that takes them three steps forward for each step backward may nevertheless choose to emphasize losses over gains. Such behavior may seem irrational to many, but it is understandable to many social psychologists and experts on risk perception.21 In cases where the implementation of the technology or policy being considered is virtually a foregone conclusion, as with IVHS, the tendency to focus on problems rather than opportunities may grow even stronger. Given the decentralized, staged deployment process that IVHS will almost surely follow, there will be multiple intervention points and policy venues for those who wish to stop or slow implementation. As any activist knows, it is usually easier to block initiatives in our political system than it is to get them adopted. Those who believe that market forces will sweep away these islands of resistance would do well to remember the lessons of the American SST program or the RU 486 "abortion pill."

To some extent, IVHS represents a set of technologies in search of applications. But it could also be said that IVHS represents a set of disparate policy goals in search of integration. Environmental and other non-transportation objectives will have to play a major role in determining IVHS configurations and applications if substantial compliance with pre-existing goals and policies is to be achieved. In the policy arena, tails do wave dogs, especially when they are dogs (e.g., transportation) with multiple tails (e.g., air quality, access for the disabled, energy conservation, etc.). But this indicates a further problem with the conventional wisdom. It conceives of problems and solutions too narrowly. The remedy perhaps can be found in the emerging insights of sustainable transportation thinking, an alternative viewpoint that offers a much more integrated and collaborative approach to problem solving. The sustainability paradigm begins with a simple and, some say, simplistic goal: "[To meet] the needs of the present without compromising the ability of future generations to meet their own needs."[22] The test of a sustainable transportation technology is whether it is compatible in the long run with basic ecological precepts and collective human needs. Rather than drawing sharper distinctions between technology, politics, and markets, the approach of sustainable transportation is to recognize the interdependence of all three in forging long-term solutions to what are predominantly urban problems. As important as markets and trade are in shaping our future way of life, they are nevertheless derivatives of politics, and probably always will be. They cannot operate independently of politics anymore than Wall Street can separate itself from the actions of the Federal Reserve. Based on the premise that there is no such thing as a free market or free trade, only designed markets and designed trade, the central question becomes how to foster cooperation within and between business and government for the purpose of designing technologies, policies, institutions, and markets that will improve our quality of life. IVHS represents a test case for this kind of thinking, and the "greening" of IVIIS, if indeed it occurs, will reflect a change in values every bit as important as the change in technology that it represents.

POLICY WEDGES

The analytical challenge of sustainable IVHS deployment is essentially one of optimizing across competing public policies for the purpose of minimizing the zone of incompatibility between stated or implied policy goals. Although the idea that official policies often work at cross purposes may sound like an indictment of the American policy making process, in reality, a certain amount of incongruity in policy objectives is unavoidable in political systems that depend on compromise and on the strategic use of ambiguity in coalition building. Our system being one that occasionally raises policy incompatibility to absurd heights (e.g., tobacco subsidies and anti-smoking programs), it should come as no surprise that intelligent transportation technology and intelligent transportation ***policy*** may sometimes follow different paths. Successful deployment of

IVHS will require more of a reconciliation process involving multiple goals and objectives than a linear implementation process pegged to efficiency. Furthermore, given the interjurisdictional challenges of federalism, it will require a reconciliation of the interests of multiple agencies and levels of government, not to mention a profound reconciliation of the different cultures and customs that divide public and private sector actors.

In thinking about how to relate advances in vehicle emissions control and fuel efficiency to prospects for IVHS deployment, it is helpful to recognize three cross-cutting policy issues that link the goals of clean air, energy security, mobility, and access to transportation. The first is the growing preference for demand-side management (DSM) rather than supply-side management of public problems.[23] The second, and related, issue is the growing reliance of governments on market-based tools for problem solving (and the concomitant erosion of command-and-control regulation).[24] The third involves the application of technology-based solutions to problems that were previously thought to require fundamental changes in human behavior for their successful management. While achievements made possible by DSM, market-based tools, and technical fixes are often oversold or uncritically accepted (especially in the case of technical fixes), the unmistakable trend over the past decade has been nevertheless toward greater reliance on these approaches. Applications of joint DSM-market incentive programs have revolutionized energy and water resource management, for example, and seem poised, with the help of automatic vehicle identification (AVI) and road pricing, to offer the same kind of benefits for the management of transportation. Technological innovations, such as IVHS, heated catalysts, gas-sipping vehicles, and the information highway, promise large additional benefits that should ease the transition to more sustainable lifestyles and forms of development, despite some unforeseen and unintended consequences that are likely to be viewed negatively by some groups in society.[25]

Tying these three policy trends together in a way that assures broad political support and mutual gains is a matter of some urgency for the IVHS community. Without greater attention to the empirical bases for environmental, energy, and social concerns about IVHS, some members may make the mistake of assuming that public relations and education campaigns will overcome any negative images. A long list of failed efforts in this vein -- from nuclear power to chlorofluorocarbons -- reveals that control of the public agenda is often fleeting.[26] A far more promising strategy may be to develop a common core of tools and objectives that treat environmental, energy, mobility, and transportation access issues in an interactive fashion, using sustainability as a design standard.

One approach worth considering would be to note the consistent patterns in policy design that are developing in each of these four issue areas. All reveal the same basic substitution trends whereby centralized, technology-forcing regulations and supply enhancement programs are slowly replaced by decentralized, market- and performance-based standards, and demand reduction programs. For reasons that will soon become obvious, I have termed this the "Wedge Strategy." Figure 2 depicts a rudimentary form of the wedge strategy as it might be applied to each of the aforementioned issues. Each wedge represents a policy instrument that is either growing or declining in use over time. Those showing growing reliance involve demand-side management, market-based tools, and green technology innovations. Those portrayed with a proportional drop in reliance are measures based on supply-side management and command-and-control regulation. The wedge strategy is merely a heuristic device for the present; something intended to help in the construction of conceptual frameworks with which to understand IVHS goal conformity. The point of the strategy is to recognize that IVHS will contribute positively to goal integration and conformity on multiple fronts if and when it is employed in the service of DSM, market-based pricing, and development of green vehicles.

Of the policy goals presented, equitable access may be the most difficult to achieve politically and economically. As an overconfident Werner von Braun once observed, technology has the potential to address all public problems except for equity and corruption. In the case of IVHS, addressing the equity problem may become easier as telecommunications substitutes for both work and nonwork-related travel become available for low-income households, but this will depend on progress achieved in other areas, such as the degree to which universal access is achieved in deployment of the super-information highway.

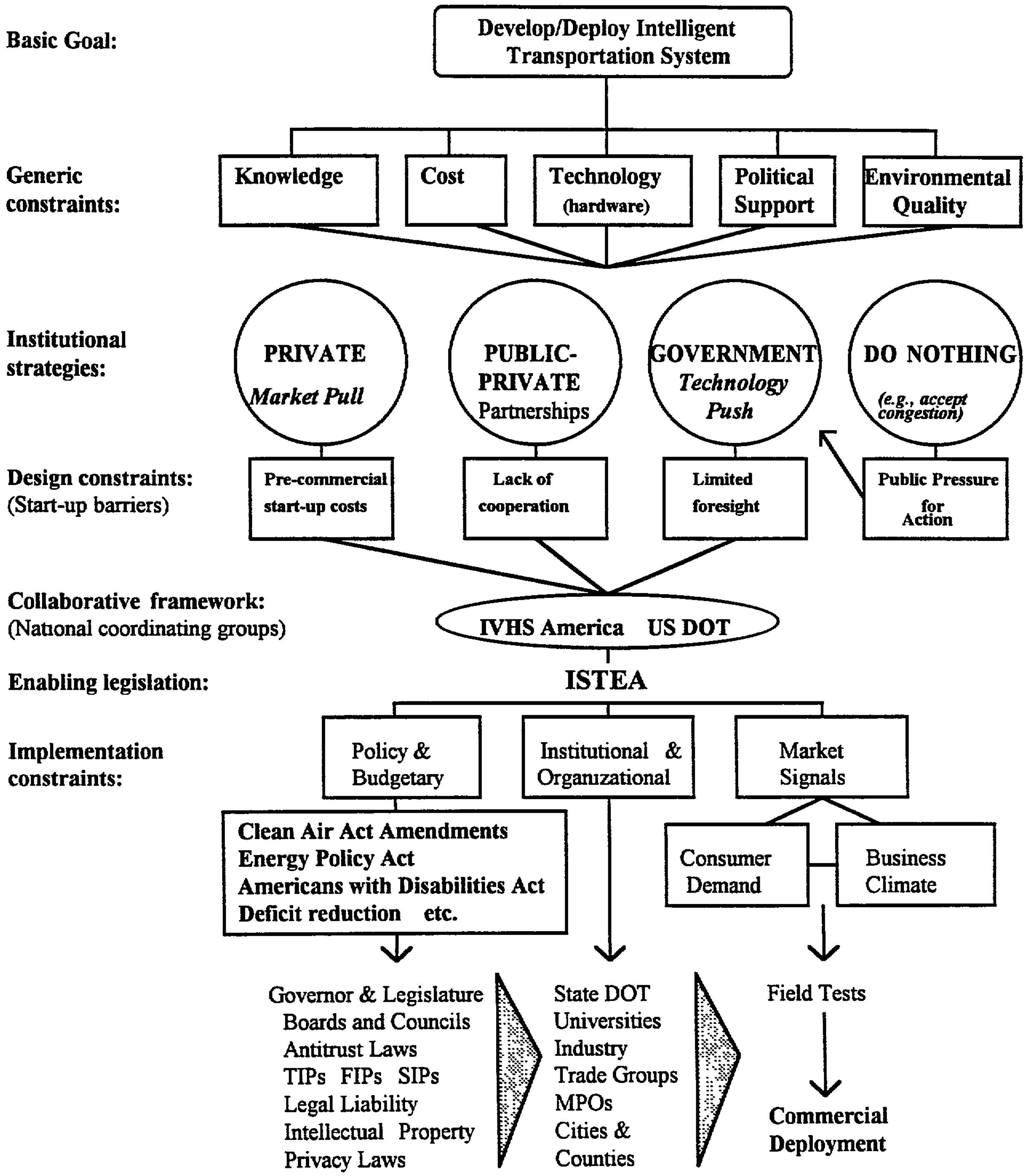
CONCLUSION

This paper has assessed the role of IVHS as an amplifier of emissions and fuel consumption characteristics of on-road vehicles. To a lesser extent, it has addressed equity issues that arise in the course of using IVHS to resolve conflicting policy goals in the transportation, environment, energy, and land use arenas. It is clear from the preceding discussion that reducing travel delay is desirable, with or without accompanying net reductions in vehicle emissions and fuel consumption (as long as there are no net increases). At the same time there is a growing suspicion on the part of many environmentalists that IVHS will be deployed primarily as a capacity enhancer, without accompanying growth management incentive programs. As such, it could justifiably be viewed as a "ratchet" policy that merely pushes back or defers many urban problems, while increasing their scale.

I have tried to demonstrate that advances in green vehicle technology provide strong reason for optimism about our future ability to increase the volume of vehicles, trips and miles traveled, while sharply reducing the levels of emissions and fuel consumption. The political will and market capability to introduce that technology appropriately and in a timely fashion is a matter for more sober consideration. If the current pace of political support and technological innovation continues, advances on the clean car front are likely to reduce concerns about emissions associated with IVHS capacity enhancement. Fuel economy concerns, on the other hand, will prove to be a more difficult challenge for IVHS designers, given current policies on automotive fuel efficiency and gasoline pricing.

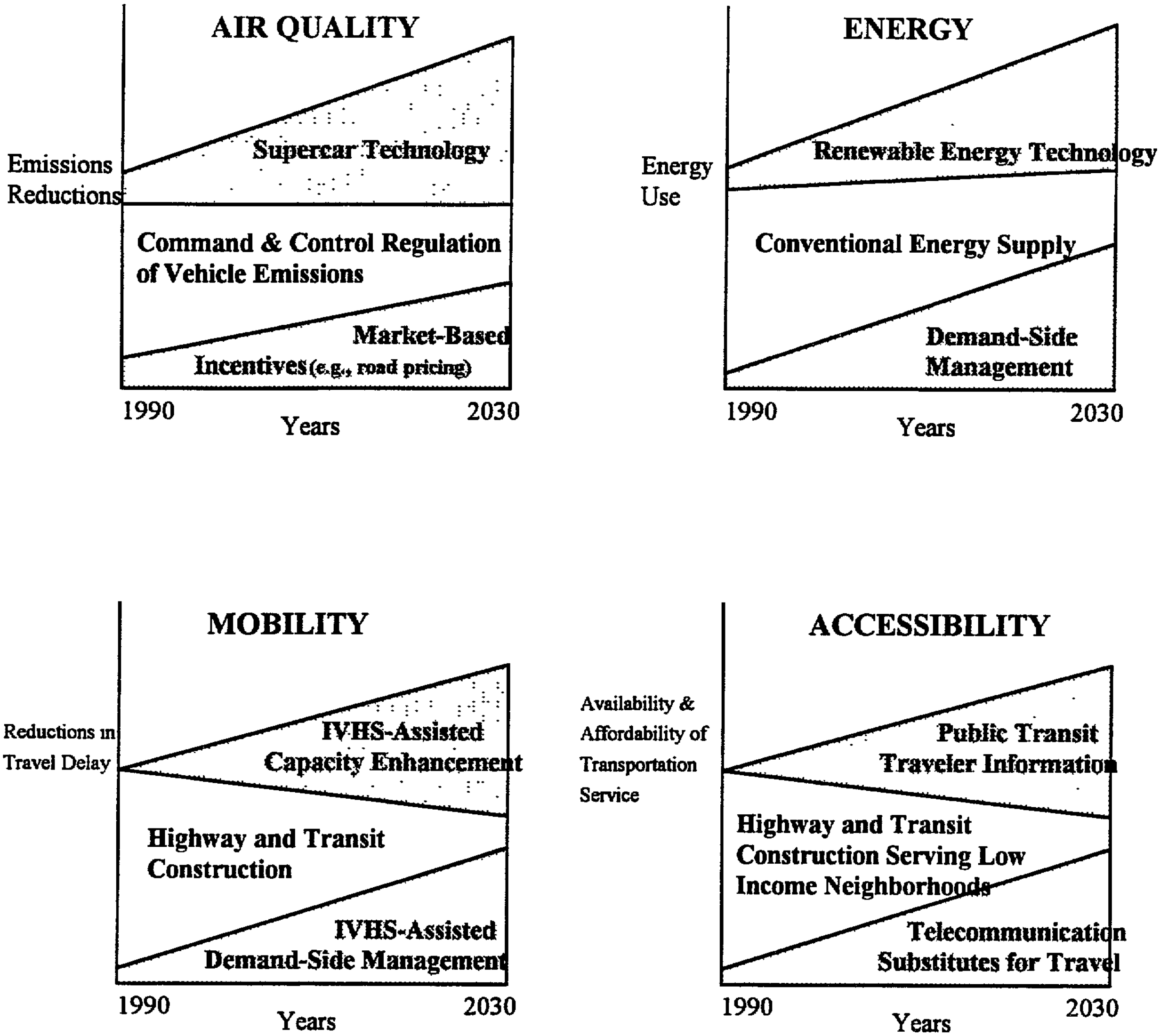
Figure 1

CONSTRAINTS MAP OF I.T.S. IMPLEMENTATION



Hempel, 1994

Figure 2
"Wedge Strategies" for Achieving Transportation-Related Policy Goals



ENDNOTES

1 Intelligent Vehicle Highway Systems (IVHS) is used here in recognition of the technical transportation community' s familiarity with and historical preference for the term. The author, however, prefers "Smart Access," or the term "Intelligent Transportation Systems" (ITS). The reliance of IVHS on the words "vehicle" and "highway" has unnecessarily widened the gulf separating the concerns of many transportation professionals from those of environmental, energy, and community equity/access groups.

2 A doubling of capacity would probably require widespread use of AHS/AVCS technology. Depending on assumptions about transit use and the type and configuration of AHS/AVCS and other IVHS technologies, some analysts have suggested that even a tripling of capacity may be economically possible.

3 Harry W. Richardson (with Chang-Hee Christine Bae), "Brown Sky Blues: Are Transportation Rx's a Cure?" in ***Resource Papers for the 1994 ITE International Conference,*** Institute of Transportation Engineers, March 1994, p. 17.

4 The compliance cost to employers of the South Coast Air Quality Management District's ridesharing program (Regulation XV) in 1992 was estimated to be $160 million. It was credited with eliminating approximately 54,000 vehicles from the road, making the cost per vehicle $2,963. Generously assuming that each vehicle removed due to ridesharing was a super emitting vehicle, one could compare cost effectiveness by applying the $2,963 to an on-road remote sensing and repair program in which it is assumed that 80 percent of super-emitters (representing 10 percent of all vehicles in use) are correctly identified and 80 percent of that number are successfully repaired or retired at an average cost of $200 per vehicle. Assuming that the average test costs $1.00 per vehicle, a minimum of 14 super-emitters (from a tested field of 215 vehicles) would be successfully repaired or retired for each one that is removed by ridesharing (in reality, of course, only about 10 percent of vehicles eliminated by rideshare programs are likely to be gross polluters, hence the cost advantages of abatement programs based on remote sensing are being understated in this example).

5 J E. Moore, "Ridership and Cost on the Long Beach-Los Angeles Blue Line," ***Transportation Research Annual,*** 1993, p. 27.

6 Langdon Winner, ***Autonomous Technology: Techniques-out-of-Control as a Theme in Political Thought*** (Cambridge: The MIT Press. 1977), pp. 226-251.

7 The conformity requirements imposed by the Clean Air Act (CAA) amendments of 1990 are among the most important constraints affecting future IVHS deployment. But it is important to note that ISTEA, itself, is a powerful constraint on the way in which intelligent transportation technologies are utilized. It is, of course, also the principal enabling legislation for developing IVHS. The linkage of Air and Transportation policy is provided principally through the Congestton Mitigation and Air Quality Improvement Program (CMAQ) of ISTEA and the periodic review (joint EPA-DOT analysis) of transportation impacts on air quality required in Section 108(f)(3) of the CAA.

8 For a discussion of the concepts and potentials of Supercars, see Amory B. Lovins et al., "Supercars: The Coming Light-Vehicle Revolution" (Rocky Mountain Institute, 1739 Snowmass Creek Road, Snow-mass, Colorado:81654-9199, Publication T93-10, 1993).

9 Jack Keebler, "Makers Look at Setting Trap for Emissions," ***Automotive News,*** July 27, 1992, p. 35.

10 Elmer Johnson, ***Avoiding the Collision of Cities and Cars: Urban Transportation Policy for the Twenty-first Century*** (Chicago: Academy of Arts and Sciences, 1993) p. 4.

11 Calculated on the basis of annual new passenger car registrations, 1960-1990, in ***World Motor Vehicle Data*** (Detroit: Motor Vehicle Manufacturers Association, 1992 edition).

12 Steve Nadis and James J. Mackenzie, ***Car Trouble*** (Boston: Beacon Press, 1993), p. 18.

13 A proposal to introduce vehicle speed governors is developed by Michael Replogle in "IVHS At Risk: A Review of Draft National Program Plan for Intelligent Vehicle Highway Systems" (Washington, DC: Environmental Defense Fund, November 25,1993).

14 Robert J. Farrauto, Ronald Heck, and Barry Seronello, "Environmental Catalysts," ***Chemical and Engineering*** News, September 7, 1992, p. 34.

15 California Air Resources Board, "Draft Discussion Paper: Low-Emission Vehicle Program Costs" (Sacramento, CA: March 25, 1994 CARB Workshop), Table 4. Note: 8 cylinder engines qualifying for California's ULEV standards are assumed to require a dual EHC system costing approximately $285.

16 Data in Table 1 is taken from S. Albu, M.J. Heimrich, and M. Ahuja, "Electrically Heated Catalysts for Cold Start Emission Control," ***Transactions of the American Society of Mechanical Engineers,*** July 1992, pp. 496-501; California Air Resources Board, March 25, 1994 Workshop; and S. Wallman, I. Gottberg, and H. Swars, "New Potential Exhaust Gas Aftertreatment Technologies for 'Clean Car' Legislation," SAE Technical Paper Series, No. 910840 (1991)

17 Steve Nadis and James J. Mackenzie, ***Car Trouble*** (Boston: Beacon Press, 1993), p. 18.

18 M. Cheslow, "Energy Estimates for ***the Years 2000*** and ***2010," Surface Transportation and the Information Age: Proceedings from IVHS America 1992*** (Washington DC: IVHS America), Vol. I, pp. 404-4 12.

19 Amory Lovins, Presentation at the 1993 Conference on Transportation and Energy, Asilomar, CA (August 22-25). A summary is provided in the Winter 1994 issue of ITS Review (November 1993/February 1994), p. 6.

20 Advocates of "pay at the pump" no-fault auto insurance have been conducting a statewide initiative campaign in California to offer voters an alternative to the current system of auto insurance. They plan to have their initiative on the March 1996 ballot. Orgamzed as the Coalition for Common Sense Auto Insurance, supporters claim that a 25-cents-per-gallon surcharge on gasoline, plus an annual vehicle registration fee of $141 ($91 for low income and senior citizens), would provide basic coverage for all California motorists, while reducing insurance premiums for most drivers by 30% to 40%. The initiative campaign has encountered heavy resistance from the state's trial lawyers and insurance industry, and is not expected to make it to the 1996 ballot with the pay at the pump provision in tact.

21 See, for example, Amos Tversky and Daniel Kabneman, "The Framing of Decisions and the Psychology of Choice," ***Science*** 211 (1981), pp. 453-458; and Mary Douglas and Aaron Wildavsky, ***Risk and Culture: An Essay on the Selection of Technological and Environmental Dangers*** (Berkeley: University of California, 1982).

22 World Commission on Environment and Development, ***Our Common Future*** (London: Oxford University, 1987), p: 8.

23 Demand-side management generally holds that when scarcity and the cost of technological fixes for providing public services are greater than the costs of limiting demand for those services, governments should seek to reduce public demand through education, market incentives and, if need be, rationing.

24 For a general discussion of this trend, see David Osborne and Ted Gaebler, ***Reinventmg Government- How the Entrepreneurial Spirit IS Transforming the Public Sector (New*** York: Penguin/Plume, 1993), pp. 280-3 10. For a

discussron focused on environmental and energy implications, see Robert Stavins and Bradley Whitehead, "The Greemng of Amenca's Taxes: Pollution Charges and Environmental Protection," ***Policy Report No. 13*** (Washington, DC: Progressive Policy Institute, February 1992).

25 For example market and technology innovations will be viewed by some as offering unwanted reprieves for a discredited car culture. It is difficult., however, to imagine voluntary behavior changes (e.g., widespread use of transit and ridesharing programs) that promise the same degree of benefits without assuming sweeping and unprecedented changes in human values and economic rationality.

26 See for example, Frank R. Baumgartner and Brian D. Jones, ***Agendas and Instability in American Politics*** (Chicago: University of Chicago, 1993). A model for IVHS deployment that would obviously be more appropriate than that of nuclear power would be an environmentally sensitive and access-oriented version of U.S. commercial airline development. Being able to convince millions of people that they could move safely, affordably, and efficiently at 30,000 feet above the grotmd was no small feat. Convincing even more people that a diverse set of electronic, robotics, and information technologies will rescue their grotmd transportation systems from traffic "crawl" may require no less imagination and critical awareness.

CAPACITY-INDUCED INCREASES IN THE QUANTITY OF TRAVEL WITH SPECIAL REFERENCE TO IVHS

BY
Sergio J. Ostria, Michael F. Lawrence, and Don H. Pickrell

ABSTRACT

Many IVHS products and user services have been designed to alleviate urban traffic congestion by improving level of service and increasing vehicle throughput. There is concern that such improvements in the efficiency of the transportation system could lead to increases in travel demand and motor vehicle emissions. The cornerstone of arguments against IVHS deployment on the basis of air quality is the notion that increased roadway capacity will result in a new system with equal congestion but more vehicles and emissions. Some IVHS detractors argue that the detrimental effects of induced demand, manifested in increases in the number and length of vehicle trips, may outweigh the potential emission benefits of improved traffic operations and system efficiencies that are brought about by IVHS This argument, however, reflects a misunderstanding of the economic mechanisms leading to changes in the quantity of travel, as well as confusion between demand increases associated with induced traffic versus secular volume growth The purpose of this paper is to present an analytical framework based on microeconomic principals for evaluating the potential impacts of IVHS on travel demand with emphasis on changes in consumers' surplus and external costs.

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, and promote economic productivity in the country' s transportation system. However, there is concern that while IVHS technologies alleviate congestion, resulting mobility improvements could lead to further increases in travel demand with the concomitant potential for increases in emissions. This concern stems from widespread community opposition ***to*** highway investments on the basis of the potential for "induced travel" and its associated external effects such as increased congestion, noise, air pollution, and energy consumption. Since the 1970's, environmental advocates have viewed highway investments, specifically road building, as causing a degradation to air quality because of the effect of induced traffic on trip generation and trip length.[l] The potential for IVHS to improve level of service and increase vehicle throughput has generated a similar undercurrent of opposition to 1VHS investments. Arguments against IVHS on this basis are often articulated as follows:

> "A principal objective of IVHS — to minimize total vehicle-hours of delay — has little in common with the social imperative of reducing the environmental impacts of driving. The stated measurable goal for IVHS is to effectively double infrastructure capacity; these are the

gains predicted for highly advanced technologies. Thus a successful IVHS program could effectively double (or significantly increase) vehicle-miles of travel assuming that total demand for travel is not fixed. And even if there is a theoretical saturation point for the number of automobiles and the number of trips taken, distances traveled have a tendency to increase as people and jobs move farther out to the suburbs and even back to more affordable rural areas."[2]

The underlying economic principals behind travel demand and transportation supply have been largely ignored in the debate concerning the induced travel impacts of IVHS. But in order to evaluate the potential for induced travel from IVHS, it is necessary to understand the behavior mechanisms that lead to induced travel, as well as the different components that define changes in the quantity of travel. This latter issue is of special importance since there seems to be confusion between travel growth that stems from induced travel versus travel growth that is generated by demand increases in rapidly growing areas or individual corridors where highway investments tend to be located. Therefore, it is critical to distinguish between increases in travel demand caused by decreases in ***perceived user costs*** and increases in the quantity of travel caused by demographic and economic factors.

The central purpose of this paper is to present an analytical framework based on microeconomic principals for evaluating the potential impacts of IVHS on the quantity of travel with emphasis on changes in consumers' surplus and external costs. A second objective is to identify the policy implications of these impacts. The paper is targeted to non-economists involved in the evaluation of the air quality and emission repercussions of IVHS or any other highway investment project.

AN ECONOMIC INTERPRETATION OF TRAFFIC VOLUMES

The first step in formulating the analytical framework is to review the interaction between transportation demand and facility performance (i.e., supply). The need for transportation originates from the interaction among social and economic activities dispersed in space. Unlike most goods and services, transportation services ***are*** derived demands, meaning that in isolation travel seldom generates any measurable utility to the consumer. Rather, travel is an intermediate input to the consumption and production process.

When separated by space, individuals satisfy their need for social and economic interaction by engaging in travel. In most urban areas, the production of trips is satisfied by three general modes of travel: motor vehicles, walking and bicycling, and mass transit. IVHS has the potential to influence all three of these modes but most predominantly motor vehicle and mass transit, which are the focus of this paper. While many of the concepts that are elaborated in this paper are applicable to commercial vehicle travel, this type of motor vehicle travel is not the focus of the analysis.

As with any other economic activity, tripmaking involves a cost. Faced with alternative modes of transportation and routes from an origin to a destination, the consumer selects a mode and route on the basis of money cost, time cost, comfort, carrying capacity, and convenience.[3] In the case of motor vehicle travel, money costs often include operating costs, such as gasoline, parking, vehicle repair, and toll costs, and ownership costs, such as vehicle depreciation and insurance. Costs associated with the time involved in undertaking a trip are referred to as the time costs of travel. These costs reflect an opportunity cost to the consumer since the time devoted to travel could be used to generate income, consume utility, or engage in leisure. The perceived comfort and convenience of a given route or mode must also be accounted for in the total cost of tripmakmg. These qualitative cost measures differ from one individual to another, and modes and routes are often rank-ordered by consumers based on comfort and convenience given an estimate of the associated money and time costs.

An important element in the derivation of the factors that determine the demand for travel is the effect of carrying capacity (i.e., facility performance) on perceived user costs. Congestion can be defined as affecting activities in which:

- motorists (i.e., consumers) supply some of the variable inputs (i.e., time, vehicles, fuel, etc.) required to produce travel (i.e., the service); and
- the required quantity of these inputs per unit of output or the quality of the product itself (e.g., level of service) depend on the consumption rate.

As a given highway becomes congested, virtually every component of user cost increases. Money costs increase in proportion to fuel costs and vehicle depreciation (the wear and tear of stop and go driving). Comfort and convenience decrease. But more importantly, time costs increase dramatically. As congestion worsens on a given facility, consumers switch to alternative modes, routes, or times of travel. Travel demand on the highway is inversely related to perceived user costs — as costs increase, users demand less travel on the facility. Therefore, travel demand is a function of user costs, and given a cost level, demand varies based on income, population, and other variables described later in the analysis.

Likewise, facility performance is influenced by the quantity of consumers using the system. In general, the supply function (i.e., facility performance) gives the level of service attributes that affect the realization of traffic volumes, as they are affected by these volumes. Level of service attributes include those components of travel cost that are outlined above. The relationship between travel cost and the supply of transportation services is opposite to that of demand. The demand function shows how traffic volume is affected by the level of service attributes of the transportation system, while the supply function shows how these attributes are influenced by the traffic volume using the system.[4]

The observed level of traffic on a highway or system reflects the interaction between travel demand and the performance of capital facilities (i.e., supply). As mentioned above, demand varies with the perceived prices or opportunity costs of user-supplied inputs necessary to produce trips. The quantity of user-supplied inputs, and thus the price to users of making trips, varies in response to traffic volume given a fixed complement of highway facilities.

The discussion presented above focuses on the general interaction between travel demand and supply. However, even the casual observer of traffic notices the differences in volume during different hours of the day and along different highways. Spatial and temporal variations in traffic volumes along individual corridors or on specific highways reflect the dynamic nature of the equilibrium between demand and supply. Traffic volumes on individual corridors and the utilization of specific facilities reveal the interaction between corridor- or facility-specific demand and supply functions. For a particular highway during a given hour of the day, a unique supply and demand relationship will prevail that characterizes the traffic volume on that highway at that time.

Various IVHS strategies have the potential to directly alter the interaction between demand and supply by changing the perceived user costs of travel. For instance, route guidance systems could decrease time costs by allowing users of the system to select the most expedient route from an origin to a destination.By diverting travelers from congested routes to free flowing routes, or less congested routes, geographic and temporal travel patterns may change, altering the global and local equilibriums between travel demand and supply. The remainder of this section derives the demand curve and supply curve for motor vehicle travel. This derivation will facilitate the analysis of the impact of IVHS on facility performance and travel demand.

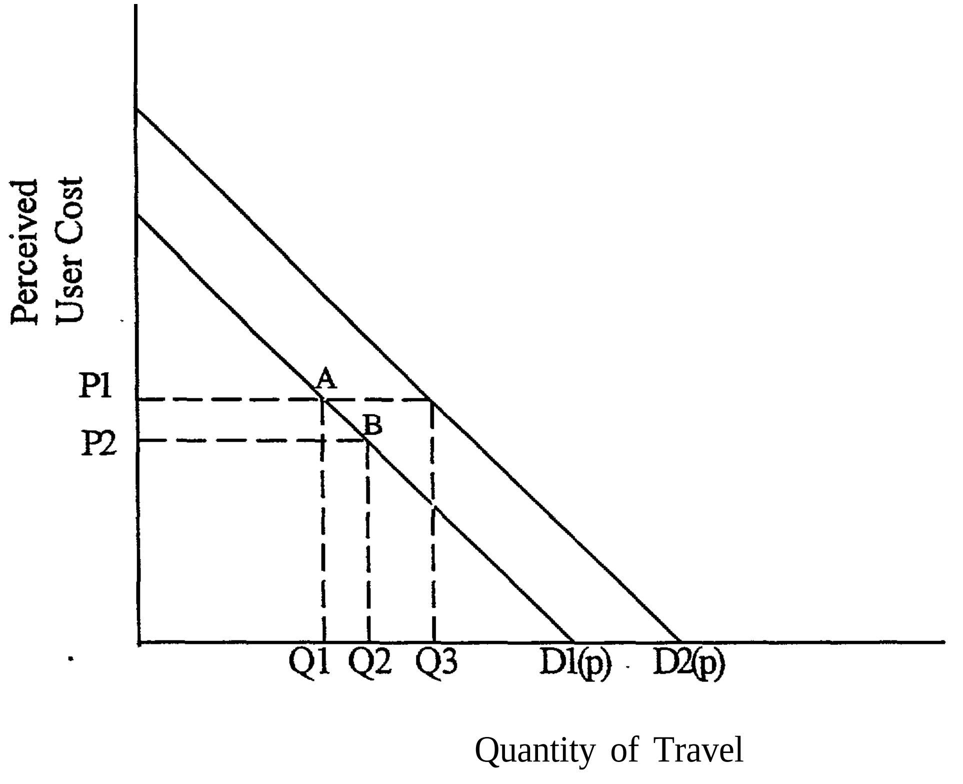
Characteristics of the Demand Curve for Motor Vehicle Travel

The quantity demanded of a good or service at different price levels — holding constant all other determinants of demand, such as income, population, prices of all other goods, etc. — is represented in economics by a demand curve. For most goods and services, the law of demand suggests that as price increases the quantity demanded of the good or service decreases. As a result, demand curves are usually downward sloping.

Exhibit 1 shows a hypothetical demand curve for motor vehicle travel — drawn as linear in order to simplify the analysis. Perceived user cost is represented on the vertical axis and the quantity of travel (e.g., traffic volume, vehicle trips, vehicle miles traveled) on the horizontal axis. Unlike most goods, transportation is a derived demand since by itself it does not produce any measurable utility but rather serves as an intermediate service in the supply of labor or consumption of goods, services, and leisure. If it is accepted that tripmakmg permits individuals to partake of a socioeconomic activity that generates utility and that transportation is simply a means to overcome the spatial separation between an origin and a destination of a trip, then transportation will be governed by the same microeconomic demand principals as all other normal goods.[4] Specifically, and as depicted in Exhibit 1, as perceived user cost increases (as a result of either increases in money cost, time cost, or increased inconvenience), the demand for motor vehicle travel decreases.

Several basic features of the demand curve for motor vehicle travel should be noted. First, the demand curve depicts the functional relationship between travel and perceived user cost assuming that there is no change in the values of other pertinent variables such as the prices of complementary and substitute services (e.g., automobile travel versus public transportation), personal income, vehicle ownership, population, and other pertinent economic and demographic factors. Second, the demand curve depicts the situation at a single point in time and a specific geographic location (e.g., a segment of a roadway, a corridor, a network, etc.). Hence, all but one of the user costs (prices) and travel quantities must be hypothetical — the curve must generally answer the "iffy" question: "If price were to change, how much travel would be demanded by an individual or set of individuals)?"[5] Third, changes in perceived user costs cause movements along the demand curve (depicted in Exhibit 1 by the movement from point A to point B). Corresponding changes in the quantity of travel demanded (i.e., depicted in Exhibit 1 as the change from Q1 to Q2) represent what has been referred to as "induced demand". (It should be noted that "induced demand" is not a term used in economics since the entire area beneath the demand curve is potential demand. Price simply determines the level of demand throughout the demand function.) Fourth, changes in the price of complementary and substitute goods, personal income, vehicle ownership, population, or other economic and demographic factors cause the entire demand curve to shift so that either more or less travel is demanded at a given price. For example, an increase in population (in a particular region) causes the demand curve (for that region) to shift outward to D2 as shown in Exhibit 1. This shift generates an increase in the quantity of travel from Q1 to Q2 that is generated by secular growth rather than by a reduction in price. It is important to distinguish between increases in travel caused by decreases in price and increases in travel stemming from demand increases in rapidly growing urban areas or individual corridors where highway investments tend to be located. Finally, the magnitude of changes in demand in response to changes in price depends on the elasticity of demand. Elastic demand (i.e., represented by a relatively flat demand curve) implies that a change in price leads to

Exhibit 1
Demand Curve for Road Travel: Induced vs. Secular Growth



It is important to distinguish between increases in travel associated with changes in perceived user cost and increases resulting from changes in economic and demographic factors.

A decrease in price from P1 to P2 causes an increase in the quantity of travel of Q2-Q1. This change in travel is what has been termed as "induced demand".

An increase in personal income, for example, causes the entire demand schedule to shift from D 1 to D2 so that at P 1 the quantity demanded is now Q3. The difference, Q3 - Q1 , is secular growth.

large changes in quantity. Inelastic demand (i.e., represented by a relatively steep demand curve) implies that a change in price leads to small changes in quantity. In the short run, the demand curve for travel is relatively inelastic since travelers cannot readily alter their fixed travel demand resulting from existing housing and employment locations. As a result, changes in price have a relatively smaller impact on travel demand. In the long run, however, households have the capability to select different housing locations and alter behavior. Therefore, the long-run demand curve for travel is more elastic than short-run demand. An important conclusion is that land use patterns are represented by the more elastic long-run demand curve, and changes in these patterns do not change the short-run demand curve. Exhibit 2 graphically depicts this relationship.

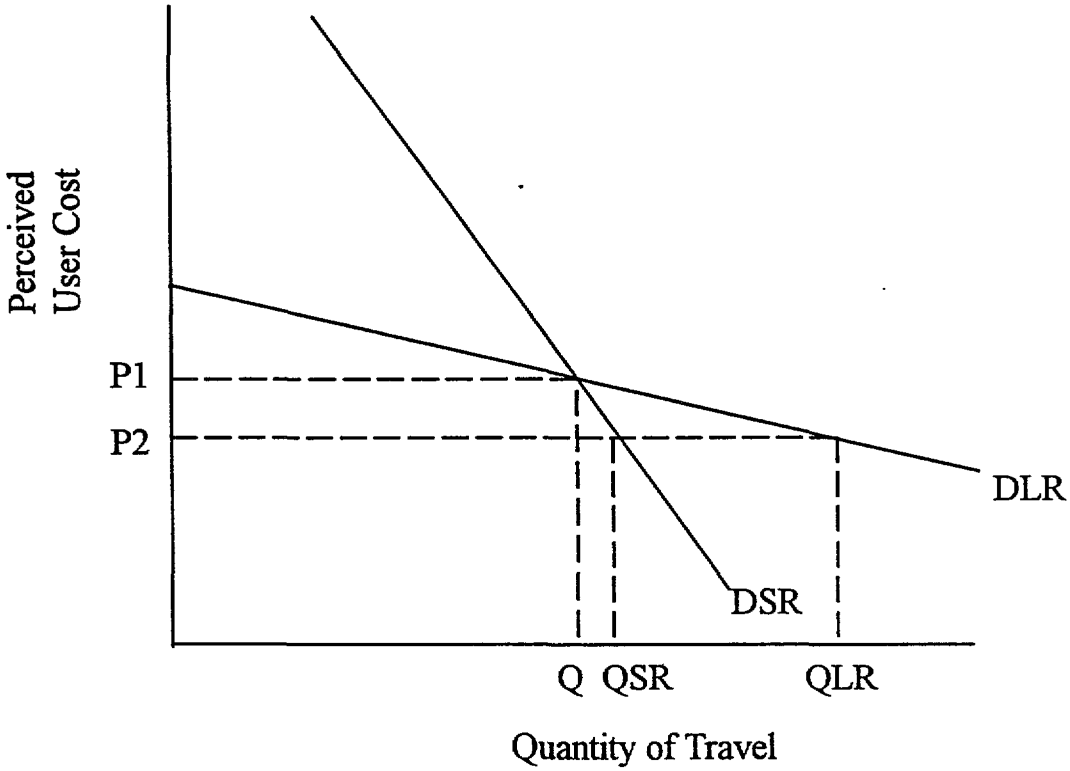
Consumers Surplus

Individuals engage in travel so that they can engage in socio-economic activities and accrue some sort of economic or social benefits. In economics, the benefits of consuming a good or service are represented by consumers' surplus. Consumers' surplus is defined as the net benefit that consumers get from being able to purchase a good at the prevailing price — i.e., the difference between the maximum amounts that consumers would be willing to pay and what they actually do pay. As depicted in Exhibit 3, consumers' surplus is represented by the triangular area under the demand curve and above the prevailing market price (e.g., P1). Changes in the market price for travel (i.e., the perceived user cost) alter the magnitude of consumers' surplus. For example, decreases in travel time that result from highway investments, such as advanced traffic management systems or capacity expansion, lower total user cost, represented in Exhibit 3 by the fall in price from P1 to P2. The fall in price results with increased benefits to the system's users depicted by the increase in consumers' surplus. Therefore, insofar as analyzing IVHS projects in this manner indicates that they are likely to induce traffic growth, they will also produce benefits to users of the system or roadway. Determining the net effect of changes in externalities associated with increased travel and increases in consumers' surplus requires the incorporation of the supply curve for travel into the analytical framework, which is the subject of the following subsection.

Derivation of the (Short-Run) Supply Curve for Motor Vehicle Travel

Microeconomic theory defines the supply curve as a function that provides the quantity of a good that a seller is willing to offer in a market at a given price. The higher the price, the more of the good that the seller is willing to offer. While this definition is adequate for many goods and services, it is not well suited for analyzing travel supply. This inadequacy largely stems from the fact that much of what determines the attributes of travel supply is a result of user rather than supplier behavior. As discussed above, facility performance is directly determined by how travelers use the transportation system. Thus, many of the

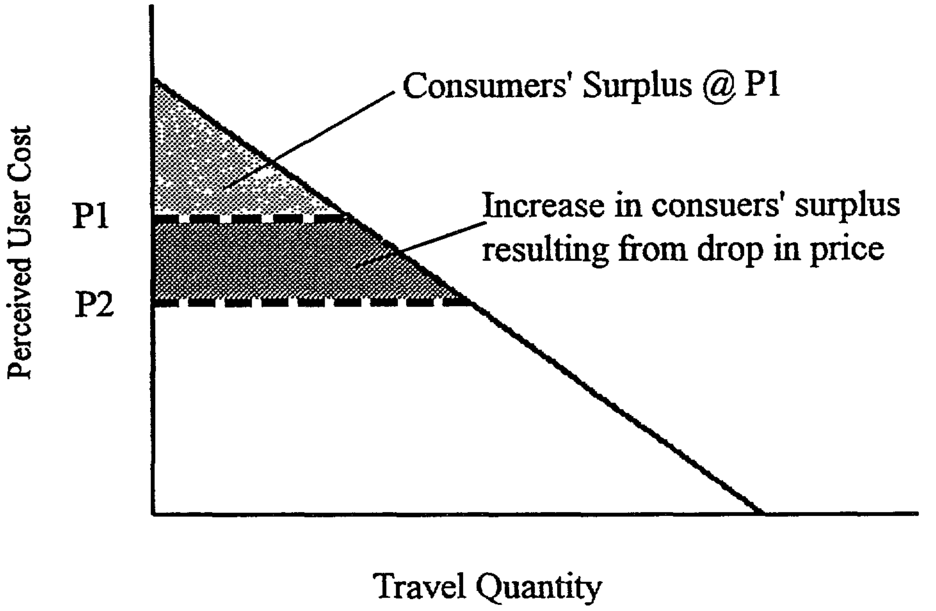
Exhibit 2
Short-Run vs. Long-Run Demand and the Role of Land Use



Short-run demand is relatively inelastic when compared to long-term demand. In the short run travelers cannot easily alter housing location nor travel behavior so that changes in user cost have a relatively smaller impact on travel demand. For example, as price falls from P1 to P2, the effect on long-run demand is much greater (i.e. QLR-Q>QSR-Q).

Land use patterns are represented by the long-run demand curve, when businesses and/ or households can alter location decisions.

Exhibit 3
Consumers' Surplus



Consumers' surplus represents benefit to users (i.e. consumers) of the transportation system. Investments that decrease user cost increase consumers' surplus as depicted above.

important aspects of transportation level of service that directly affect the evolution of traffic flows depend on user behavior and cannot be considered as supply attributes determined by a supplier.[4] In deriving the short-run supply curve for travel, the following measures which define the operational state of any given traffic stream must be considered:

- ***Speed,*** defined as the rate of motion expressed as distance per unit of time, usually expressed as miles per hour (mph);
- ***Traffic Density,*** defined as the number of vehicles occupying a given length of a lane or roadway, averaged over time, usually expressed as vehicles per mile (vpm); and
- ***Traffic Volume,*** which measures the quantity of traffic passing a point on a lane or roadway during a designated time interval, usually expressed as vehicles per hour (vph).

Travel time, or the reciprocal of speed, is an important measure of the quality of traffic service provided to the motorists. It is used as one of the more important measures of effectiveness defining level of services for many types of facilities.[6] As a result, speed is an important component of facility performance and perceived user cost which determines driver behavior.

Traffic density is a critical parameter describing traffic operations since it describes the proximity of vehicles to one another. Vehicle proximity is a function of ***spacing.*** Spacing is defined as the distance between successive ‘vehicles in a traffic stream, as measured from front bumper to front bumper. As speed increases, spacing increases (usually at a decreasing rate) so that spacing is also a function of speed. The time between successive vehicles as they pass a point on a lane or roadway is defined ***as headway,*** which is also a function of speed. Empirical evidence suggests that vehicles do not travel at constant headways. Rather they tend to travel in groups, or platoons, with varying headways between successive vehicles.[6] As a result, these phenomena also depend on driver behavior, specifically the rules that motorists follow to determine a safe following distance.

Mathematically the relationships between speed, following distance, and traffic density are expressed below.

1. $H = G/S$

   where:

   H = headway, in seconds per vehicle;

   G = spacing (or the gap between vehicles), in feet per vehicle; and

   S = the speed of the second vehicle in a given pair of vehicles, in feet per second.

   Rearranging this equation, we see that spacing is given by $G = H * S$.

2. $D = 5{,}280/G$

where:

D = traffic density, in vehicles per mile;

5,280 represents the number of feet in a mile; and

G = spacing, in feet per vehicle.

Since spacing is itself a function of speed, traffic density also depends on speed. Specifically, as speed increases traffic density decreases at an increasing rate. As traffic density increases, speed decreases. The relationships between speed, following distance, and traffic density are depicted graphically in Exhibit 4.

Traffic volume is given by

$$V = S * D,$$

where:

V = rate of flow, in vehicles per hour (vph);

S = average travel speed, in miles per hour (mph); and

D = traffic density, in vehicles per mile (vpm).

Given the expression for traffic density and headway, we can show that traffic volume can be expressed as follows:

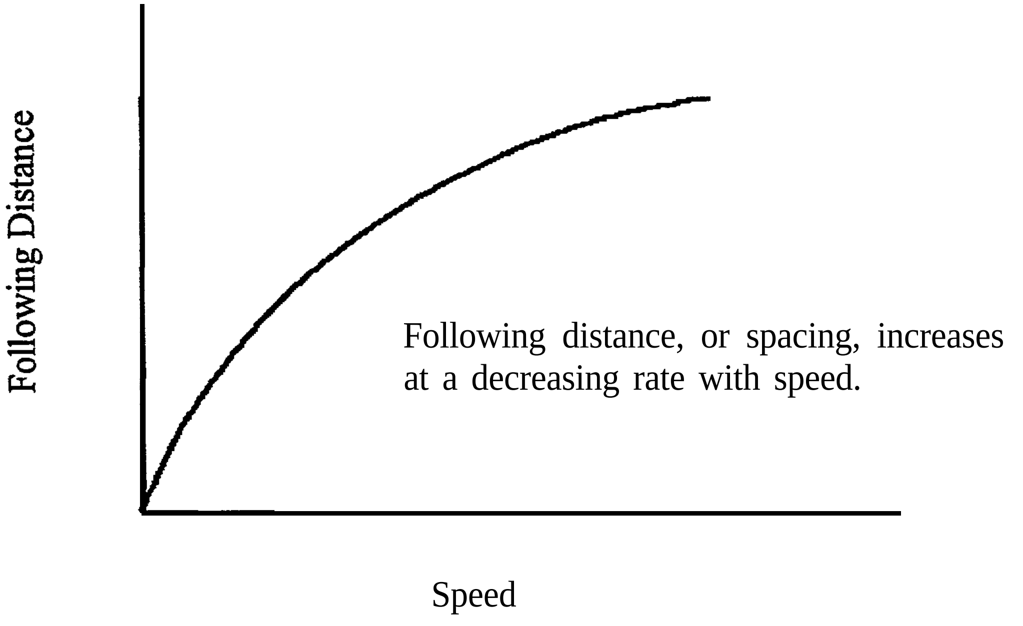
$$V = (5280 * S)/G.$$

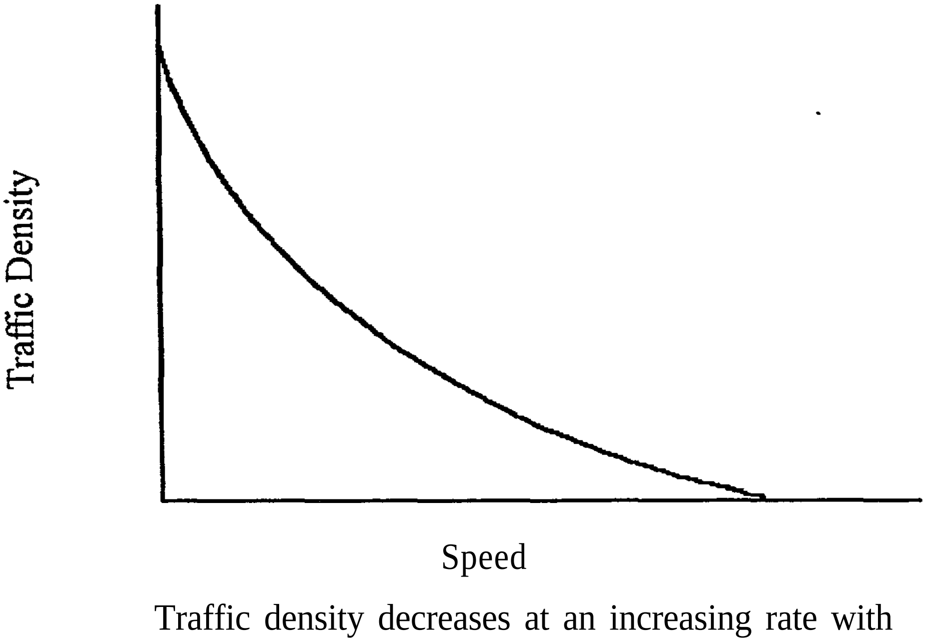
Note that G, or the distance between successive vehicles in a traffic stream, increases with speed. Given the correct functional relationship between spacing and speed, the interaction between traffic volume and speed takes the form of that shown in Exhibit 5. Note that a zero flow rate occurs under two very different conditions [6]:

1. When there are no vehicles on the facility, the rate of flow is zero since density is zero.
2. When density becomes so high that speed converges to zero (total gridlock), the rate of flow is also zero. The density at which all movement stops is referred to ***as jam density.***

As density increases from zero, the rate of flow also increases as vehicles enter the roadway. Due to the interaction of vehicles, speed begins to decline as flow increases (i.e., we move backwards on the spacing-speed curve shown in Exhibit 4). As more and more vehicles enter the traffic stream, a point will soon be reached where with increase in density, speed is reduced so much that the flow of vehicles reaches a maximum. If the density of vehicles on the road is increased further, the reduction of speed will be so large that the flow will be reduced.[7] The maximum rate of flow, or capacity, is reached when the product of increasing density and decreasing speed results in reduced flow. Therefore, any rate of flow other than

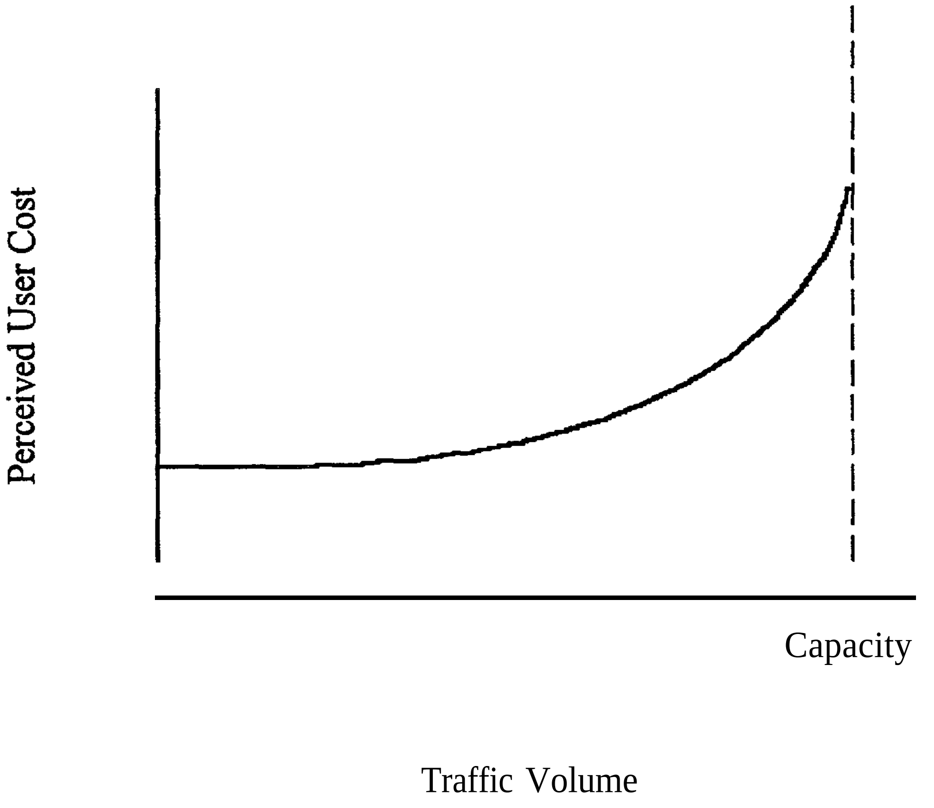
Exhibit 4
Derivation of the Supply Curve for Road Travel: Spacing: and Density as a Function of Speed





Traffic density decreases at an increasing rate with speed.

Exhibit 6
Supply Curve for Road Travel



As volume approaches its maximum flow rate (i.e., capacity), perceived user cost increases rapidly.

effect of IVHS implementation and operation on the out-of-pocket aspect of travel 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 costs through changes in excise taxes to support the Highway Trust Fund and state and local highway funding.

- ***Total travel time.*** This cost element involves opportunity costs associated with access time, waiting time, transfer time (applicable to transit), and line-haul time (time actually spent in motion). Many IVHS products and user services will reduce total travel time by decreasing recurrent and nonrecurrent congestion. For example, traffic signalization systems allow vehicle movements to be controlled through time and space segregation, speed control, and advisory messages. Advances in traffic signalization involve the incorporation of real time data on network capacity and demand, thereby facilitating the optimization of network efficiency and reducing delays associated with congestion.

Other parameters accounted for by the supply function include comfort and convenience. The discomfort and inconvenience of travel will be alleviated by many IVHS strategies, such as advanced vehicle control systems that will eventually remove, or minimize, the human element from the vehicle operation process.

These attributes of the supply function suggest that even a facility with fixed physical capacity has a supply curve associated with it, and congestion (resulting from changes in driver interaction behavior with travel speed) causes supply curves to be upward sloping.

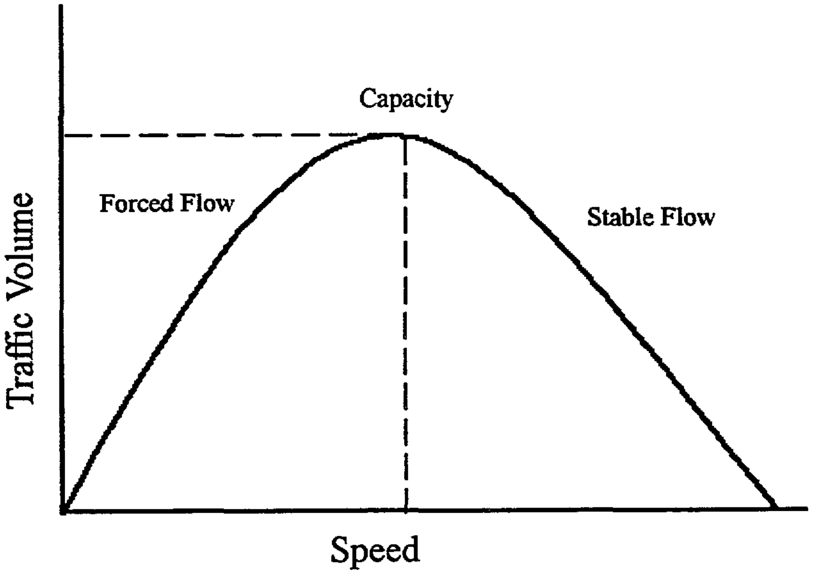
The steepness (i.e., elasticity) of the supply curve as congestion sets in depends on driver behavior. The influence of a facility's physical design on traveler behavior determines the sensitivity of travel cost to changes in the quantity of travel services. The effect of IVHS on travel supply will depend on the cumulative impact of IVHS on travel cost, often as a result of decreases in travel time,

External Costs

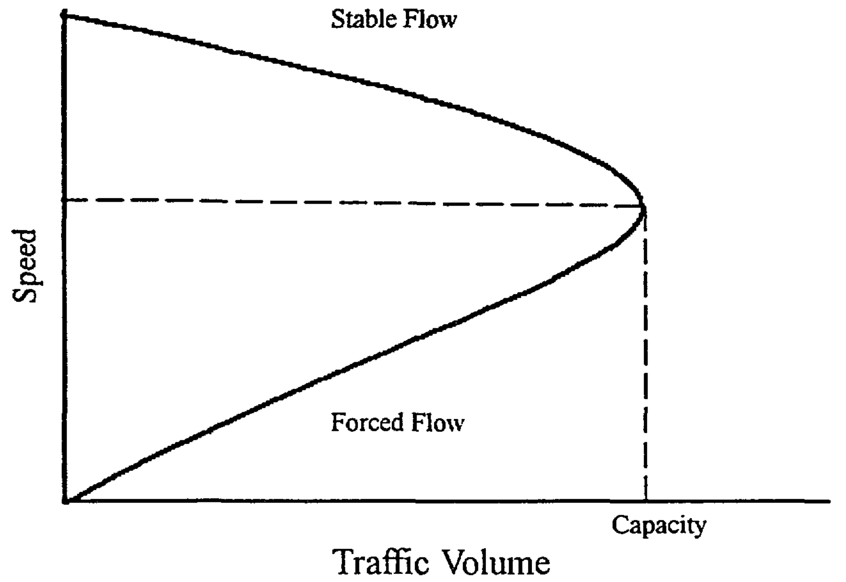
Externalities in the form of congestion, air pollution, noise, and other disamenities are prevalent in motor vehicle travel, so that the private cost of a mile of urban travel is often significantly Iess than its full social cost. Congestion is a societal as well as a private problem. By entering a congested traffic stream, an individual motorist not only increases his/her own private cost, but also increases the private cost of other motorists on the roadway. Therefore, congestion costs are a form of externality — the action of one individual imposes costs on others in addition to those he/she bears.[3] The quantification of this component

Exhibit 5

Derivation of the Supply Curve for Road Travel: Traffic Volume - Speed Relationship



The maximum rate of flow is reached when the product of increasing density and decreasing speed results in reduced flow.



Inverse of volume-speed relationship (above) gives conventional backward bending speed-volume curve.

capacity can occur under two different conditions — with high speed and low density, or with high density low speed.[6] Conditions characterized by high-density and low-speed reflect roadway congestion. So, points to the left (or to the south) of the maximum flow on Exhibit 5 reflect congested conditions.

The translation of the speed-volume relationship depicted in Exhibit 5 into the supply curve for travel involves the dependency of perceived user costs on travel time (i.e., the reciprocal of speed). Realizing that travel time per unit of distance (e.g., minutes per mile) is given by the amount of time spent traveling (such as 60 minutes) divided by speed (miles per hour), the cost of travel time per unit of distance traveled can be represented as:

$$c = t * v,$$

where,

c = travel time cost per unit distance, in cents per mile;

t = travel time per unit distance, in minutes per mile; and

v = value of time, in cents per minute.

Total perceived user cost (TC) per unit distance traveled is then given by the following expression:

$$TC = OC + c$$

where OC represents vehicle operation cost. Since c is a function of speed — as speed decreases c increases — perceived user cost increases as speed decreases. The resulting relationship between the cost per unit of travel (marginal cost) and volume is depicted in Exhibit 6. As volume increases, marginal perceived user cost increases slowly, if at all, at first. As volume approaches its maximum rate of flow, marginal perceived cost begins to increase very rapidly. This relationship describes the short-run travel supply curve that shows the quantity of travel services that can be accommodated by a facility (or corridor, region, etc.) as a function of marginal perceived personal cost. Quantity of travel can be represented by a number of measures including traffic volume, number of vehicle trips, vehicle miles of travel, and others. Cost functions that represent a system with fixed capacity are referred to as ***short-run functions.*** When the capacity of the system is expanded as the output level increases, then the resulting cost function is referred to as a ***long-run*** cost function.[4]

ln summary, perceived user costs are critical to driver behavior including mode and route choice. For a particular trip, the supply function for passenger travel is therefore commonly dependent on the following user cost parameters.

- ***Total money cost.*** In addition to vehicle operation costs, such as fuel, parking and vehicle depreciation costs, out-of-pocket costs include implicit costs such as indirect taxes. The potential of social cost is a difficult task but can be measured as losses in productivity, wages, fuel, etc.

Noise and air pollution are also disamenities associated with motor vehicle travel that cause divergences between private costs and social costs. Both of these phenomena worsen with increases in road travel. The measurement of these external costs depends on the societal value placed on cleaner air, for example.

External costs can nevertheless be calculated in abstract. For illustration purposes, assume that the cost of motor vehicle travel is given by the following expression:[7]

$$TC_{n-1} = M*C*(n-1)/S$$

where,

TC = the total cost of motor vehicle travel,

M = the number of miles traveled,

C = the marginal cost of travel per minute,

S = the average travel speed, and

n-1 = the number of travelers on the facility.

Assuming that as soon as an additional driver enters the traffic stream, the average speed per vehicle will fall by X as a result of congestion, total cost will change as follows:

$TC_n = M*C*n/(S-X)$, where X is positive but smaller that S.

Therefore, marginal social cost, or the additional cost imposed by the ***nth*** motorist, is simply the difference between TC_n and TC_{n-1}, given by:

$$MSC_n = [M*C*n/(S-X)] - [M*C*(n-1)/S]$$
$$= [M*C/(S-X)] + [M*C*X(n-1)/S*(S-X)].$$

To any individual motorist, the marginal private cost of travel is given by:

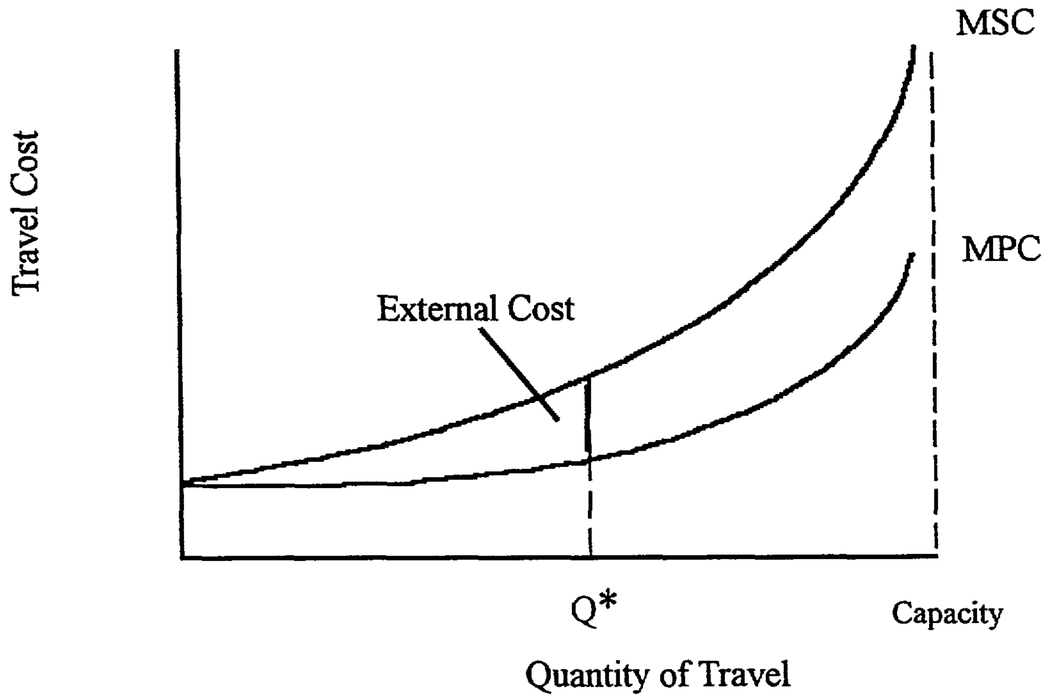
$$MPC_n = M*C/(S-X)$$

The difference between marginal social cost and marginal private cost defines the ***external cost.*** In our simplified example, external cost is given by:

$$MSC_n - MPC_n = M*C*X(n-1)/S(S-X).$$

By construction X, ***M,*** C, ***n-i, S,*** and S-X are positive. So, the expression for external cost is positive and the *nth* individual imposes an additional cost to society by entering the traffic stream. Graphically, this difference is depicted by the vertical distance between the MSC curve and the MPC curve as shown in Exhibit 7. The effect on consumer surplus and external cost determines the societal value of deploying IVHS technologies,

Exhibit 7
External Cost



External cost at quantity of travel Q* is given by the difference between marginal social cost (MSC) and marginal private cost (MPC).

products, and user services.

The Equilibrium Quantity of Travel

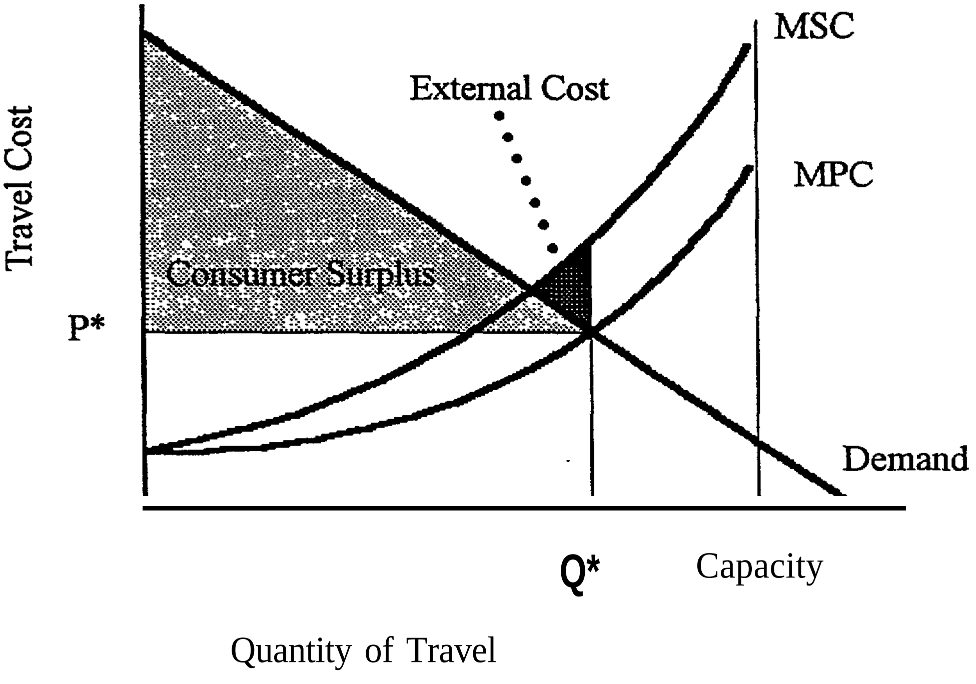
The interaction between travel demand and travel supply determines the observed level of traffk on a system at a given point in time. Exhibit 8 graphically demonstrates this interaction. Shifts in either the demand or the supply curve will establish new equilibrium levels of both the quantity of travel services (i.e., volume, vehicle trips, vehicle miles traveled, etc.) and the price per unit of those services (i.e., dollars per trip, cents per mile, etc.). The relative magnitudes of supply and demand price elasticities determine the response of the equilibrium level of travel and its associated cost to changes in demand or supply. Shifts in supply are commonly associated with capital investments that increase the quantity and/or quality of the road infrastructure, while shifts in the demand curve are brought about by changes in economic and demographic factors (as discussed earlier). The potential impact of some IVHS products on facility performance, travel demand, and the equilibrium quantity of travel is the subject of the following section.

POTENTIAL IVHS IMPACTS ON THE QUANTITY OF TRAVEL

Many IVHS technologies, products, and user services can be analyzed within the travel demand and supply framework that has been described above. For instance, advanced vehicle control systems will affect the response of driver interaction behavior, such as following distance, to variations in travel speed. Changes in the following distance-speed relationship will translate into changes in the other relationships that determine facility performance (i.e., travel supply), Other systems that improve the quality and reliability of travel information will affect travel demand by altering the departure profile of trips and route selection.

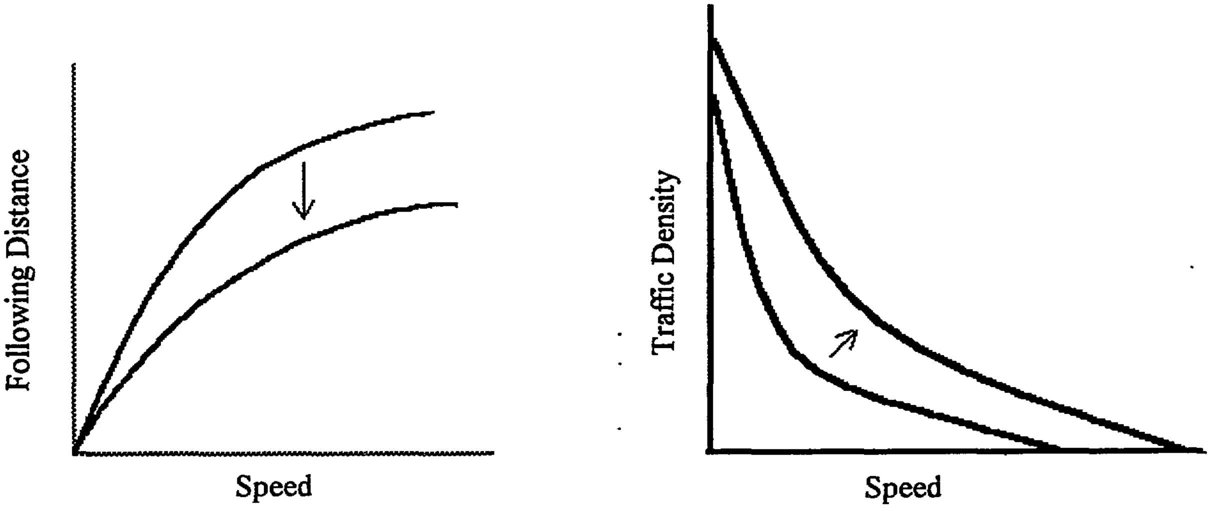
An example of the effect of an IVHS strategy on the quantity of travel is depicted in Exhibits 9 and 10. Automatic headway control systems, for instance, employ vehicle sensors to maintain constant distances between vehicles traveling in a particular lane or highway. Distance monitoring is combined with brake and speed control in order to decrease following distance and increase vehicle throughput. Therefore, the implementation of these systems will change the following distance-speed relationship depicted in Exhibit 4 by decreasing the spacing between vehicles for any given travel speed. This effect, as shown in Exhibit 9, can be represented by a downward shift in the following distance-speed curve so that at any particular speed (other than zero) shorter following distances will prevail. Decreases in spacing will also impact traffk density. Specifically, as spacing decreases for any given speed, density increases, thereby shifting the density-speed curve outward to the right. The end result will be a downward shift in the cost curves that are shown in Exhibit 7 so that facility performance (supply) increases at every user cost.

Exhibit 8
Equilibrium Quantity of Travel



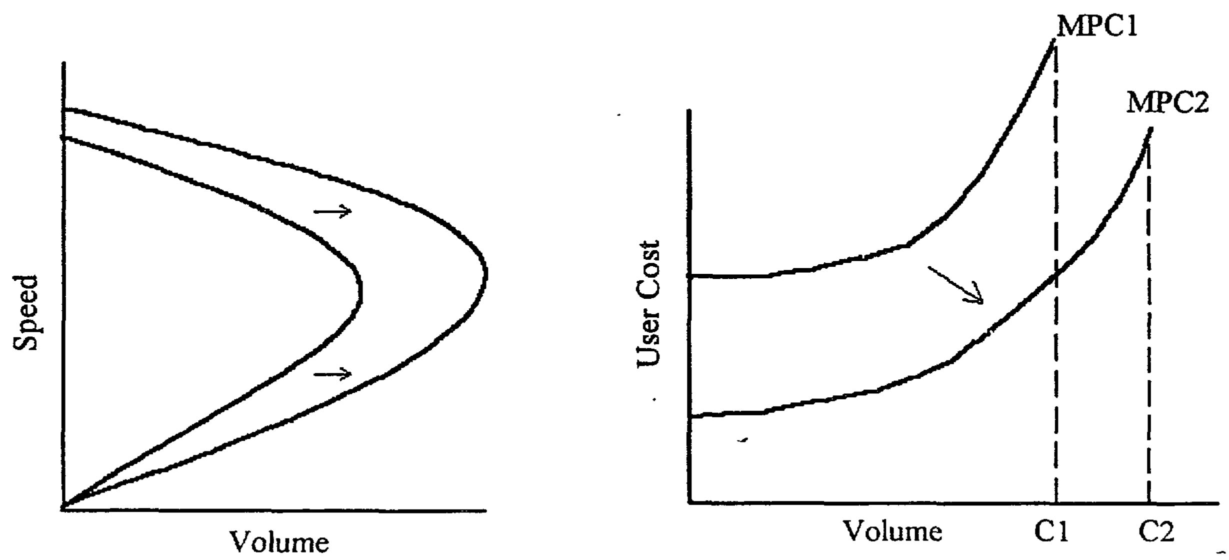
The equilibrium quantity of travel (i.e., observed traffic volumes) at a given point in time along a specific route or entire system is given by the interaction between travel demand and supply.

Exhibit 9
Example Effect of IVHS on the Determination of Supply



a) Deployment of headway control systems allows decreases in spacing without changes in speed.

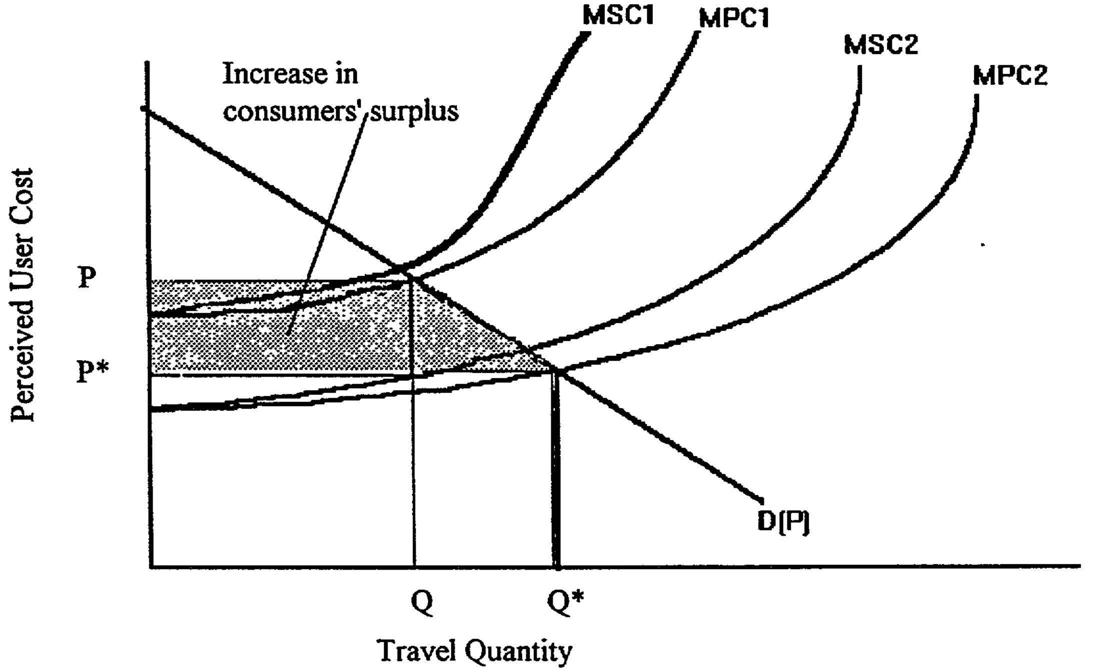
b) Translates into increased density at all speeds.



c) Effect on density increases potential volume at given speeds and capacity.

d) End result is a decrease in user costs and shift of supply curve, increasing throughput capacity.

Exhibit 10
Sample Impact of IVHS on the Equilibrium Level of Travel



Development of automatic headway control systems, for example, reduces the equilibrium price and increases the equilibrium quantity. The fall in price generates an increase in consumers' surplus.

Q*-Q represents "induced" traffic resulting from development of technologies.

When combined with the travel demand curve for that lane or roadway (at a given point in time), the effect of the shift in supply translates into a new equilibrium quantity of travel as demonstrated in Exhibit 10. The increase in travel reflects induced traffic resulting from decreases in marginal user costs, or the increase in facility utilization that is prompted by the resulting reduction in the user cost per unit of service that the facility provides (e.g., cents per vehicle-mile traveled on the facility at a point in time). Several observations are in order.

- Induced demand should be regarded as an indication that an investment such as IVHS is generating benefits, rather than as evidence of an unforseen or unintended side-effect that can only be avoided by eliminating the investment. As shown in Exhibit 10, at the new equilibrium quantity *(Q*)* and marginal perceived user cost *(P*)* consumers' surplus is larger. The magnitude of the change in consumers' surplus depends on the relative elasticities of supply and demand. Therefore, where travel growth induced by the deployment of IVHS projects generates external costs, it also produces substantial benefits to users of the transportation system.
- Where travel growth induced by IVHS deployment produces external costs, it is important to deal with externalities directly (e.g., by improving emissions technology, increasing gasoline taxes, implementing road pricing, etc.), rather than to sacrifice the benefits of investment in order to minimize external costs.

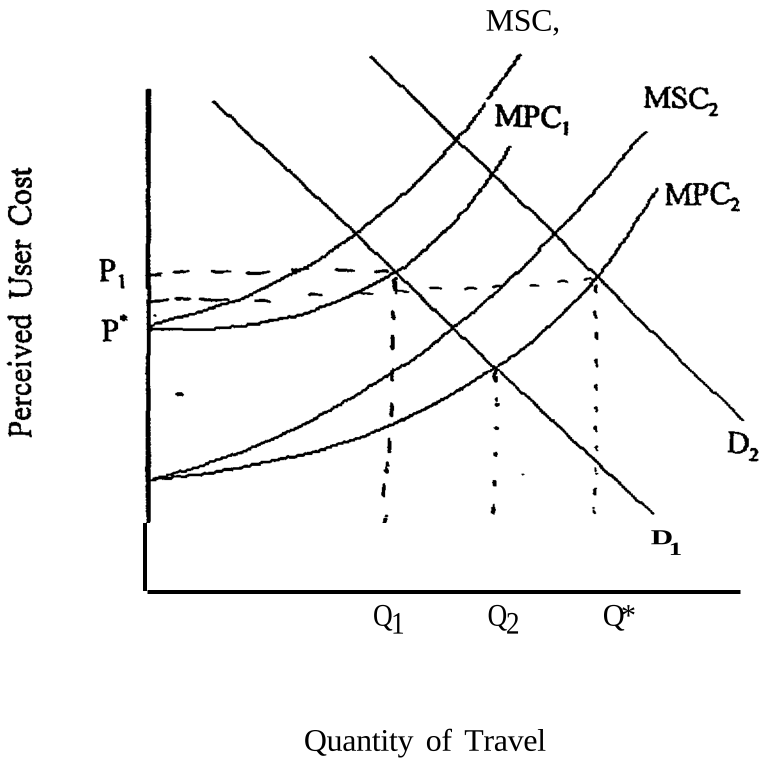
Moreover, induced demand resulting from the deployment of-IVHS should be distinguished from increases in travel and facility utilization that originates from secular growth. The dynamic nature of the market for motor vehicle travel represented by continuous shifts in demand that represent secular growth and periodic increases in supply — through either capacity expansion or in the future IVHS deployment — is depicted in Exhibit 11. Induced demand is associated with reduced user cost since the outward shift in the supply curve implies that more travel can be accommodated at ever level of cost. Outward shifts in the demand curve result in higher user costs — since as congestion sets in speed decreases and travel time increases. In fact, increases in supply are often undertaken in exactly the places where demand is growing most rapidly. This creates difficulties in separating the component of observed travel growth resulting from demand growth from the component that is induced by increases in supply. Finally, at the level of an individual facility, much of what is referred to as induced demand actually may be diverted traffic from competing facilities rather than newly induced traffic.

POLICY IMPLICATIONS

This paper has presented an analytical framework for evaluating the potential effects of IVHS products and user services on the quantity of travel. IVHS will undoubtably have supply effects as a result of

EXHIBIT 11

Simultaneous Shifts in Demand and Supply



Initially, equilibrium is given by P_1, Q_1. As demand increases (i.e., shifts from D_1 to D_2), supply increases to accomodate the secular growth. The end result is a new equilibrium level of travel given by Q*, $Q_2 - Q_1$ is the induced component of travel growth, while $Q^* - Q_2$ is the growth intravel associated with secular growth.

improvements in level of service that may result from more efficient traffic operations, reduced congestion, and better interface between the road and the vehicle. What has been termed as the induced demand repercussions of IVHS is simply represented by a movement along the demand curve for travel that results from reductions in perceived user costs in response to increases in facility performance (i.e., supply). Although it is true that many IVHS strategies will decrease user cost and increase travel, the external costs of increased travel must be weighed against the benefits that are accrued by users of the system. Policies that discourage highway investment projects (e.g., advanced traffic management systems) to address the externalities of motor vehicle travel restrict growth in social welfare by restricting growth in consumers' surplus. It is important to implement policies that directly deal with external costs.

Various IVHS technologies are also well suited for enhancing the effectiveness and logistics of transportation demand management programs, such as road pricing, that can help to internalize the external costs associated with motor vehicle travel. IVHS 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, fees can be set to vary over time and distance 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.

Similarly, on-board diagnostics, that monitor a vehicle's emissions, and remote sensing devices, that measure exhaust pollutants from moving vehicles, are examples of IVHS technologies that can facilitate the identification, repair, or removal from service of super-emitting vehicles and that can supplement conventional control strategies such as inspection and maintenance programs. In this manner, policies that directly address external costs can be formulated with the assistance of IVHS.

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ENERGY CONSUMPTION IMPLICATIONS OF TELECOMMUTING ADOPTION

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Abstract

Telecommuting, advocated as a promising transportation management strategy, is intended to substitute a portion of physical commuting trips during peak hours by information flow, thereby reducing energy consumption and air pollution. This paper discusses the potential for energy savings from telecommuting and its implications for the transportation planning process.

Although several pilot telecommuting projects have demonstrated a reduction in commuting trips, a network-wide assessment has not been reported in the literature, partly due to the lack of mathematical models to predict telecommuting adoption. This paper applies recent telecommuting adoption models to predict adoption. The commuting trips substituted by telecommuting are then taken into account in the network-wide estimate of potential reduction in travel and energy consumption. Results suggest that about 14.5% of total workers in Austin will work from home about twice per week under a “salary neutral” program scenario; this is equivalent to 5.8% workers telecommuting every day and will save about 2.5% (18,400 gallons) of total fuel consumed by vehicles. The predicted values of telecommuting adoption in Dallas and Houston are 5.9% and 5.0% (on a everyday equivalent basis), and fuel savings are 2.6% (126,700 gallons) and 2.1% (94,400 gallons), respectively.

The estimation results also have implications for telecommuting program design. For example, the results confirmed that both employee participation and employer support are influenced by the economic implications of the program design. While employees are not willing to sacrifice salary to work from home, employers are not inclined to favor a program that decreases the telecommuter’s salary, either, implying that a salary-neutral telecommuting program design may be acceptable to both employees and employers. In addition, both models reveal that the effect of changes in salary is stronger than responsibility for bearing additional telecommuting costs.

ENERGY CONSUMPTION IMPLICATIONS OF TELECOMMUTING ADOPTION

1. INTRODUCTION

Advances in information technology during the past decade have two primary types of implications for transportation planning strategies, with potentially significant impacts on environmental concerns such as energy consumption and air pollution. The first is intended to improve transportation system performance through the use of information technology, such as advanced traveler information system (ATIS) functions under the IVHS umbrella, where drivers are provided real-time network information to improve network utilization. The second, focusing on transportation demand management, is telecommuting, which is intended to substitute part of physical commuting trips during peak hours by information flow and therefore reduce energy consumption and air pollution. This paper discusses the potential energy savings resulting from telecommuting and its implications for the transportation planning process.

Although several pilot telecommuting projects on the west coast have demonstrated a reduction in commuting trips during peak hours, few attempts have been reported on estimation of aggregate impacts at the network level. For example, energy savings have been estimated primarily as the product of individual trip savings (due to telecommuting) and the average fuel consumption per trip. A network-wide assessment has not been addressed in the literature, partly due to the lack of mathematical models to predict telecommuting adoption. This paper applies the results of telecommuting adoption models developed by the authors to predict adoption. Commuting trips substituted by telecommuting are then incorporated in a network-wide estimate of potential reduction in travel and energy consumption.

The interactions between telecommuting and its environment are discussed in the following section. Models of the telecommuting adoption process by employees and employers, respectively, are then presented along with their implications for telecommuting program design. The estimated models are used to predict the extent to which telecommuting will be adopted, a key determinant of the impacts of telecommuting on energy consumption and air pollution. The prediction then forms the input to a model to estimate network-wide travel and energy savings due to telecommuting. Additionally, telecommuting implications for the transportation planning process are discussed.

2. TELECOMMUTING AND ITS ENVIRONMENT

The interactions between telecommuting and its environment are illustrated in Figure 1, which indicates that telecommuting adoption, a joint outcome of employee and employer decisions, is influenced by four external factors: telecommunications technologies, transportation systems performance, public policies, and land use patterns. The consequences of telecommuting adoption typically include three different levels of impacts. Short-term impacts refer to changes in travel behavior and activity patterns of telecommuters. Medium-term impacts include household activity allocation and car ownership. Long-term impacts involve possible relocation of telecommuting households and offices of organizations .

Telecommuting is one of a range of telecommunications applications (e. g. teleconferencing and teleshopping) that have potential impacts on transportation and the environment. The availability of telecommuting is influenced by the penetration of telecommunications related facilities in the community of interest. In addition, increasing concerns over urban traffic congestion and air quality have heightened interest in telecommuting as a promising transportation demand management strategy. Other external factors, such as land use patterns and public policy also have a bearing on telecommuting adoption, primarily on employer decisions. Pacific Bell's first telecommuting program, for example, was initiated when the local government asked businesses to reduce traffic during the 1984 Summer Olympics in the Los Angeles area (Bailey and Foley, 1990). On the other hand, the Interactive System Corporation, a computer software company in Santa Monica, California, adopted telecommuting because it could not afford to lease an office (SCAG, 1985).

The impacts of telecommuting derive primarily from the changes in travel behavior (e.g. frequency, departure time, trip chaining) and activity patterns of the telecommuter. Some pilot projects indicate that such changes may also be experienced by household members of the telecommuting adopter (Kitamura *et al.*, 1990), as telecommuting households reallocate activities among members in order to adapt to the new work and travel pattern of the telecommuter. For example, a former commuter who usually drops a child off at school on the way to the office and purchases groceries on the way back home would no longer do so during telecommuting days, unless he/she makes morning and evening trips specifically for these purposes. These duties may be transferred to other household members who still drive to work, or the pattern of some activities (e.g. shopping), namely frequency, time of day, or day of week may change. The reallocation of household activities may interact with the relative priority of car use among household members and perhaps lead to a reduction of household car holdings.

The changes described above may also cause eventual reconsideration of household residential location, as well as organizational office location. A household might move closer to the workplace location of a non-telecommuting household member. Insufficient evidence is available to confirm the impact of telecommuting on household residential location. During a two-year telecommuting pilot project in California, about 50% of the respondents who either relocated or were considering it reported that telecommuting influenced their residential location decisions. However, a formal statistical test did not reject the hypothesis that household shift patterns are not significantly different between telecommuters and non-telecommuters (Nilles, 1991).

It is mainly the short-term and medium-term impacts (i. e. changes in travel patterns and activities at individual and household levels) that affect transportation system performance. To the extent that work trips have been recognized as the major determinants of energy consumption by vehicles, the change in commuting travel behavior has a bearing on energy savings as well. Thus, the aim of this paper is to investigate network-wide energy savings due to the substitution of work trips by telecommuting.

3. TELECOMMUTING ADOPTION MODELS AND POLICY IMPLICATIONS

Tables 1 and 2 show the parameter estimation results of two models of telecommuting adoption by employees and employers, respectively. These models are based on an ordered-response formulation derived by the authors and estimated using employee and executive stated-preference data, respectively, obtained from three Texas cities (Austin, Dallas, and Houston) (Mahmassani *et al.,* 1993; Yen *et al.* 1994a, 1994b, and 1994c). The ordered-response model maps the range of a continuous latent variable onto a set of discrete outcomes. For a given decision situation, the latent variable represents the decision maker's perceived utility or attractiveness toward the decision object of interest (telecommuting in this research). A set of ordered thresholds for the latent variable associated with each decision maker define ranges corresponding to each discrete decision outcome. The decision-maker's choice then depends on the corresponding interval within which the perceived utility or attractiveness lies. In the present models, choice alternatives are ordered from lower preference for employee participating in and employer support for telecommuting to higher preference. It follows that for a given set of utility thresholds the greater value of the perceived attractiveness of telecommuting (the latent variable), the more likely are employees (or employers) to adopt telecommuting. On the other hand, for a given latent variable, the higher the thresholds are, the less likely are employees or employers to adopt telecommuting.

Readers interested in model development and specification are referred to other papers by the authors (Yen *et al.,* 1994b and 1994c). This section interprets the estimation results and their policy implications. Please note that only estimated coefficients of variables specified in the systematic components are indicated in the Tables; estimates of the variance-covariance structure aimed at capturing autocorrelation among observations are not shown.

With respect to the employee model, Table 1 shows that salary increase (SI5) has a positive effect on the latent variable, and thus will increase the probability that employees choose telecommuting, for a given set of utility thresholds. On the other hand, the coefficients of salary decrease (SD5 and SD10) imply that employees are less likely to choose telecommuting if they have to sacrifice part of their salary. Similarly, responsibility for additional costs to work from home (ANL, BPC, and PART) negatively affects employee preferences, with all estimated coefficients being negative.

The relative magnitudes of estimated coefficients reveal useful information on employee preferences from the standpoint of program design and public policies. For instance, coefficients of SD5 (-1.311) and S15 (0.293) indicate that salary decrease exerts a stronger effect on employee preferences than a comparable increase. Additionally, the coefficients of both dummy variables for 10% salary decrease (-1.909) and 5% decrease (-1.311) confirm that the former has a stronger effect but suggest a non-proportional relationship between the amount of salary decrease and its influence on the latent variable, with a decreasing marginal effect of further salary decrease. Significant differences among the coefficients of variables ANL, BPC, and PART (-0.643, -0.901, and -0.807, respectively) indicate that requiring telecommuters to buy a personal computer (BPC) is a stronger deterrent to telecommuting than other additional cost items. The coefficients of SD5 and SD10 are statistically less than those of ANL, BPC, and PART, indicating that salary sacrifice has a stronger negative effect than having to acquire additional equipment. This finding has important implications on telecommuting program design for organizations willing to provide such work arrangement.

Other variables that exert positive effects on employee telecommuting adoption include number of children under age 16 (CHIL16) or personal computers at home (HOMEPC), employee computer proficiency (SKILL), number of hours in which employees use a computer on work each day (HRCOMP), distance from home to the workplace (DSTRIP), as well as employee attitudes toward job suitability for telecommuting (FJOBSU) and effect of telecommuting on family. Variables that have negative effects include amount of time employees need to communicate face-to-face with co-workers (HRFACE), average number of stops (STOPS) on commuting trips (a proxy of employee activity pattern) and employee attitude toward the importance of social interactions with co-workers (FSOCIO).

Table 2 shows the estimation results of the employer adoption model parameters, based on stated preference information supplied by executives and managers. As expected, employer responsibility for some (ES) or all (ET) additional telecommuting costs has a negative effect on executive preferences. Similarly, the negative coefficient of variable SI5 indicates that an increase in the telecommuter salary reduces the probability that executives will support such a program, all else being equal. Interestingly, a decrease in telecommuter salary (SD5) also exerts a negative influence on executives' willingness to support telecommuting, indicating that a program that reduces telecommuters' salary will not necessarily increase the likelihood of executive support. This result might *be* contrary to the *a priori* speculation that executives would support any program that could cut the organization's costs. Executives undoubtedly believe that it would be unfair to penalize a telecommuter if he/she could have the same job performance, and that reducing telecommuter salary would not be viewed favorably by employees, and would therefore lead to a poor public image of the organization.

The relative values of the coefficient estimates of SI5 (-1.031) and SD5 (-0.676) indicate that an employee salary increase exerts a stronger negative effect on executive support than a decrease. Though executives may not wish to decrease the telecommuter salary, they find it less tolerable to increase telecommuting employee salary. As expected, the significant difference between the coefficients of ES (-0.414) and ET (-0.572) indicates that the executive is less inclined to support a program when the organization incurs all rather than only part of the additional costs. The results also imply that an increase in telecommuter salary is less tolerated by executives than having to assume some or all telecommuting costs.

Other variables that affect executive telecommuting adoption include educational achievement (EA), job title (IT), management span (SOM), awareness of telecommuting (AW), as well as attitudes toward the effect of a telecommuting program on data security, the performance and morale of telecommuting workers, and management concerns such as executive work load and ability to supervise telecommuters.

The models presented in this section provide a methodology for predicting telecommuting adoption, which in turn forms the basis for predicting trip reduction and fuel savings potential of telecommuting, as described next.

4. IMPACTS OF TELECOMMUTING ON ENERGY SAVINGS

Four methods have been used previously to estimate fuel savings from telecommuting. The first calculates fuel savings as the product of the average fuel efficiency and average number of miles saved from each telecommuting occasion. The second takes into account differences among individual vehicles and aggregates individual savings, obtained from self-reported fuel efficiency and reduced travel distance due to telecommuting. The third method goes a step further to consider trip characteristics that influence fuel efficiency, including travel speed and whether it is a cold or hot start (Handy *et al.,* 1993). None of the three methods considers network effects in the estimation of energy savings.

The fourth method, developed by Sullivan et al. (1993) and used in this paper, relies on the "two-fluid model" of traffic in an urban network (Herman and Prigogine, 1979), which provides a macroscopic network-level description of traffic interactions in a network. It is used in this analysis to translate the fractions of vehicular trips substituted by telecommuting into total savings in vehicle-miles traveled (VMT) in a network. Fuel savings are then calculated based on a calibrated fuel consumption model. The two-fluid model takes into account network attributes such as average speed, concentration, and directional factors. The procedure also recognizes the possible increase in speed experienced by non-telecommuters that continue to commute.

To assess fuel savings due to telecommuting, it is essential to predict the extent to which telecommuting will be adopted. Recognizing that telecommuting adoption is the joint outcome of employee and employer decisions, both models presented in the preceding section are used. Since the probability of employee participation is conditional on the provision of such a program by employers, the probability of joint adoption is the product of the conditional probability of employee participation and the marginal probability of employer support. Because employees apparently do not want to sacrifice salary in order to telecommute, and employers are generally disinclined to increase telecommuters' salary, the reasonable program scenario for the prediction of possible telecommuting adoption is the one under which telecommuters' salary remains the same. Detailed procedures for aggregate telecommuting prediction are given elsewhere by the authors (Yen *et al.,* 1994d). Table 3 lists the separate and joint predictions for employees and employers in three Texas cities under the program scenario with neutral telecommuter salary and employers incurring all additional telecommuting costs (such as a new phone line).

For employee participation, results in Table 3 are intended to represent possible adoption by the target group of potential telecommuters, namely information related workers. To facilitate aggregate prediction, the population of information workers is stratified into two groups of employees: those having computer proficiency at the medium or high level as group 1, and others as group 2. The composition of groups 1 and 2 are obtained from the telecommuting survey sample (83% vs. 17%, 87% vs. 13%, and 83% vs. 17% for Austin, Dallas, and Houston, respectively). The values of exogenous variables specified in the estimated adoption models used in the prediction are obtained through the following rationale. First, it is assumed that the distributions of variables such as commuting attributes and the number of children under 16 among members of the target group is the same as the whole population. Therefore, the former are based on surveys with random observations in Texas (Jou *et al.,* 1992), and the latter is based on the U. S. census data (1990). Finally, other job attributes for the target group are based on information from the telecommuting survey conducted to calibrate the adoption models.

Predicting employer adoption is fraught with even greater uncertainty, especially with regard to the characteristics of the population of pertinent decision-makers in information-related organizations. Recognizing this uncertainty, employer adoption is predicted under three alternative scenarios: optimistic, middle, and conservative, as illustrated in Table 3, reflecting different composition of the underlying executive population. For aggregate prediction, the population of “representative” decision makers is conveniently stratified into two groups. Members in group 1 do not hold titles of president or vice president, have a management span of less than 6, and possess awareness of telecommuting. Members in the second group hold president or vice president titles, with management spans of at least 6 subordinates, and are not aware of telecommuting. The optimistic scenario assumes that the population of representative decision makers for employer adoption consists of 80% in group 1, and 20% in group 2. The population compositions for the middle and conservative prediction scenarios are 50% vs. 50% and 20% vs. 80%, respectively. Employee adoption (conditional on employer sponsorship) is assumed to be the same across the three prediction scenarios for each city. For each scenario, while employee adoption is predicted by city to reflect differences in transportation system performance and demographic data in the three cities (Table 4), employer adoption levels are assumed to be the same in the three cities. Under the optimistic scenario, about 42% of information workers in Austin will choose to work from home about twice per week, with 42% and 36% for Dallas and Houston, respectively. These probabilities decrease to 29%, 29%, and 25% for the middle scenario, and l6%, 17%, and 14% for the conservative scenario, respectively.

To predict fuel savings due to telecommuting, the middle scenario prediction is used as the base case. According to Woods and Poole (1990), 50% of total workers are information related in these cities. Assuming that telecommuting occasions are uniformly distributed across five work days per week, the predicted percentage of total workers who work from home every day is equivalent to 5.8% in Austin, 5.9% in Dallas and 5.0% in Houston, respectively, as listed in Table 5. These equivalent percentages of telecommuters are then applied to predict network-wide fuel savings due to telecommuting using the method proposed by Sullivan et al. (1993). Table 5 shows that predicted adoption of telecommuting will save about 18.4 thousand gallons of gas in Austin per day, 126.7 thousand gallons in Dallas, and 94.4 thousand gallons in Houston. These savings are equivalent to 2.53%, 2.62%, and 2.08% of the total fuel consumed by vehicles every day in each city, respectively. Table 5 also indicates that vehicle fuel savings during peak hours (7-9 A.M. and 4-6 P.M.) on arterial are 3.6 thousand gallons in Austin per day, 23.3 thousand gallons in Dallas, and 22.0 gallons in Houston, which are equivalent to 5.73%, 6.17%, and 5.05% of total fuel consumed by vehicles everyday in the peak on arterial in each city, respectively. As expected, results reveal that fuel savings in terms of percentage in peak are higher than on the daily basis.

To reflect the variation of fuel savings according to different levels of employer adoption, which is believed to play a relatively more important role than employee adoption to date, fuel savings are also predicted under the conservative and optimistic prediction scenarios. In Austin, the conservative prediction indicates an equivalent 3.3% telecommuting penetration every day, resulting in 1.44% savings of daily fuel, or 3.26% fuel savings in peak hours. These numbers increase to 8.3%, 3.62%, and 8.19% under the optimistic scenario, respectively. Overall, the equivalent telecommuting penetration under the conservative scenario is about 3.0% in the three cities, 5.5% under the middle scenario, and 8.0% in the optimistic case. In terms of fuel consumed, daily savings range from about 1.5%, 2.5%, to 3.5% under three different prediction scenarios. Peak savings are about 3.0%, 5.5%, to 8.0%. The results show that fuel savings highly depend on the level of employer telecommuting adoption, and suggest that executives may need to be targeted by public policy makers to promote telecommuting acceptance and penetration.

5. SOME TELECOMMUTING IMPLICATIONS FOR TRANSPORTATTON PLANNING

The implications of telecommuting on the transportation planning process can be illustrated in Figure 2. Conceptually, the aggregate travel demand on transportation systems derived from each individual's activities motivates capacity addition to the transportation infrastructure and/or policy measures to manage the resulting congestion. These changes in the transportation system influence the land use pattern in the community, which in turn affects individuals' activities. Empirically, in order to predict travel demand and the associated performance of the transportation system, traditional transportation planning procedures use different types of land use models to predict future economic activities in-the area of interest. The results of land use models and demographic data then provide the input to the four-stage transportation planning process intended to project the performance of the transportation system for the particular land use pattern under consideration (Manheim, 1979; Paquette *et al.*, 1982; Meyer and Miller, 1984).

Although a plethora of critiques of the traditional four-stage procedure can be found in the literature, it remains well entrenched in transportation planning practice. Recent policy concerns such as air quality, congestion management and advanced technologies have led to renewed interest in alternative transportation planning methodologies. In practice, activity-based approaches to travel demand analysis appear particularly attractive. Their basic premise is that activity and trip patterns rather than individual trips should be at the center of demand analysis procedures Activity-based approaches are particularly appropriate to analyze the transportation impacts of telecommunications technology applications. The latter can directly and indirectly influence activity patterns as they have the potential to transform the movement of people and goods on transportation networks by information transmission.

The development of telecommunications technologies may affect land use patterns and hence the economic and social activity system. For example, Kutay (1986) argued the importance of communication networks as a determinant of office location, paralleling the role of transportation systems in regional economic development (Adler, 1987). To the extent that telecommunications networks might be a substitute for transportation systems in the future, they may be expected to play a role in the growth of economic activities and spatial distribution of industry. Thus businesses today with high information-related activities may be located where easy access to telecommunications networks is available (Salomon, 1988).

The impacts of telecommuting on transportation system performance are due to the substitution of commuting trips by information flow. The reduction of travel ultimately mitigates traffic congestion and air pollution. It has long been recognized that transportation infrastructure improvements tend to generate additional demand for travel that is attracted by better service levels (Adler, 1987). Therefore, it may not be unreasonable to expect at least part of the potential savings from telecommunications applications to be offset by induced demand. Additionally, the impacts of telecommuting on activity patterns at the individual and household levels have been discussed in section 2. As a result, the implications of telecommuting on transportation planning have to be recognized through its impacts on land use, activity, and transportation systems. Finally, policies and regulations enacted by the public sector may target telecommunications technologies, the transportation system, or the land use pattern. Intervention by governments is primarily on the supply side of these factors, and may include control of pricing and level of service. Such supply side actions will affect demand side as well.

6. CONCLUSION

This paper predicts potential savings in fuel consumption resulting from telecommuting in three cities in Texas. The prediction procedure relies on the “two-fluid model” of traffic in urban networks, and calculates fuel savings based on a calibrated fuel consumption model. Results indicate that for the middle prediction scenario about 14.5% of total workers in Austin will work from home about twice per week under the salary neutral program, which is equivalent to 5.8% workers telecommuting every day, and will save about 2.5% (18,400 gallons) of total fuel consumed by vehicles per day. The predicted portions of telecommuting adoption in Dallas and Houston are 5.9% and 5.0% (on a everyday equivalence), respectively. Fuel savings are 2.6% (126,700 gallons) and 2.1% (94,400 gallons), respectively. However, alternative prediction scenarios reflect considerable uncertainty regarding the levels of employer adoption and support of telecommuting, suggesting that executives form a critical target group for public policy action aimed at encouraging telecommuting.

The above prediction is based on two models of telecommuting adoption by employees and employers, respectively, and a set of assumptions to derive reasonable values for the explanatory variables from exogenous data source. The estimation results also have policy implications in terms of telecommutinp program design. For example, estimation results found that both employee participation and employer support are influenced by economic implications of the program design. Specifically, both changes in employee salary and the costs incurred by telecommuters (or employers) significantly influence these two decision makers’ adoption decisions. While employees are not willing to sacrifice salary to work from home, employers are not inclined to institute programs that decrease the telecommuter’s salary, either. In addition, both models reveal that the effect of changes in salary is stronger than the responsibility for assuming additional telecommuting costs. The results imply that a salary-neutral telecommuting program design may be acceptable to both employees and employers.

While the fuel consumption savings potentially achievable through telecommuting are meaningful, they are not likely to be the primary motivation for greater telecommuting adoption and support through public policy. Ultimately, it is the benefits that both employees and employers might derive in terms of enhanced lifestyle options and eventually greater productivity that will determine the degree of penetration. Employees benefit from the decrease in the time and cost spent commuting, and the resulting increase in discretionary time and scheduling flexibility. Employers benefit by reducing overhead cost of offices and employee turnover. It is only incidental that society also benefits through reduced congestion and fuel consumption savings.

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Table 1 Estimation Results of Employee Telecommuting Choice Model

Variables		Parameter estimates*	
Specified in the latent variable			
Constant		-0.190	
(Economic implications)			
SI5:	Change in telecommuter salary (1 if increase 5 %; 0 otherwise)	0.293	(30.0)
SD5:	Change in telecommuter salary (1 if decrease 5 %; 0 otherwise)	-1.311	(-4.9)
SD10:	Change in telecommuter salary (1 if decrease 10 %; 0 otherwise)	- 1.909	(-9.8)
ANL:	Additional phone costs assumed by employee (1 if need to add a new phone line at home; 0 otherwise)	-0.643	(-31.0)
BPC:	Additional computer costs assumed by employee (1 if need to buy a personal computer; 0 otherwise)	**-0.901**	**(-7.3)**
PART:	Additional partial costs assumed by employee (1 if need to pay part of the costs; 0 otherwise)	-0.807	(-8.9)
(Employee personal and household characteristics)			
CHIL16:	Number of children under age 16 at home	0.142	(3.2)
HOMEPC:	Number of personal computers at home	0.202	(9.6)
SKILL:	Index of computer proficiency (1 if at least one skill at medium or high level; 0 otherwise)	0.272	(16.0)
(Employee job characteristics)			
HRFACE:	Number of hours communicating with co-workers face-to-face per day	-0.344	(- 18.0)
HRCOMP:	Number of hours using a computer on work per day	0.175	(17.0)
(Employee commuting attributes)			
DSTRIP:	Distances from home to the workplace, miles	0.028	(15.0)
STOPS:	Average number of stops on the way to work and back home per week	-0.124	(-14.0)
Specified in the utility thresholds			
Utility threshold 2			
Constant		2.270	
FJOBSU:	Regression score of employee attitudes toward job suitability for telecommuting	-0.436	(-33.0)
FFAMIL:	Regression score of employee attitudes toward telecommuting effect on family	-0.577	(-31.0)
FSOCIO:	Regression score of employee attitudes toward the importance of social interactions with co-workers	0.568	(14.0)
Utility threshold 3			
Constant		2.864	
FJOBSU:		-0.3 18	(-3.4)
FFAMIL:		-0.126	(-2.0)
FSOCIO:		0.820	(8.4)

Number of observations	545
Log likelihood value at zero	-5228.7
Log likelihood value at convergence	-3909.0

* Numbers in parentheses are t-values

Table 2 Estimation Results of Employer Telecommuting Choice Model

Variables		Parameter estimates*	
Specified in the latent variable			
Constant		0.229	
(Economic implications)			
SI5:	Change in telecommuter salary (1 if increase 5 %; 0 otherwise)	-1.031	(-3.5)
SD5:	Change in telecommuter salary (1 if decrease 5 %; 0 otherwise)	-0.676	(37.0)
ES:	Employer responsibility for partial additional telecommuting costs (1 if some costs; 0 otherwise)	-0.414	(-32.0)
ET:	Employer responsibility for all additional telecommuting costs (1 if total costs; 0 otherwise)	-0.572	(-22.0)
(Executive personal characteristics)			
EA:	Executive's educational achievement (1 if a master or Ph.D. degree; 0 otherwise)	0.493	(12.0)
AW:	Awareness of telecommuting (1 if the executive knows someone who telecommutes; 0 otherwise)	0.537	(19.0)
(Executive job characteristics)			
JT:	Executive's job title (1 if president or vice president; 0 otherwise)	-0.772	(-38.0)
SOM:	Number of subordinates directly supervised by the executive (1 if <= 5; 0 otherwise)	0.45 1	(23.0)
Specified in the utility thresholds			
Utility threshold 2			
Constant		3.923	
FTELE:	Regression score of executive attitudes toward telecommuting effect on telecommuters and public image of the organization	-0.488	(-60.0)
FMANG:	Regression score of executive attitudes toward the management impacts of telecommuting	-0.118	(-22.0)
Number of observations		80	
Log likelihood value at zero		-791 0	
Log likelihood value at convergence		-407: 1	

* Numbers in parentheses are t-values

Table 3 Predicted Probabilihes of Telecommuting Adoption for Information-Related Workers

Cities	**Predicted Choice Probabilities**		
	Employee	Employer	Joint
Optimistic Scenario			
Austin	.650	.641	.417
Dallas	.657	.641	.421
Houston	.556	-641	.356
Middle Scenario			
Austin	.650	.446	.290
Dallas	.657	.446	.293
Houston	.556	.446	.248
Conservative Scenario			
Austin	.650	.251	.163
Dallas	.657	.251	.165
Houston	.556	.251	

Table 4 Mean Values of Explanatory Variables Used for Telecommuting Prediction

Variables		**Austin**	**Dallas**	Houston
Specified in the latent variable				
(Employee personal and household characteristics)				
CHIL16:	Number of children under age 16 at home	0.64	0.71	0.82
HOMEPC:	Number of personal computers at home	0.56	0.53	0.48
(Employee job characteristics)				
HRFACE:	Number of hours communicating with co-workers face-to-face per day	1.56	1.44	2.17
HRCOMP:	Number of hours using a computer on work per day	4.48	3.90	3.91
(Employee commuting attributes)				
DSTRIP:	Distance from home to the workplace, miles	10.80	13.00	13.90
STOPS:	Average number of stops on the way to work and back home per week	4.25	4.10	4.92
Specified in the utility threshold				
FJOBSU:	Regression score of the employee's attitudes toward the job suitability for telecommuting	3.98	3.90	4.29
FFAMIL:	Regression score of the employee's attitudes toward the effect of telecommuting on family	2.65	2.38	2.67
FSOCIO:	Regression score of the employee's attitudes toward the importance of social interactions with co-workers	3.42	3.33	3.38

Table 5 Fuel Consumption Savings from Telecommuting Under Realistic Network Data (Conservative Scenario)

	Austin			Dallas			Houston		
	C	**M**	**0**	**C**	**M**	**0**	**C**	**M**	**0**
portion of total workers working from home twice per week (%)	8.2	14.5	20.9	8.3	14.7	21.1	7.0	12.4	17.8
equivalent portion of total workers working from home everyday (%)	3.3	5.8	8.3	3.3	5.9	8.4	2.8	5.0	7.1
fuel savings, thousand gallons per day	10.5	18.4	26.3	71.1	126.7	180.4	52.7	94.4	132.2
fuel savings, percentage (%)	1.44	2.53	3.62	1.47	2.62	3.73	1.16	2.08	2.91
fuel savings, gallons, peak on arterial	2.1	3.6	5.2	13.0	23.3	33.1	12.3	22.0	31.2
fuel savings, percentage (%), peak on arterial	3.26	5.73	8.19	3.45	6.17	8.78	2.83	5.05	7.17

Prediction scenarios: C, conservative
M, middle
0, optimistic

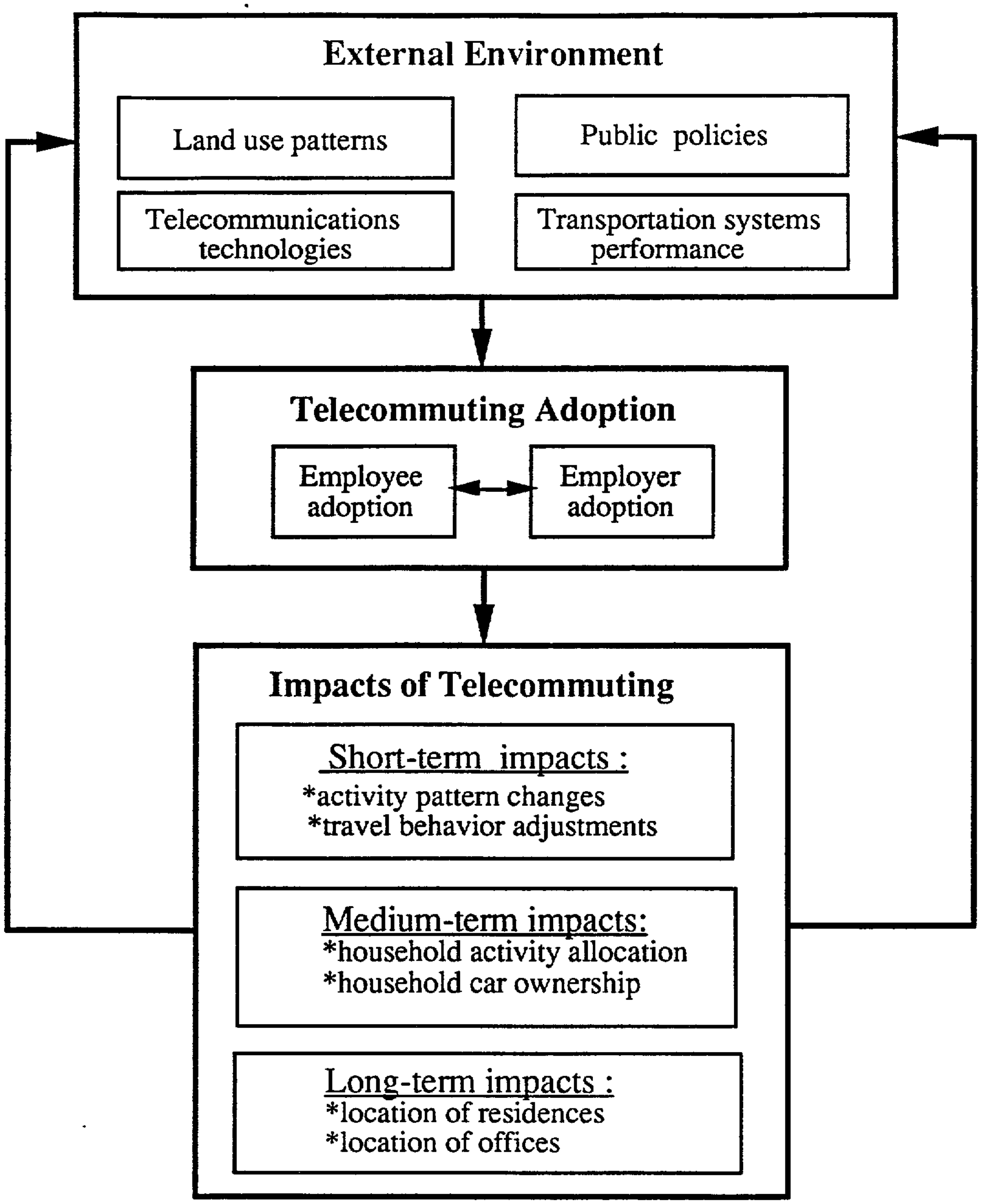

Figure 1 Interaction between Telecommuting Adoption Process and External Environment

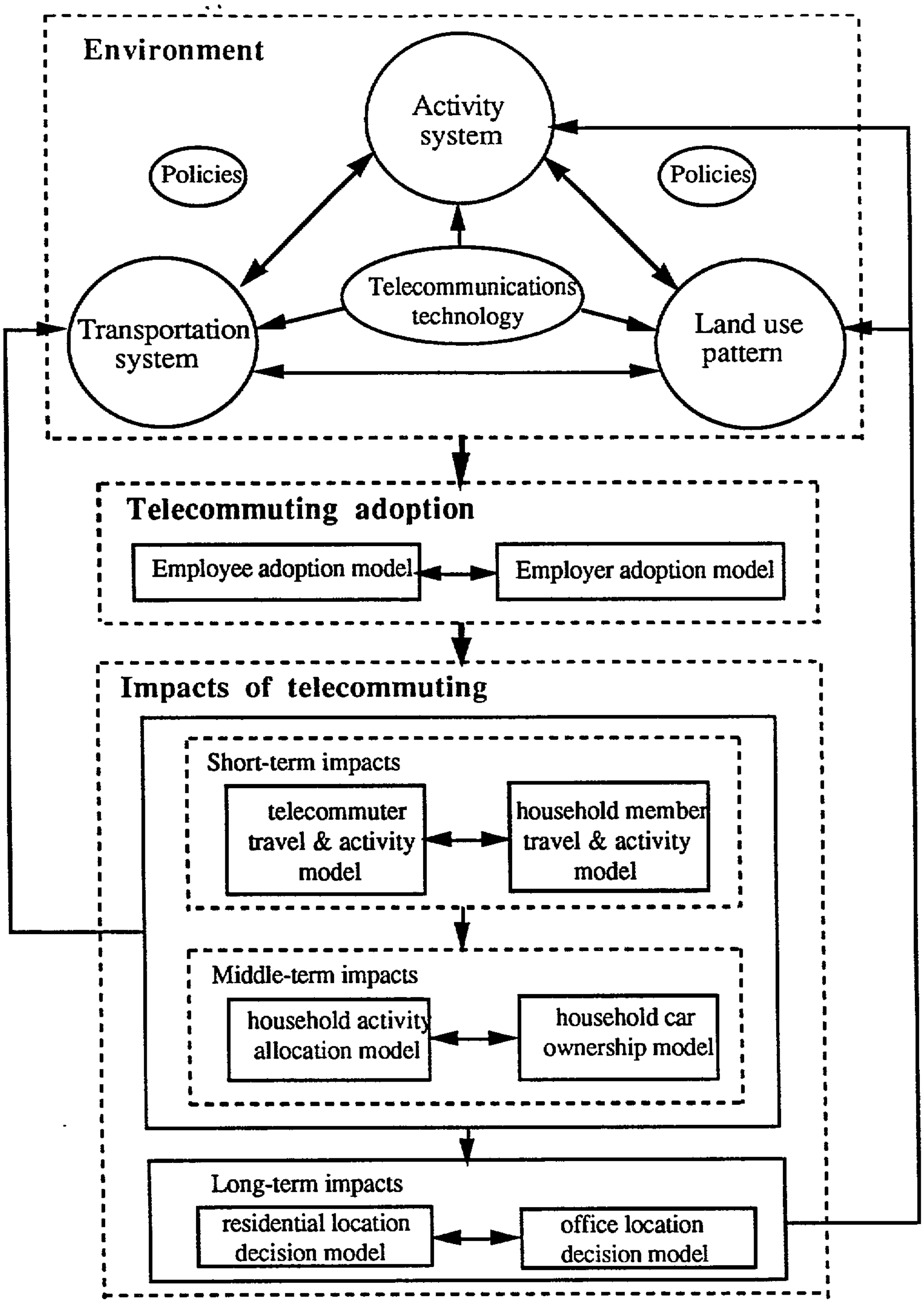

Figure 2 Implications of Telecommuting on Transportation Planning

CARBON MONOXIDE IMPACTS OF AUTOMATIC VEHICLE IDENTIFICATION APPLIED TO VEHICLE TOLLING OPERATIONS

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INTRODUCTION

Intelligent transportation technologies (ITT's) are being promoted as a means of reducing congestion delay, improving transportation safety, and also as a means of making vehicle travel "...more energy efficient and environmentally benign (USDOT, 1990)." In theory, IVHS technologies will increase the efficiency and capacity of the existing highway and roadway systems to reduce congestion (Saxton and Bridges, 199 1; Conroy, 1990; Shladover, 1991; Shladover, 1989). We are not confident, however, that vehicular emissions will be reduced by the Ml range of proposed ITT's.

The transportation-air quality community has in the past lacked the appropriate tools in which to predict the effects of microscopic changes to vehicular activity induced by ITT's. The currently used emissions models. EMFAC in California, and MOBILE in the remainder of the US, are unable to provide the resolution needed to quantify the effects of these changes. Research at UC Davis is focusing on estimation of a statistical 'modal' model capable of simulating the emissions impacts from individual vehicles under various operating scenarios. The emissions model, currently a significantly modified version of the mathematical algorithms employed in the CALINE 4 Line Source Dispersion Model developed by Paul Benson and others at Caltrans (Benson, 1989), predicts emissions based upon individual vehicle speed-time profiles and laboratory measured emission rates. The model, therefore, can quantify vehicular emissions under various ITT scenarios.

This paper examines the carbon monoxide (CO) emission impacts of one such applied ITT, namely Automatic Vehicle Identification (AVI) used to implement automatic tolling. AVI used in lei of conventional toll booths has previously been identified as an ITT that is likely to offer air quality benefits (Washington, Guensler, & Sperling, 1993a). By allowing vehicles to be tolled either through a windshield displayed debit card, or by some other mechanism, vehicles could forgo the deceleration, stop-delay, and ensuing acceleration that results from an encounter with a conventional tolling station. The results presented here are preliminary, and represent the beginning stages of an ongoing research effort. More substantial and complete results will be provided as they become available.

BACKGROUND

The six basic ITT "technology bundles" (Jack Faucett Associates, 1993) include Advanced Traffic Management Systems (ATMS), Advanced Traveler Information Systems (ATIS). Advanced Vehicle Control Systems (AVCS), Commercial Vehicle Operations (CVO), and Advanced Public and Transportation Systems (APTS). Each of these technology bundles is designed to achieve the same general goal; improve the efficiency of the transportation system through the application of communications and computational technologies. However. the efficiency objectives targeted by each technology bundle are distinctly different, and will have different potential effects upon the parameters that effect vehicle emissions (Washington, Guensler, Sperling, 1993a).

Previous research has concluded that one of the most likely technology bundles to improve air quality is Advanced Traffic Management Systems (Washington, Guensler, Sperling, 1993b). As the name implies, ATMS employ computer control technologies to 'optimize' or smooth traffic flows on a transportation network. Examples of ATMS technologies are real-time traffic signal network optimization, real-time ramp metering, and automatic vehicle tolling via automatic vehicle identification technologies (AVI). These computer controlled systems are designed to reduce congestion levels; minimize system-wide delay levels, and generally smooth vehicular flows. ATMS technology bundles also include various signal actuation bundles, incident detection, rapid accident response, and integrated traffic management.

Automatic toll collection, the topic of this paper, aims to smooth traffic flows by implementing advanced communications technologies between roadway and vehicles. If conventional tolling operations performed on bridges or tolled turnpikes were replaced with automatic and transparent vehicle identification and debiting, for example, then toll plaza delays experienced by motorists could be eliminated. The elimination of these activities would further result in fewer declarations, idling, and acceleration events prevalent under conventional tolling operations. These 'modal' activities. representing high load and power conditions, have been shown to contribute significantly to the production of emissions from motor vehicles (LeBlanc, et al., 1994; CARB, 1991; Benson, 1989; Groblicki, 1990; Calspan Corp., 1973a, Calspan Corp., 1973b; Kunselman, et al., 1974). In fact one sharp acceleration may cause as much pollution as does the entire remaining trip (Carlock 1992). This suggests that a small percentage of a vehicle's activity may account for a large share of it's emissions (LeBlanc, et. al., 1994). In addition, longer enrichment events are more highly correlated with large emission excursions than are shorter events (LeBlanc, et. al., 1994) and furthermore, deceleration events are capable of producing significant emissions (Darlington, et al., 1992). In contrast to cold start emissions that occur over a period of minutes, acceleration and deceleration related emissions occur over a period of a few seconds.

Using a preliminary 'modal' model that accounts for relative contributions of CO emissions from acceleration, deceleration, cruise, and idle events, we assess the impacts of automatic tolling using AVI. The goal is to quantify the expected CO emission differences between a toll-plaza and AVI scenario. In addition, the expected variation in these benefits is approximated given current limitations of the vehicle emissions data. The results provided represent preliminary research findings, and will be supplemented with further findings when they become available.

DESCRIPTION OF THE MODAL MODEL

The preliminary 'modal' model employed in these analyses is a derivative of the CALINE Line Source Dispersion Model that has been developed over many years by the California Department of Transportation (Benson, 1989). The model is different from the CALINE model in several very important respects. First, individual vehicle 'FTP BAG 2' (Washington, Guensler, and Sperling 1994) emission rates are used in the model, rather than an 'approximated' average values applied to the vehicle fleet. Second individual idle emission rates are used in the model, rather than 'approximated' average values applied to the vehicle fleet. Finally, the dispersion' portion of the CALINE model is not employed, but rather, only the algorithms used to determine the emissions inventory are used. These differences result in a statistical model tbat can explain approximately 70% of the variation in emissions for individual vehicles tested on 14 different emission testing cycles. This is in comparison to both the current EMFAC and CALINE models, while employing fleet average FTP Bag 2 and idle emission rate values, explain about 13% and 2% of the variation in emissions for individual vehicles respectively (Washington, Guensler, and Sperling, 1994).

The latest version of the CALINE4 model is similar to the Colorado Department of Highways (CDOH) model released in 1980. The data used to estimate model coefficients were derived from 37 discrete modes driven by 1020 light-duty vehicles ranging from 1957 model year to 1971 model year. In both the Caltrans and CDOH model development efforts, a strong relation was noted between modal emissions and the average acceleration speed product (AS) for the particular acceleration mode. Consequently, AS is one of the explanatory variables *used in the CALINE4* model (Benson, 1989).

The CALINE4 model is descriptive and not deterministic. This means that the model is estimated using observed emissions and vehicle behavior, rather than using more causal variables such as fuel volatility, cylinder size, mechanical efficiency losses, etc. The model employed in this research effort is identical to the functional form contained in CALINE model, except for the significant and important differences noted earlier (and described below).

The modified CALINE model can be written as:

$TE_{ik} = EI_{ik} + EA_{ik} + EC_{ik} + ED_{ik}$ *where;*

TE_{ik} = Total CO emission estimate for vehicle i on cycle k in grams,
EI_{ik} = CO emissions from idle events for vehicle i on cycle k in grams,
EA_{ik} = CO emissions from acceleration events for vehicle i on cycle k in grams,
EC_{ik} = CO emissions from cruise events for vehicle i on cycle k in grams,
ED_{ik} = CO emissions from deceleration events for vehicle i on cycle k in grams,

The emission contributions from modal events are defined as:

$EI_{ik} = (IR_{[grams/sec]}) * (t_{1[secs]})$, where;

IR is the measured individual vehicle idle emission rate,

t_i is time in the idle operating mode.

$$EA_{ik} = [FTPB2_{[grams/min]}) * (C1) * EXP\ (C2 * AS)] * t_{a\ [sec]} * 1_{[min]}/60_{[sec]},$$ where:

FTPB2 is measured emission rate on FTP Bag2 for individual vehicles,
Coefficients Cl = 0.75 and C2 = 0.0454 for acceleration condition 1,
Coefficients Cl = 0.027 and C2 = 0.098 for acceleration condition 2,
AS is the acceleration speed product based upon average speed and average acceleration rate of the accel mode,
Acceleration condition 1 is for vehicles starting at rest and accelerating up to 45 mph,
Acceleration condition 2 is for vehicles starting at 15 mph or greater and accelerating up to 60 mph,
ta is the time in the acceleration mode.

$$EC_{ik} = FTPB2_{[grams/min]})) * [(0.494 + 0.000227 * S_{[mph]})^{2})] * (t_{c\ [sec]} * 1_{[min]}/60_{[sec]},$$ where;

FTPB2 is measured emission rate on FTP Bag2 for individual vehicles,
t_c is the time in the cruise event. .

$$ED_{ik} = (IR_{[grams/sec]}) * (t_{d[secs]}),$$ where,

IR is the measured individual vehicle idle emission rate,
t_t is time in the deceleration operating mode.

The modified CALINE model is used in conjunction with summed emissions from steady-state modal events for a vehicle on any cycle. For example, a given speed-time trace is parsed into discrete model events of idle, cruise, acceleration, and deceleration. The emissions from these events are then summed over the cycle to obtain the total emission estimate.

EXPERIMENTAL DESIGN

To estimate the difference in CO emissions between a vehicle encountering a conventional toll plaza, and the ‘no delay’ experience by automatic vehicle identification tolling operations, the modified CALINE model is employed. To perform these comparisons, a toll plaza is first simulated on a typical transportation link. The link could be a typical tolled bridge entrance, or could be the entrance to a tolled freeway. The toll plaza design follows that described by Lin (1994), representing a Gate type ‘C’ operating at level of service A. Under these conditions, the average vehicle experiences about 6 seconds of delay waiting for previously queued vehicles (Lin, 1994). Since the emissions estimates from vehicles encountering toll plazas are done on a per-vehicle basis, and because level of service A is assumed in these initial analyses, the traffic volume is not important (congestion delay induced by toll plazas and high traffic volumes will be covered in subsequent analyses).

To simulate vehicular activity under the two different scenarios, speed-time profiles were developed four different vehicle trajectories. Table 1 displays some characteristics of these speed-time profiles. Two speed-time profiles were developed for vehicles entering a toll plaza, one for drivers exhibiting ‘aggressive’ driving behavior and one for drivers exhibiting normal’ driving behavior. All vehicles were assumed to begin and end their speed-time trajectory at a speed of 60 mph (other speeds will be covered in subsequent analyses). Aggressive driving

Table 1. Characteristics of Assumed Vehicle Speed-Time Profiles Under both Toll-Plaza and AVI Scenarios

Cycle Description	Maximum Acceleration Rate (mph/sec)	Length of Cycle (seconds)	Distance of Cycle (miles)	Deceleration Time in seconds (60mph to 0mph)	Acceleration Time in seconds (60mph to Omph)
Toll Plaza, 'Aggressive' Driving	4.5	37	0.249	14	15
Toll Plaza, "'Normal' Driving	2.0	66	0.517	30	30
AVI, 'Aggressive' Driving	1.0	15, 31	0.249, 0.517	n/a	n/a
AVI, 'Normal' Driving	0.5	15, 31	0.249, 0.517	n/a	n/a

includes acceleration and deceleration rates of about 4.5 mph/sec, while normal driving includes acceleration and deceleration rates of 2 mph/sec. These rates agree with current car following and instrumented vehicle research that has substantiated acceleration and deceleration rates as high as 6 mph/sec (Cicero-Fernandez, et. al., 1993).

Two more speed-time profiles were developed for the non-toll plaza scenario. Again one for drivers exhibiting 'aggressive' driving behavior and one for drivers exhibiting normal' driving behavior. In the former case, aggressive drivers 'floated around their 60 mph target speed by 3 mph with 1 mph/sec maximum acceleration and deceleration rates. 'Non-aggressive' drivers were assumed to 'float' around their 60 mph target speed by 1 mph with 0.5 mph/sec maximum acceleration and deceleration rates. Both of these cycles were 'length corrected' so cross*comparisons could be made between all categories of driving.

A BASIC computer program was used to 'parse' cycles into discrete modes of acceleration, deceleration, cruise, and idle (see Washington, Guensler, and Sperling, 1994). The program is also used to apply the modified CALINE algorithms to estimate the CO emissions estimates from generated speed-time profiles.

All of the vehicles contained in the current Speed Correction Factor Data Base (see Guensler, 1994) were used to estimate CO emissions from a 'fleet' of vehicles passing through the toll plaza and AVI scenarios. After several outlying test results were discarded, 436 remaining vehicles were used to approximate the vehicle fleet. The appropriateness of the vehicle fleet represented will be treated in subsequent analyses.

Since the modal model can predict CO emission contributions from acceleration and deceleration events, the resulting emissions predictions reflect the effect of microscopic traffic flow adjustments under the two different scenarios. The results of the modeling runs can be seen in Table 2. The model predicts that 'aggressively' driven vehicles will emit about 52 fewer grams of CO with AVI (on average) than with a toll-plaza. The median difference is about 11 grams of CO, which suggests that the distribution of CO emissions from this fleet of vehicles is non-normal and heavily skewed by influential 'dirty' vehicles. The standard deviation under the same scenario, about 123 grams, illustrates the extreme influence of these high emitting vehicles.

Table 2. Carbon Monoxide Emission Prediction Differences Between Toll Plaza and AVI Scenarios.

Driving Behavior with Toll-Plaza	Driving Behavior with AVI	Mean Carbon Monoxide Difference (grams / vehicle)	Median Carbon Monoxide Difference (grams / vehicle)	Standard Deviation in Carbon Monoxide Difference (grams)
Aggressive	Normal	53.68	11.04	127.10
Aggressive	Aggressive	51.67	10.59	122.66
Normal	Normal	12.17	2.97	27.85
Normal	Aggressive	8.03	1.87	18.52

The table also illustrates that 'normal' driving behavior, i.e. vehicle activity incorporating moderate acceleration and deceleration rates, results in much smaller CO emission rate differences. These findings agree with current literature that has identified high emission rates with extreme modal activity.

DISCUSSION

These findings suggest that a large reduction in CO emissions can be realized through the application of an Intelligent Transportation Technology (ITT). This limited scenario, the replacement of conventional toll plazas on a freeway link with automatic vehicle identification technologies to debit passing vehicles, has been previously identified as an applicauon of ITT' s with likely benefits to air quality. If we could implement this scenario for 6 months on a freeway segment. for example, with an average daily traffic volume of 15,000 vehicles per lane, in approximate numbers we could expect a reduction in CO emissions from about 33 to 140 metric tons per lane. The uncertainty in these estimates however, need to be addressed.

Although it is a significant improvement over currently employed models in terms of individual emissions estimations, the statistical model employed here still needs improvement and refinement This research is currently underway at UC Davis.

The representativeness of the vehicles contained in the Speed Correction Factor data set are not likely to be representative of the current vehicle fleet (Guensler, 1994). There are several methods in which to approach this deficiency. Subsequent analyses will incorporate a random sampling scheme, which will provide a means to mimic actual sampling from the real-world population of vehicles (from an emissions standpoint). Furthermore, we need to test new vehicles and sample the existing fleet to determine which fleet characteristics are truly 'representative'.

The impact of high-emitting vehicles and aggressive driving behavior is extremely important in these analyses. Subsequent analyses will address this effect, and will try to quantify the influence these vehicles and activities have on estimated emissions.

We need to look at many different implementation scenarios. Different approach speeds need to be considered, as well as different levels of congestion. In the above analyses, congestion is assumed not to exist, but practical experience shows that toll plazas are generally bottle-necks during peak periods, and we need to consider these congestion effects on emission estimates. We will address some of these issues in subsequent analyses.

Finally, we need to address the behavioral changes that might be induced by application of ITT' s.For example, previous peak-period congestion induced by toll-plazas, now eliminated by application of automatic tolling using AVI, might make the travel route more attractive to motorists. If this short-term increase in peak period level of service attracts 'new' motorists to the facility, then the projected emissions reductions may be partially or fully offset by increased traffic and congestion.

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USER ACCEPTANCE OF IVHS:
AN UNKNOWN IN THE ENWRONMENTAL EQUATION

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USER ACCEPTANCE OF IVHS:
AN UNKNOWN IN THE ENVIRONMENTAL EQUATION

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Intelligent Vehicle Highway Systems (IVHS) have been characterized as both a boon and a bane to environmental quality (1). On the one hand, proponents see IVHS as a means to achieving a more efficient transportation system that will lead to less wasted fuel and fewer vehicle emissions. On the other hand, a fear of latent travel demandunleashedby IVHS-improved traffic flows has others doubting the long-term benefits. Still others see environmental promises being realized if IVHS is applied to manage travel demand through road pricing, modal shifting and other such measures which employ IVHS technology.

Running through this debate are assumptions, expectations, and projections about the users of IVHS technologies. These IVHS users will, by virtue of the travel behavior they exhibit, have an impact on environmental quality. Despite this fundamental linkage between users and the environment the truth is that a good picture has yet to be painted about IVHS users. Basic questions remain unanswered, such as how many people will use IVHS technologies, how will they change their travel behavior, what motivates those changes, and what are the impacts of those changes on environmental conditions?

This paper examines the role that one set of users, individual travelers, plays in the assessment of IVHS and the environment. First discussed are points of entry for IVHS in travel decisions. Next, a selection of research to date is examined for the likelihood of penetration of IVHS technology and services among traveler markets. In the final section, observations are made on implications for the marketing of IVHS among travelers and how that activity plays into the environmental equation.

IVHS TECHNOLOGIES AND TRAVEL DECISIONS

IVHS has the potential to enter into travelers' decision-making at several points in the decision process. A useful framework capturing those relationships has been presented by Shaldover [2]. Figure 1 represents a modification of Shladover's framework for the purposes of this paper.

The demand for transportation arises from an individual's desire to satisfy certain needs (economic, social, recreational, etc.) that can be met at another location. In the long run an individual may reduce or eliminate the spatial separation of desired locations by such means as changing jobs or relocating his or her residence. In the near term, other factors come into play that determine whether a trip takes place and the characteristics of that trip. Travel behavior research [3] has shown that individual and household characteristics such as employment status, gender, residential location, and household structure are important determinants to number, length, and mode of trips.

While traditional travel behavior research has helped to identify the underlying structural determinants of travel demand, the application of IVHS technologies and services takes a dynamic view of tripmaking. In this view an individual has the opportunity to consciously decide whether, when, where, and how each trip is made. The technologies of communications and information processing, upon which IVHS is based, enable this constant reassessment process to take place.

IVHS technologies and services can come into play in an individual's travel decision-making in several ways. As shown in Figure 1, and described in the following section, IVHS points of entry are represented by the following boxes:

Substitution of telecommunication alternatives
Demand management policies
Pre-trip travel information
En-route travel information

The end result of the trip-making process shown in Figure 1 is a trip and, with it, all the environmental effects that trip entails. There are several potential environmental benefits of a traveler's use of IVHS services that results in a change in trip-making behavior:

IVHS-BASED TRIP-MAKING CHANGE	ENVIRONMENTAL IMPACT
avoidance of traffic congestion & stop/go traffic	improved fuel efficiency, reduced emissions
efficient routing	fewer vehicle miles of travel
elimination of trips	fewer vehicle miles of travel
increase in persons per vehicle	fewer VMT/person

This paper looks at the traveler's decision-making process, how IVHS fits into it, and reviews a selection of research to date that suggests how soon IVHS-based travel changes and their environmental impacts are likely to be realized.

USE OF IVHS IN TRAVEL DECISIONS: WHAT RESEARCH HAS SHOWN

Substitution of Telecommunication Alternatives. The first decision a potential traveler has to make is whether to travel at all. Increasingly, travelers are being offered opportunities to substitute telecommunications for trip making in overcoming the spatial separation between traveler and the desired destination. Telecommuting to work, distant learning for education, and teleshopping are some examples of how individuals can substitute the capabilities of telephones, televisions, facsimile machines, and data modems for the trip to work, school, and store.

Certainly eliminating trips altogether has the greatest positive impact on the environment. How significant an impact are telecommunication substitutions likely to have? The answer appears to be a limited amount, based on current trends. Data cited by Hopkins et al. [4] indicate that, while positively perceived by workers, telecommuting will be used by less than 5% of the labor force by 1997. Moreover, in one study they cite, even among employees who had tried telecommuting, the attrition rate was high (33%). In the Los Angeles area, a survey of workers in 1993 [5] found that while 90% took advantage of the opportunity to telecommute a few days each month, only 10% actually had been given that opportunity.

The behavior describedinthese studies suggests that telecommutingwill continue to have a persistent but modest effect on work trips and hence on their environmental impact. Additional impacts may be realized if telecommunication substitutions become significant for shopping, education, and leisure-time pursuits, as proponents of the Information Superhighway are envisioning. Until then, substitution of telecommunications for trips is unlikely to be very great.

Demand Management Policies. Once an individual makes the decision to travel, demand management policies represent the next opportunity for IVHS to affect travel behavior. IVHS technologies enable traffic managers to apply incentives and enforce regulations aimed at smoothing traffic flow and optimizing the transportation network. For example, technologies such as automatic vehicle identification, electronic payment, personal telecommunication devices, software and databases facilitate implementation of congestion pricing plans and programs to reduce the number of single occupancy vehicles through use of HOV lanes, ridesharing/ridematching programs, and modal shifts to transit.

Has research to date indicated how effective the application of IVHS to demand management will be in getting people to change their trip making behavior? While the literature on congestion pricing is scant, one study [6] based on data on tolls at the Golden Gate Bridge indicates that pricing can reduce traffic during peak periods. Either modal shifts occurred or travelers gave up trips altogether; the data are silent on this point. Getting people out of their single-occupant vehicle represents perhaps the greatest challenge for IVHS. One study, based on a survey of Virginia commuters, found that casual car-pooling (a.k.a. dynamic ridesharing) was projected to attract 18% of Beltway commuters, if time savings for both driver and passengers were a prerequisite. On the other hand, a test of a dynamic ridematching service in Bellevue, Washington, has found more people offering rides than accepting [7]. Koppelman et al. [8] found in suburban Chicago, that direct disincentives for single occupancy vehicles need to be combined with incentives for ridesharing to produce substantial increases in ridesharing. For example, fees at employee parking lots were needed to equalize the relative attractiveness of transit and van pools with driving alone.

While these data are far from conclusive, one might speculate that IVHS-based demand management will need to rely heavily on economic signals to induce significant changes in trip-making behavior, such as time or mode changes. Ridesharing in the abstract may sound attractive to travelers, even with dynamic ridematchingthat IVHS enables, but observedbehavior suggests major hurdles must be overcome for it to succeed.

Pre-trip Travel Information. The third point at which IVHS enters the traveler's decision-making process is in having information available before the trip commences, or pre-trip travel information. Such Advanced Traveler Information Systems offer the traveler the opportunity to base the time, mode, destination, and route of a trip on information about the status of the transport network at a particular point in time. The technologies providing these services include the end-user devices for access (PCs with modems, televisions, telephone, personal digital assistants, kiosks, etc.); wireless and wired communication networks; the software and databases for collection and delivery of information; and a variety of sensor technology by which information is collected.

What do we know about the use of pre-trip information in changing travel behavior? A Southern California survey [9] revealed that 36.5% of commuters seek traffic information before leaving home, but of these less than 20% change their route. In New Jersey, 72% of commuters would prefer to use a potential incident information service to change route, 20% to change mode, and 8% to change time of departure [10]. In Washington State, 75% of surveyed commuters showed a willingness to use information to make changes in their commute 1111. However, even among those willing to make a change, few would change modes.

Results from the single actual field test of a traveler information service, the fifteen-month test of Boston's SmarTraveler service [12], paint a more conservative picture for pre-trip information services than the other studies might suggest. Overall usage was low relative to the total Boston market that had access to the service. Noticeable peaks in usage did occur during severe weather conditions, when traffic conditions were at their worst. Travelers who used the service said they made changes to their trip in 29% of the cases, with change in departure time and using a different route the most frequent types of changes. Canceling a trip altogether and switching modes were much less common, 2.2% and 1.0% respectively.

To have significant beneficial environmental results, many travelers will need to make use of pre-trip information. Surveys indicate that travelers are interested in taking advantage of such information and make changes in trip decisions. As yet, modal shifts are unlikely to occur based on information services alone. Moreover, to achieve significant penetration pre-trip information services may need to be provided at no charge. In New Jersey and in Boston, interest in the service dropped dramatically as prices were introduced.

En Route Travel Information. The final stage of trip decision-making where IVHS comes into play is en route. En route travel information allows a traveler to alter a trip once it has commenced. Technologies similar to pretrip travel information services are used, with the exception that communications tend to be wireless. Also, in-vehicle navigation units and routing systems track a traveler's progress through the transportation network and provide real-time route guidance.

What do we know about the potential usage of such systems? Results from a couple studies are available. Among cellular network subscribers in Boston, the SmartTraveler service cited earlier [12] was used in much higher proportion than among land-line subscribers, suggesting a greater perceived value for en-route usage. In the TravTek trial in Orlando, Florida, drivers experienced a perceived and actual travel time savings with the route guidance system [13, 14]. Moreover, drivers thought the system helped them drive more safely.

These positive findings suggest that en route information will be well received in the market, assuming that price and other factors are satisfactory to travelers. As the experience to date has been with in-vehicle devices, the potential for modes other than a traveler's own vehicle is not known. Besides the benefits of reduced time and stress for the traveler, potential environmental benefits may be achieved by avoiding traffic tie-ups and more efficient routing.

OBSERVATIONS ON THE RESEARCH AND CONCLUSIONS

The environmental benefits of IVHS depend in large part on the decisions that individual travelers will make regarding their trips and the use of IVHS in those trips. The studies cited in this paper indicate that the penetration of most IVHS technologies and services among travelers in general may be low for quite some time. To achieve greater user acceptance, aggressive market promotion will need to be undertaken, but it will need to be based on users' perceptions of the real benefits they can obtain. However, there is reason for optimism, since greater potential for penetration may exist within certain segments. Some of the studies revealed correlations among demographic or other characteristics of the traveler [e.g., 8, 9, 10, 111, such as gender, income, attitudes about independence, or length of commute. A successful marketing approach would seek to identify these segments,develop technologies and services that meet their needs, and institute an effective campaign for winning their acceptance of IVHS services. Such an approach might well be more effective in seeing that IVHS is part of the travel decision making process for those travelers where it can make a difference. The result will be a greater likelihood that the environmental benefits of IVHS can be achieved.

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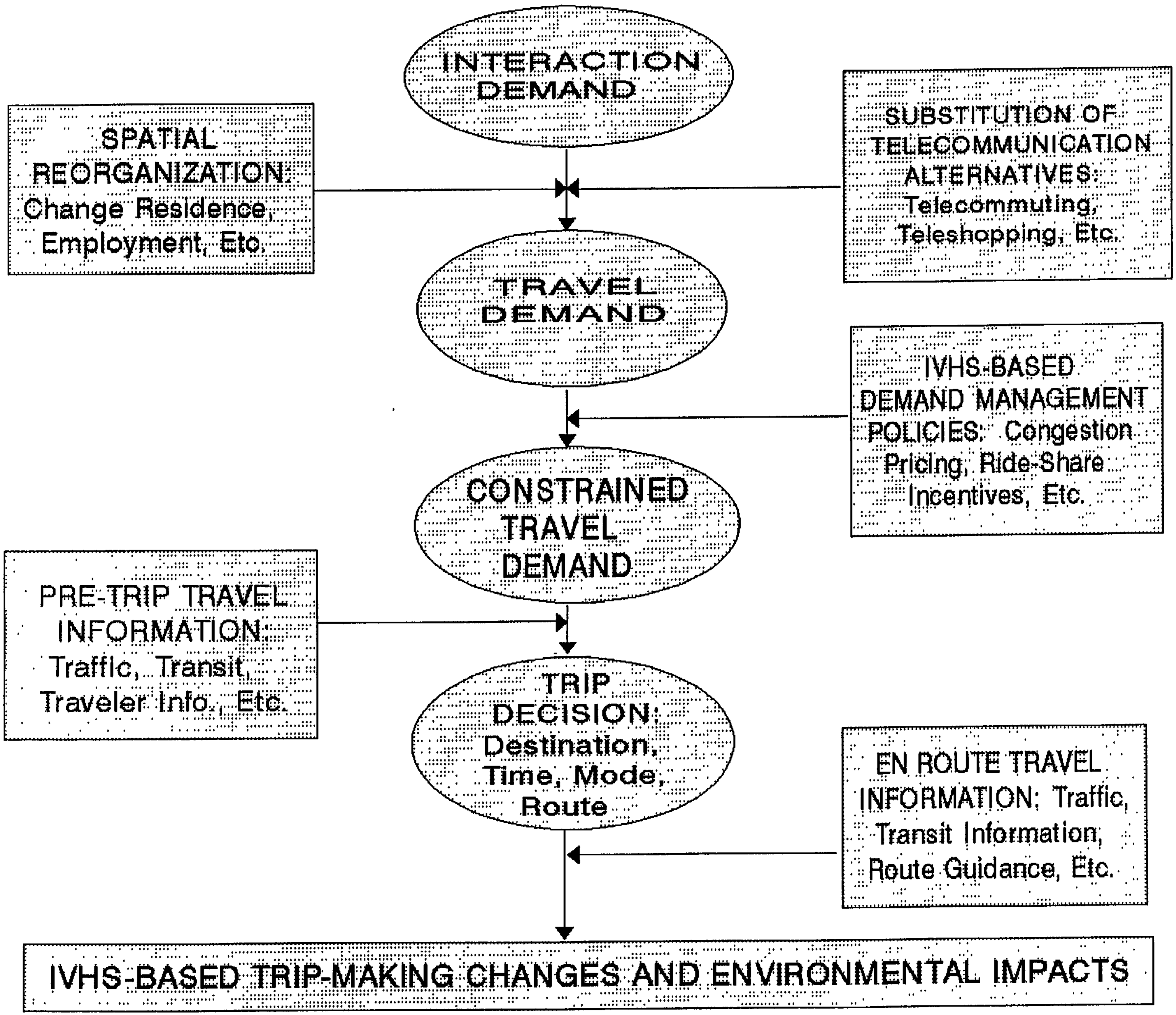
FIGURE 1. IVHS IN THE TRAVEL DECISION-MAKING PROCESS



Based on Shladover, 1993 [2].

Evaluating the Impact of IVHS Technologies on Vehicle Emissions using a Modal Emission Model

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ABSTRACT

One of the key goals of Intelligent Vehicle/Highway Systems (IVHS) is to improve mobility through the reduction of traffic congestion and increased throughput on today's road network. As congestion decreases and traffic flow is smoothed, associated air quality should improve. However, roadways with improved mobility and better throughput may induce an increase in traffic, resulting in a negative air quality benefit. In order to determine the impact of IVHS on air quality, models must be developed that can: 1) accurately predict vehicle emissions reductions due to smoother traffic flow; and 2) predict the induced demand for roadways when their throughput is increased due to IVHS. We am currently developing and applying a set of transportation/emission models in addressing this first issue. Current emission inventory models (e.g. MOBILE, EMFAC) simply relate vehicle emissions to average traffic densities and speeds on a specific network, and are not adequate for analyzing traffic at the microscale level required for IVHS evaluation. However, by using transportation simulation models that can accurately simulate dynamic vehicle activities (e.g., accelerations, decelerations) and integrating this information with detailed modal emissions models, precise emissions inventories for various IVHS scenarios can be achieved. Using a power demand-based modal emission model, we are currently evaluating total vehicle emissions associated with Automated Highway System (MS) designs. Preliminary results indicate that with AHS's approximate four-fold increase of capacity, emissions will increase over current manual conditions by a factor of two if the system is used at full capacity (~8000 vehicles/hour-lane), stay the same at half capacity (-4000 vehicles/hour-lane), and will decrease by half at current traffic volumes (-2000 vehicles/hour-lane).

INTRODUCTION

Two central research questions pertaining to air quality exist for IVHS: Potential vehicle emission reductions through the application of advanced technology, and potential induced traffic demand.

Potential Vehicle Emission Reductions-IVHS has the potential to reduce vehicle emissions through several of its "technological bundles" (see, for example, [l] for an IVHS overview). Advanced Vehicle Control Systems (AVCS) implemented at the vehicle level are intended to safely smooth traffic flow on the roadways by minimizing the stop-and-go effect of vehicles in congestion, and increase overall throughput. The heavy acceleration and deceleration components of vehicle trips can be eliminated, minimizing energy consumption and associated emissions of these vehicle operating modes. Advanced Traffic Management / Information Systems (ATMIS) will allow dynamic re-routing to take place on the roadway network, minimixing congestion and subsequently emissions. Further, navigational systems will allow users to reduce unneccessary driving and will aid in trip-chaining practices PI.

Potential Induced Traffic Demand-In contrast, the implementation of some M-IS technologies may lead to an increase of total vehicle miles traveled (VMT). If IVHS allows smoother flow and higher speeds on the roadways, people may choose to live farther away from work while still commuting in the same amount of time-thereby increasing VMT. Further, attractive trip-ends will become reachable, again increasing VMT. Further, advanced navigational technology may divert travelers from higher-occupancy modes such as buses and carpools to single-occupant vehicles. In general, if travel becomes easier due to advanced technology, VMT will likely increase.

In order to determine the impact of M-IS on air quality, significant improvements must be made in traffic simulation and travel demand models by closely integrating vehicle emission models. Existing traffic, emissions, and planning models have been developed independently of each other and are difficult to integrate together when determining accurate air quality impacts. Current emission models (i.e., MOBILE, EMFAC [3]) functionally relate emissions to average vehicle speed and density, and are not appropriate for analyzing IVHS scenarios. Under IVHS conditions, the dynamic behavior of vehicles will be very different compared to today's traffic conditions, upon which the current emissions models are based. As a result, *modal emissions data* (i.e., emissions data associated with vehicle modes, e.g., idle, acceleration, cruise, deceleration, etc.) should be used with microscale traffic simulations to obtain more realistic results.

In this paper, a power demand-based vehicle emissions modeling approach is first described, followed by a discussion of its application to evaluate emissions associated with automated highway system designs.

POWER DEMAND-BASED VEHICLE EMISSIONS MODELING

Second-by-second emissions data that are registered with vehicle dynamic operation are often referred to as *modal emissions data*—emissions data that correspond to a vehicle's operating mode, e.g., acceleration, deceleration, steady state cruise, idle, etc. Using modal data in an emissions model is in sharp contrast to the current driving cycle-based emission inventory techniques (i.e., the Federal Test Procedure, FTP [4]), where emissions are collected in bags over long periods of time (on the order of 500 seconds), and then analyzed as a whole.

Second-by-second emissions data can be combined with an analytical model of the instantaneous power requirements placed on a vehicle's engine. A vehicle's acceleration performance (in the longitudinal direction) is limited by the engine power and the traction limits on the drive wheels. Given the instantaneous power requirements placed on a vehicle (at the wheels) for it to move depend on three types of factors: 1) *Environmental factors* (e.g., mass density of air, road grade), 2) *Static vehicle parameters* (e.g., vehicle mass, rolling resistance coefficient, aerodynamic drag coefficient, cross sectional area), and 3) *Dynamic vehicle parameters* (e.g., commanded acceleration, and velocity). Given these parameters, it is possible to first determine the demanded tractive power, as shown in figure 1. Further, the power demand on the engine can be determined by modeling the power transfer through the vehicle's drive system and incorporating other variables such as use of accessories (e.g., air conditioning, power steering).

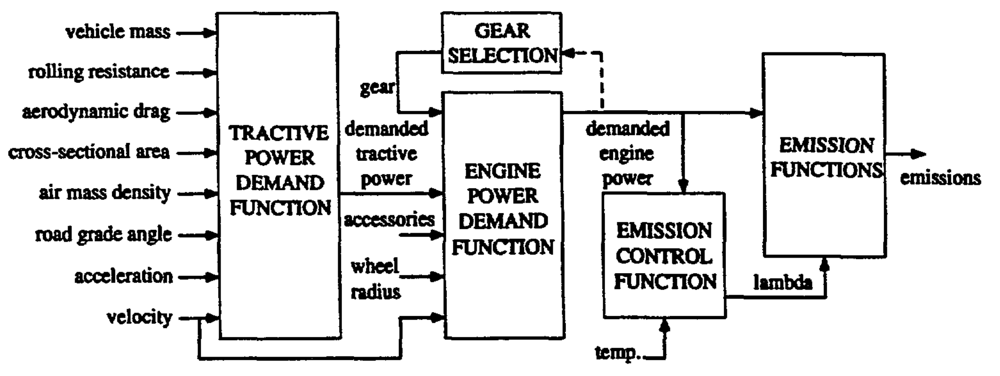

Figure 1. Load-based modal emissions modeling methodology.

One of the most important aspects of this power demand-based method for estimating emission output is modeling the vehicle's emission control system. Modern vehicles have complex emission control systems that include as the primary component a catalytic converter. An electronic engine controller regulates the air-fuel ratio to the engine so that the ratio is as near as possible to the stoichiometric ratio where the catalytic converter operates most efficiently. During normal operation of the vehicle, the air-fuel ratio is kept at the stoichiometric ratio (lambda = 1). However, there can be cases when the conversion efficiency of the emission control system is reduced. One example is during cold-start events, when the catalytic converter is not at its proper operating temperature and thus is not operating at its peak performance. Another important example includes power enrichment events. When a vehicle has a high engine power demand (which may be induced by a hard acceleration or steep grade), it has been shown that the emission control system can go "open-loop" and the air-fuel ratio is commanded rich for peak demand power and protection of engine components. Recent studies have shown that power enrichment events can contribute significantly to overall emission production (e.g., [5, 6, 7]). As a first approximation to modeling power enrichment events, a simple thresholding technique is used. When the demanded engine power exceeds a particular threshold, the emission control system goes into an open-loop state, and the air-fuel ratio is rich, producing significant emissions. When the demanded power is below that threshold, the system maintains the air-fuel ratio at stoichiometry, resulting in low emissions. The emission output of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOx) can be measured and correlated to demanded engine power induced under numerous operating conditions. The emission output can then be approximated by a function that relates emission species output to demanded power.

For use in our traffic simulations, the vehicle dynamics equations and load-based emissions were calibrated to a 1991 Ford Taurus, using data received from Ford Motor Company. As further modal emission data becomes available for other vehicles from Ford and other sources, they can easily be incorporated into this type of model when determining a more complete, comprehensive emission inventory.

AUTOMATED HIGHWAY SYSTEMS

IVHS technology in the form of AVCS can be applied to control vehicle motion so that vehicles can operate in "platoons", i.e., follow each other very closely at high speeds, while still maintaining a high safety margin. This has several implications: 1) traffic flow will increase dramatically over current highway conditions due to denser traffic traveling at higher speeds; 2) congestion should decrease since the stop-and-go effect caused by relatively long human reaction delays will be eliminated and accidents will be minimized.

Current highway traffic (i.e., uninterrupted traffic flow) can be characterized by the traffic volume (v), average vehicle speed (S), and vehicle density (D). These terms are generally related by the product $v = S \times D$ [8]. Further constraints operate on these parameters which restrict the type of flow conditions on a highway link. The general form of these constraints is shown in figure 2, which illustrates some key points of uninterrupted traffic flow:

- Zero rate of flow occurs in two distinct cases: 1) when there are no vehicles on the roadway, and 2) when the density is so high that all vehicles are stopped and can not move. In the first case, the density is zero, thus the flow rate is zero, and the speed in this case is assumed to be the driver's desired speed (i.e., vehicle free speed). In the second case the density is at its maximum and the vehicle speed is zero. The density at which this occurs is called the jam density.

- As density increases from zero, the traffic flow increases due to the increased number of vehicles. The average vehicle speed is reduced to maintain safety during higher density conditions.

- Traffic flow is maximized at a specific critical density. As density increases above the critical density point, speed drops off at a faster rate. Traffic flow tends to become unstable in this region due to perturbations from lane change maneuvers, merging, or any external variables (e.g., debris in roadway, accident in adjoining roadway, etc.). These perturbations can create disturbances that are not damped or dissipated in the flow. These unstable, forced flow regions in the curves are characterized by stop-and-go congestion.

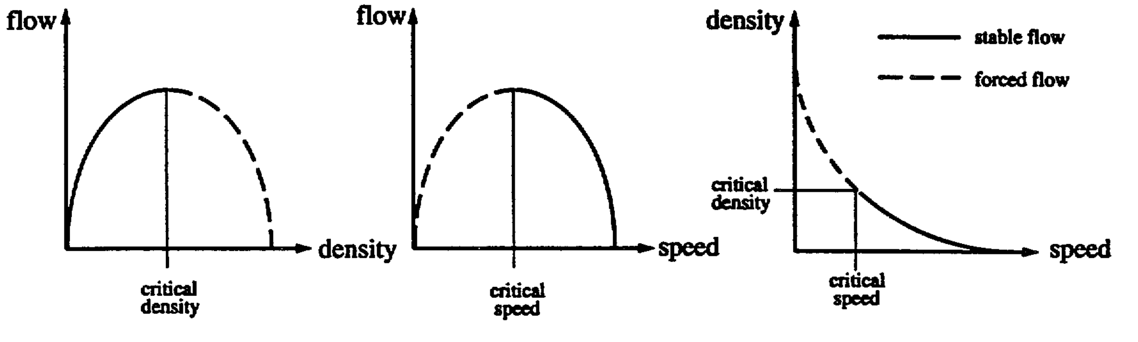

Figure 2. Flow, density, and speed relationship of traffic flow.

Human driver flow-density-speed relationships can be approximated mathematically by specifying the headway, or gap, between vehicles required for safe stopping if one car suddenly brakes, and after a time lag, the second car also brakes without collision. The lower flow-density curve in figure 3 was produced for the case when the first car brakes at 0.9 g (8.82 meters/second^2) and the second car brakes at 0.6 g (5.88 meters/second^2) after a one second time lag. This curve (after [9]) is for a single lane and is similar to curves predicted by the Highway Capacity Manual [8].

A similar mathematical formulation can be developed for the flow-density-speed characteristics of an automated highway system. Within a platoon of vehicles, the headways are much smaller, closely regulated by automated controls. Therefore, platooned vehicles can travel faster at higher densities, thus improving the traffic throughput. Again, if we consider a single lane of platooned traffic as shown in figure 4, we can mathematically approximate the flow-density-speed characteristics.

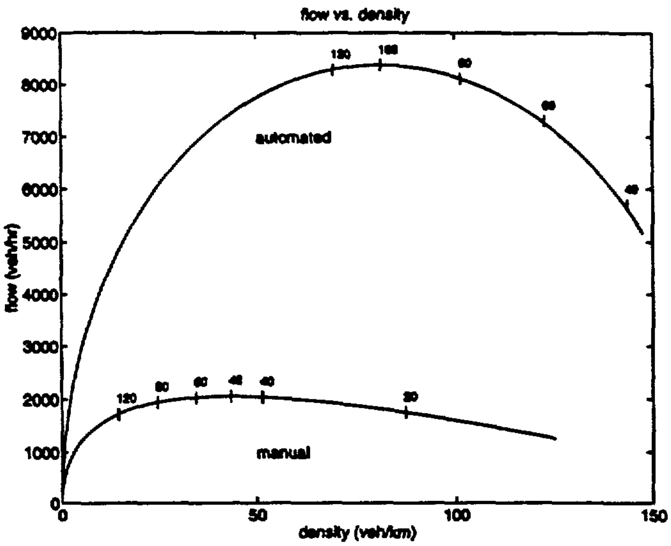

Figure 3. Flow-density relationship of traffic for both manual driving and automated driving. Velocity values (km/hr) are annotated on the curve.

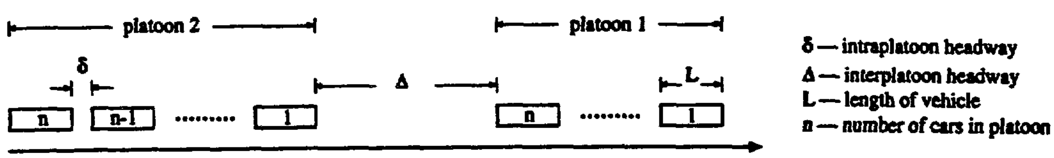

Figure 4. Platoons of vehicles on a highway.

Using the notation given in figure 4, the vehicle density for an automated lane is given as: $D = \frac{n}{\Delta + n(L+\delta) - \delta}$

The interplatoon headway is determined as before, i.e., requiring safe stops if one platoon suddenly brakes, and after a time lag, the second platoon (leader) also brakes. In the automated scenario, the time lag is much shorter than for human behavior. The upper flow-density curve in figure 3 was produced for the more restrictive case when the first platoon brakes at 2 g (19.6 meters/second^2), and after a 0.3 second time lag, the second platoon (leader) brakes at 0.3 g (2.94 meters/second^2). It is assumed that the intraplatoon headway is precisely controlled and can also perform safe stops under these specified stopping conditions. In the mathematical formulation, the intraplatoon spacing is set to one meter, the car length is five meters, the number of vehicles in each platoon is 20 vehicles, and the vehicle free speed is 120 km/hr. The difference between these two curves is substantial. The maximum traffic flow for the automated case is roughly four times that of the manual driving case. The maximum flow for the automated case occurs at an average speed of 103 km/hr, and for the manual case it occurs at 48 km/hr.

STEADY-STATE VEHICLE EMISSIONS

Emissions produced by traffic (manual or automated) will depend on several factors. In general, large variations in velocity (i.e., numerous acceleration, deceleration events) lead to higher emissions, therefore to minimize total emissions, traffic should be kept as smooth as possible. In this preliminary analysis, we only consider steady-state vehicle speeds and the associated emissions.

Using the power-demand emissions model described above, several microscale platoon simulations were carried out to determine average emission rates at different steady-state velocities. The motion parameters, engine power demand, and associated emission rates were calculated for each modeled vehicle in the simulation. Because the follower vehicles within a platoon have very small intraplatoon headways (e.g., on the order of one meter), the aerodynamic drag coefficient of each follower is significantly reduced due to the "drafting effect". Using preliminary aerodynamic drag reduction data for vehicles in platoons [10], the calculated power demand on the engine is significantly smaller at higher speeds. Based on the data, even the lead vehicle of a platoon has its aerodynamic drag coefficient reduced due to the vehicle following closely behind. A comparison between constant velocity CO emission rates* for 20 vehicles that are platooned and non-platooned is shown in figure 5. In both cases the traffic density is low, and the vehicles are traveling near their free speeds. It is apparent that 20 vehicles traveling independently with no interaction have greater emissions at higher velocities than platooned vehicles that benefit from the drafting effect.

In order to determine total steady-state emissions of an automated lane within an AHS, these emission data were applied to the flow-density curves shown in figure 3. It is important to note that the curves in figure 3 reflect traffic density and flow associated with specified safe headways. Thus to generate flow values at lower densities, vehicle speeds greater than the free speed (i.e., the maximum speed a driver will go on the freeway without interference from other traffic) were used in the calculations. For purposes of generating total link emissions at lower densities, the flow values were adjusted so that the vehicle velocities at low densities were at the constant free speed.

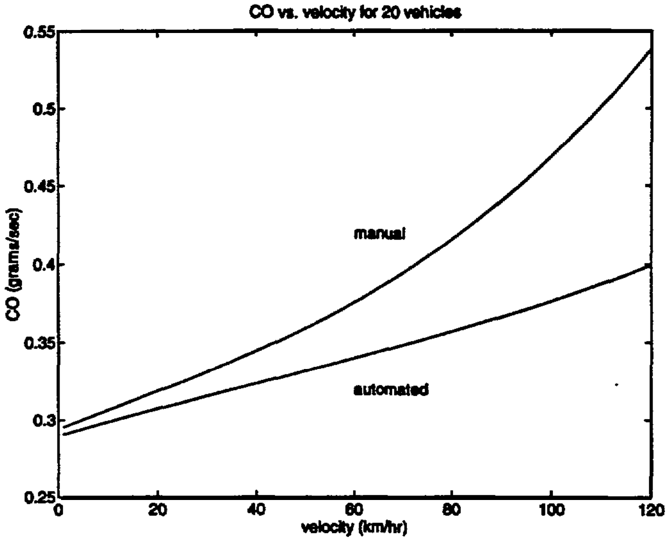

Figure 5. Constant velocity carbon monoxide emission rates for 20 vehicles platooned and non-platooned.

The total CO emissions for a one kilometer lane are shown as a function of traffic flow for both the manual and automated (platooning) cases in figure 6. There are several key points to note in this figure:

1) The maximum traffic flow for a manual lane is 2053 vehicles/hour at a average vehicle speed of 48 km/hour. At the same traffic volume, the automated lane produces roughly half as much emissions as in the manual case (manual: 0.76 grams/second, automate& 0.34 grams/second).

2) Given the emissions rate for maximum manual traffic volume of 0.76 grams/second, roughly *twice the traffic* volume can occur in the automated lane to produce the same amount of emissions (manual: 2053 vehicles/hour, automated: 4565 vehicles/hour at 0.76 grams/sec).

3) The maximum traffic flow for an automated lane is 8286 vehicles/hour at an average speed of 103 km/hour. The associated emissions at this point is roughly *twice* that of the maximum flow rate of manual driving.

It is important to point out that the emissions associated with higher traffic densities and lower average speeds are underestimated in these curves. Remember that these emissions are calculated based on steady-state velocities, and the

Results of hydrocarbon (HC) and oxides of nitrogen (NOx) emissions also were obtained for all the experiments and are similar in shape to the CO emissions and are not presented here due to limitations in space.

negative slope region of the flow-density curve is inherently unstable, leading to stop-and-go traffic. The accelerations associated with stop-and-go traffic will lead to a greater amount of emissions.

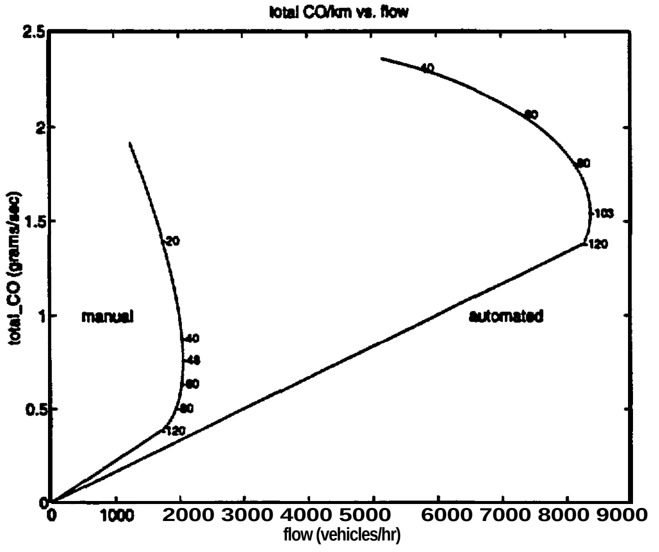

Figure 6. Total CO emissions versus traffic flow for manual and automated traffic, for a one kilometer lane.

CONCLUSIONS

Based on microscale simulation models and modal emissions data for a modem, closed-loop emission controlled vehicle, steady-state (i.e.. constant velocity) emission rates have been estimated for both manual and automated lanes. An automated lane using platooning can improve the traffic flow by a factor of four, and at maximum flow values, the total emissions increase is by a factor of two. If only half of the automated lane capacity is used, the traffic flow improves by a factor of two, and the associated emission rates are roughly the same as the full-capacity manual case. If the automated lane carries the same traffic volume as in the manual case, the emissions are reduced by a factor of two.

This analysis ignored transient emissions, i.e., emissions due to accelerations and decelerations associated with unstable traffic flow. We are currently using our models to predict the emissions associated with stopand-go traffic in the unstable traffic flow-density regions. If congestion is to be avoided, the traffic should be kept in the positive slope region of the flow-density curve (see figure 3). When in the positive slope region, interaction between vehicles in traffic is minimal, leading to smoother traffic flow. It can be seen that the extent of the positive slope region is much greater for the automated lane when compared to the manual lane.

This analysis assumed a constant platoon size of 20 vehicles, however, platoons will vary in length due to vehicles dynamically entering and leaving platoons as they travel from their specific origins to destinations. Shorter length platoons will lead to lower automated lane capacities and higher average vehicle emissions. Also, emissions associated with platoon maneuvers such *as splitting* and *merging* have not been analyzed here, but is currently under investigation.

Finally, the emission rates used in this analysis were for a single vehicle. For current manual driving, the vehicle population is quite varied, and to more accurately predict total emissions, emission rates for different vehicle classes must be incorporated. For an automated scenario, however, the vehicle population will be somewhat more restricted. Vehicles that have automated platoon technology will tend to be newer passenger vehicles with closed-loop emission control systems, similar to the vehicle modeled here.

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III.

Socio-Economic and Institutional Issues

SOCIO-ECONOMIC ISSUES AND INTELLIGENT TRANSPORTATION SYSTEMS

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INTRODUCTION

The transportation system is an integral part of the societal - economic system of every group of people on earth. It is through transportation that people gain access to the things they need to do to be functioning members of society. While other means of access (e.g., tele-commuting, tele-conferencing, television shopping) are developing and will become more common in the future, the need for transportation will remain dominant for any planning horizon that we can conceive. To plan a transportation system without explicit inclusion of the societal and economic factors that affect and are affected by transportation would be unwise.

In the United States as we have planned and implemented transportation systems over the last 200 years, precedence has been given to the technological factors of importance. Those rail transit systems that we have are functional; our Interstate Highway System is excellent; and our vehicles compete in the world market. In planning and executing the provision of transportation services, we have focused on the technology and all too often have not addressed the larger social issues. As we laid rail track across the country and built highways that would divide neighborhoods, we did not ask the local people what they thought of these innovations. With rare exceptions, the voices of individuals were not heard in the transportation planning process. (Weiner, 1992). In the 1960s and 1970s, the building of the Interstate Highway System began to be questioned by people who would be most negatively affected by it. Many would lose their homes or their neighborhoods. Their concerns began to be addressed through such forums as the Boston Transportation Planning Review in which citizens participated in the planning process through public meetings. Academics began looking at ways to incorporate societal concerns explicitly in the planning process. (Richardson 1973).

Even with these efforts, major time and cost delays occurred in the completion of the Interstate

System. We reached the point of enormous expenditures per mile of construction of roads in our urban areas -- time and expenses that could have been markedly less had major societal and economic issues been addressed early in the process. Not only is it important to address societal and economic issues for what we may consider as altruistic reasons, but it is also important to do so because it is good business. (See Underwood and Streff 1992 for a discussion of the items that need to be considered in evaluating Intelligent Vehicle-Highway System (MIS) technologies.) It will save time and money in the long run and produce a product that will better serve society. Noting, in 1972, how important it was to address societal issues in their business planning process, the Business Environment Studies component in General Electric noted "Without a proper business response, the societal expectations of today become the political issues of tomorrow, legislated requirements the next day, and litigation the day after." (Wilson 1985)

PURPOSE OF THIS PAPER

The goal of this paper is to raise for discussion the concept that it is more cost-effective and less expensive for both the public and private participants in the Intelligent Transportation Systems community to start planning and implementing intelligent transportation systems with societal and economic issues included in the planning process from the very beginning. There are several objectives that support this goal. These are:

1) to explain transportation systems as part of the larger social / economic / political / environmental system;

2) to identify many of the societal and economic factors that impact or are impacted by transportation systems;

3) to present "forecasts" of several of these factors; and

4) to suggest ways of analytically incorporating these factors into the planning process.

METHOD AND DATA

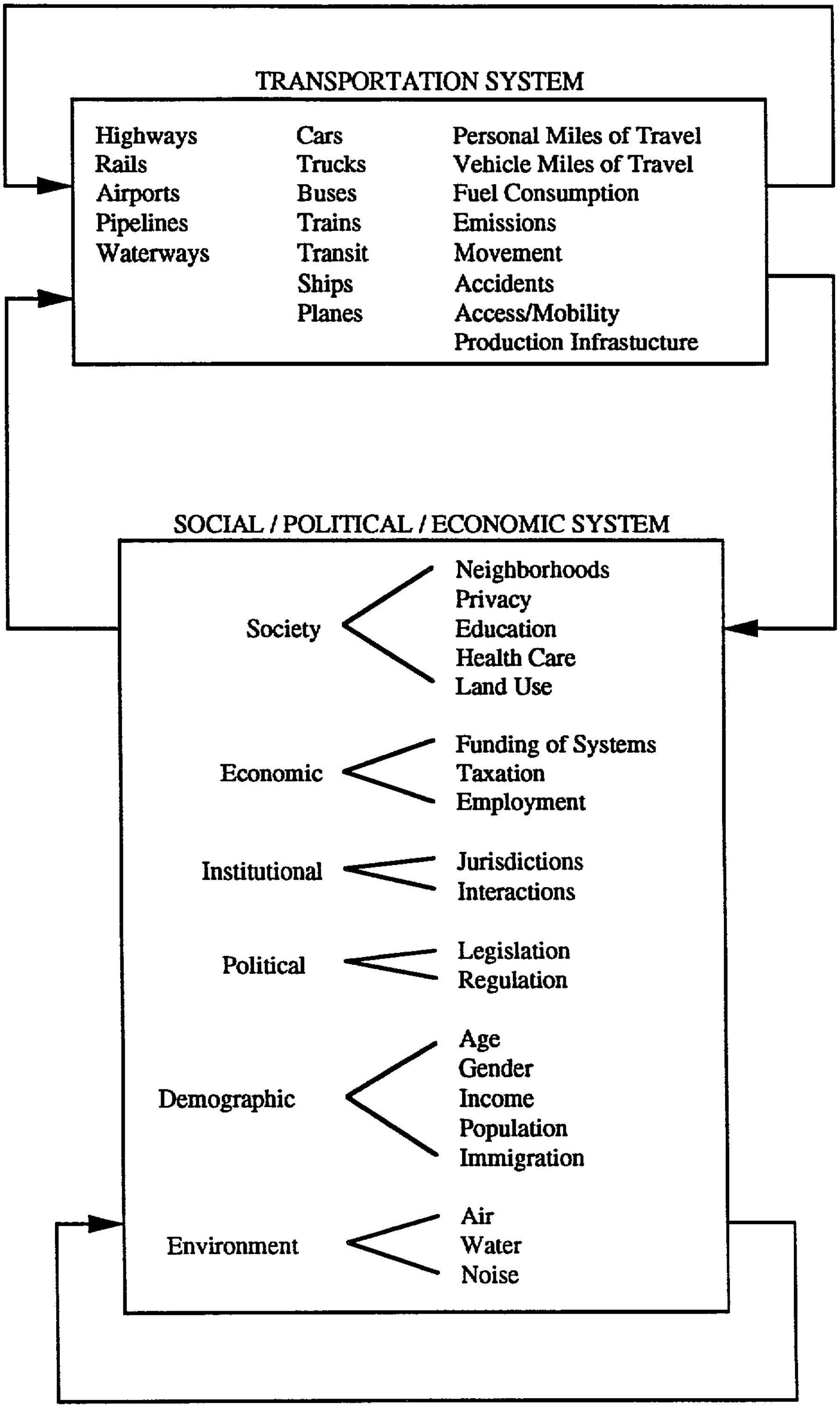
The analysis presented in this paper is supported by several sources of data. It draws together forecasts of the Bureau of the Census, experts in traffic safety, and key representatives of the automotive and supplier industries. In addition, it draws on some of the organizational methodology of influence diagrams and scenario development. Because of restrictions on the development of this paper, it was not possible to fully implement any of these methods or others that are available. Rather, the paper represents an introduction to the challenges ahead coupled with suggestions on how to address them.

TRANSPORTATION AS AN INTEGRAL PART OF THE SOCIO-ECONOMIC SYSTEM

In any discussion of a transportation system -- intelligent or otherwise - it is useful to begin with a placement of it in the larger social system. The transportation system is not a stand-alone system and cannot be studied in isolation. Economists refer to the demand for transportation as a derived demand. By this is meant that there is practically no demand for transportation in and of itself. With the exceptions of those of us who like to drive cars, fly planes, or ride in buses or trains (thrill seekers, those enchanted by movement, machines, or the lure of the sky or road), we use transportation for the purpose of meeting some other need -- that of getting to some place of business, social, educational, shopping, or other activity.

The social / economic activity system - employment, housing, schooling, health care, shopping, socializing, etc. - has a vibrant life with its own changes and interactions. The transportation system is planned and built by a combination of public and private enterprise and, to some extent, changes through the impetus of those responsible for planning and implementing such systems. In addition, the transportation system is affected by changes in the social / economic system and, in turn, the availability of transportation directly affects the function of the social / economic system. For example, a rural community begins; roads are built to the area; industry relocates because of transportation availability; housing is built to house workers and their families; schools and shopping centers are built to serve those families; more roads are built to accommodate the growing commercial and personal travel; and so on. Figure 1 illustrates the relationship of the transportation

FIGURE 1 - INTERACTIONS OF THE TRANSPORTATION SYSTEM WITH THE SOCIAL / POLITICAL / ECONOMIC SYSTEM



system and the larger social / economic / political system. It lists just a few of the social, economic, political, and other factors that interact with the transportation system such as neighborhoods, privacy, taxation, employment, regulation, age, gender, and immigration. Note in the figure that the two systems change as a result of activity within themselves (including the actions of planners and engineers responsible for transportation systems) and that each changes as a result of the activity in the other.

Waller (1994), Sobey (1990), and others have suggested many of the societal and economic factors that might be of relevance in the planning of a transportation system. Table 1 lists some sixty-one of them. This list is not meant to be exhaustive, but rather a glimpse into some of the complexity and challenges that exist in implementing transportation systems.

As growth of social /economic and transportation systems continues, there are major benefits that are experienced including economic prosperity, better access for some members of society to life's necessities, etc. At the same time, there may be many negative consequences of growth including air, noise, and water pollution, the deterioration of inner cities, the loss of open land, congestion in cities and in the residential and commercial areas surrounding them. There are many other social indicators such as increasing crime rate, lack of access to health care for people living in the inner cities, increase in the teen birth rate, increase in drug use, inability of inner city residents to get to employment in suburban areas, destruction of urban neighborhoods, a tearing of the social fabric, benefits for the haves and costs for the have-nots, health effects from air pollution accompanied by a decrease in the quality of life for those who live in smog-enclosed areas, an inability to swim in or drink polluted waters, etc. It is not clear that there is a direct relationship between transportation services and these conditions, but they cannot simply be written off when planning a new type of transportation system. Consideration of them can be made by use of any of several analytical methods, some of which are listed below.

SOCIETAL AND ECONOMIC FACTORS AFFECTING AND AFFECTED BY TRANSPORTATION

There are many societal and economic factors that affect transportation systems and/or are affected by

Table 1

A POTPOURRI OF SOCIETAL AND ECONOMIC FACTORS

Access of disadvantaged groups such as the poor, the young, the aged, and the physically disadvantaged

Access to employment	Isolation of population in rural or urban areas
Access to education	Landuse
Access to health care	Legal issues
Access to housing	Jurisdictional issues
Access to shopping	Market forces
Affordability	Minorities
Air pollution	Modal choice
Availability of food and energy	Movement of goods
Crime	Neighborhood viability
Competing social goals	Noise pollution
Congestion	Non-users of transportation system
Consensus process	Quality of life
Cross-organizational cooperation	Participation in society
Cyclists	Privacy
Day care	Product and tort liability
Defense industry refocus	Public / private interactions
Demographics	Recreation
Economic growth	Regulation
Economic stability	Retail sales
Education	Safety
Employment availability	Security
English as a second language	Societal attitudes
Equity	Telecommuting
Funding - privately	Tele-conferencing
Funding - publicly	Transit availability and use
Gender	Truckers
Health care availability	Unemployment
Immigration	Vehicle ownership
Income	Water pollution
Intermodal transfers	Who pays /who benefits

them. Several efforts have been made to identify these, although not specifically for the purposes of intelligent transportation systems planning. The Bureau of the Census provides demographic forecasts for several years into the future. A set of symposia on critical issues in traffic safety in the year 2010 provides another source of “forecasts”. A third source of data is a Delphi study of the future of factors related to the automotive industry. Data from each of these are presented below.

Census Forecasts

It is useful for planning purposes to look at the current population level and composition and Census estimates for the future. Table 2 lists 1995 population estimates for the United States for men and women, disaggregated into those greater than or equal to 16 years of age and those greater than or equal to 65 years of age. This breakdown gives us the numbers of people who are eligible to have drivers’ licenses and those who are in the pool to be elderly drivers. Total U.S. population is also included, as is the ratio of women to men and the percent of the population (disaggregated by gender) that is elderly (greater than or equal to 65).

Tables 3 and 4 provide the same information for the years 2005 and 2050. The data for 2005 are a base for a relatively near-term planning forecast, while the 2050 data give us a view of time when most of us will be either very old or no longer alive. Even though we may not be able to reap the benefits of our planning ourselves, perhaps our great-grandchildren will. Of note are the increasing numbers of the population, the elderly (both men and women), with the population of older men increasing at a higher rate than that of older women. Note that by 2005, almost 13% of the population will be elderly, with about 1.5 million more elderly women and about 1.8 million more elderly men than in 1995. By 2050, 20% of the population will be over 64 years of age. This has direct implications for both time horizons for access to societal activities, ergonomic design of vehicles, safety, intermodalism, etc.

Critical Transportation Issues

When traffic safety experts convened in 1992 under the sponsorship of American Iron and Steel Institute and The University of Michigan Transportation Research Institute to identify critical issues in traffic safety in 2010, they hypothesized what the future would hold in terms of driver behavior,

Table 2 - CENSUS FORECASTS -1995
US Population (Thousands)

AGE	TOTAL POPULATION	MALES	FEMALES	FEMALE/ MALE
≥ 16	201,543	96,964	104,579	1.08
≥ 65	33,649	13,699	19,950	1.46

Total Population	263,434
Elderly Males/Tot. Pop.	0.052
Elderly Females/Tot. Pop.	0.076
Elderly People/Tot. Pop.	0.128

Table 3 - CENSUS FORECASTS -2005
US Population (Thousands)

AGE	TOTAL POPULATION	MALES	FEMALES	FEMALE/ MALE
≥ 16	223,469	107,880	115,589	1.07
≥ 65	36,970	15,534	21,436	1.38

Total Population	288,286
Elderly Males/Tot. Pop.	0.054
Elderly Females/Tot. Pop.	0.074
Elderly People/rot. Pop.	0.128

Table 4 - CENSUS FORECASTS -2050
US Population (Thousands)

AGE	TOTAL POPULATION	MALES	FEMALES	FEMALE/ MALE
≥ 16	310,626	150,350	160,275	1.07
≥ 65	80,109	36,092	44,016	1.22

Total Population	392,031
Elderly Male/Tot. Pop.	0.092
Elderly Females/Tot. Pop.	0.112
Elderly People/Tot. Pop.	0.204

Source: U.S. Bureau of the Census (1992) vehicle occupants, vehicles, and the highway environment. (Richardson 1993) They suggested (but did not agree on) the following scenario:

"Drivers will:

- continue to drive drunk and drugged
- continue to want personal transportation, greater speed, and perhaps more vehicles per person
- include more older, female, immigrant, and minority people
- demand different types of vehicles from now, e.g., vans vs. muscle cars
- expect that the vehicle and the highway infrastructure should protect them in the event of a crash
- demand more socially responsible vehicles
- not change their attitudes about vehicles
- not buy safety for safety's sake
- change their driving patterns because of working at home, living in rural work communities, use of alternative vehicles such as motorcycles and bicycles, and changes in the types of vehicles available.

Vehicle occupants will:

- change in terms of their size, physical condition, demographics, out-of-position locations in the vehicle, and ergonomic requirements
- have more disabling injuries in relation to fatalities
- have high medical costs due to injuries.

Vehicles will:

- have greater differences and incompatibilities among them technologically because of the aging of the fleet
- contain new technology such as intelligent vehicle highway systems (IVHS) or alternative fuels with uncertain safety impacts
- be subject to different regulations such as stricter Corporate Average Fuel Economy (CAFE) standards

- be designed for ease of assembly, disassembly,recyclability
- contain light-weight materials such as composites and aluminum
- have airbags front, rear, and side; obstacle detection systems; ABS; speed control; enhanced vision systems
- have higher prices due to the built-in expense of vehicle manufacturer employee health care coverage.

The highway environment will:

- contain more vehicles of various sizes and technologies
- not increase significantly in terms of new miles of highway built
- have more travel and congestion
- deteriorate due to poor maintenance of the infrastructure
- not safely accommodate drunk and drugged drivers
- have more hazardous materials carried on them.

Given these future characteristics, tradeoffs will exist between:

- safety and other vehicle design goals
- safety and other public goals
- safety and mobility
- infrastructure maintenance and other goals
- police resources for enforcement of speed, alcohol use, and other safety factors vs. other crime needs
- impairment detection and willingness to pay.

Further, without concerted thinking, planning, and implementation, no one will:

- provide coordination among the plethora of data bases available, e.g., police data bases and medical facility data bases
- reduce or eliminate actions on the part of politicians, the media, and industry (particularly alcohol) that are potentially counterproductive to efforts to promote safety

- provide effective integration of transportation into the larger society, e.g., locations of places of employment, shopping, alcohol-licensed establishments
- modify product and tort liability legislation so as to enable the development of new products and practices to facilitate the efficiency of the transportation system and to enhance safety
- coordinate and facilitate the intermodal transfer of both people and goods
- coordinate the efforts of local, state, and federal governments and other organizations in improving safety
- control the growth of medical costs through preventive measures, including primary, secondary, and tertiary prevention."

Although traffic safety was the area of focus for this scenario, the symposia participants are also experts in the broader field of transportation, and their insights can be applied directly to the situation surrounding the planning and implementation of intelligent transportation systems. For example, drivers will have similar attitudes pertaining to their transportation, whether planners are thinking of safety or MIS. Therefore, it can be anticipated that drivers will expect that they will be taken care of by forgiving vehicles and environments; have different driving patterns; and not voluntarily curtail their drinking and driving. These drivers will be carrying passengers who will be different from today's passengers in terms of size, age, physical condition, demographics, and ergonomic requirements. Vehicle occupants will be older, more likely female, and larger and smaller than they are today. Vehicles are expected by this group to offer new technology and therefore be in potential conflict on the roadway with older, not so well equipped vehicles; have more safety equipment; and cost more than they do today. At the same time, it is expected that the roadway infrastructure will deteriorate. All this will occur in a time of a lack of cooperation across organizational entities. The warning is given by this group of experts that it is now past time to consider how to address many of the societal issues that come to bear on the transportation system and to coordinate transportation planning and implementation activities across organizational boundaries. In fact, of the over fifty issues identified by this group of experts as being important in traffic safety in 2010, the vast majority of them had to do with the people and institutional aspects of the transportation system rather than the technological ones.

Some of these same societal and economic issues are raised by Pisarski (1994). He indicates that there are societal forces of stability such as population, labor force age, drivers' licenses, vehicles, women workers, and vehicle miles of travel (VMT) “ceilings”. Also, there are forces of change including women, immigrants, the young and old, low income, and the inner city. Although the traffic safety experts did not address forces of stability, these forces of change are totally consistent with those raised by them.

Delphi Forecasts of the Automotive Industry

A Delphi survey conducted by the Office for the Study of Automotive Transportation atThe University of Michigan (Cole et al. 1994), contained the following opinions on circumstances in the year 2003. There were over 200 Delphi panel members who participated in one of three panels: Marketing, Materials, or Technology. These people are in senior management in the automobile manufacturing industry or the automotive supplier companies, or are practicing scientists or engineers. The views expressed are their current opinions of what the future will be like in about ten years. The responses reported here are based on the median scores of the panel members for the questions asked.

Political and Economic Factors Affecting Business Strategy

The forecasts of several of the political and economic factors affecting automotive business strategy (and therefore also other economic conditions) showed little change the next ten years. Among these are the personal taxation rate, business taxation rate, federal budget deficit, personal savings rate, trade value of the U.S. dollar, the trade deficit, and the unemployment rate. On the other hand, increases were expected in manufacturing competitiveness, annual GNP change, and energy prices.

Economic, Social, and Consumption Factors

Economic, social, and consumption factors that influence the level of new vehicle demand that were expected to increase slightly over the next ten years include the age of the operating fleet, real transaction price of new autos, used car prices, vehicle insurance premiums, personal loan interest rates, use of mass transportation, and real disposable personal income. None of the economic, social, nor consumption factors were expected to decrease.

Fuel Prices

Compared to a baseline of $1.10 in 1992 for a gallon on unleaded regular gasoline, panelists estimated that the equivalent real retail price of gasoline per gallon in the U.S. in 2003 will be $1.70.

Federal Regulatory and Legislative Activity

It is anticipated that the following U.S. federal regulatory and legislative standards will be somewhat more restrictive in 2003 than they are in 1994: fuel economy standards, occupant restraint / interior safety, product liability, vehicle integrity / crashworthiness, and vehicle emission standards.

Manufacturers Suggested Retail Price

Compared with a model year 1993 Manufacturers* Suggested Retail Price of $16,186 for an intermediate / family car, panelists expected the equivalent car prices in 2003 to increase as follows: Big 3 at $19,000, Japanese nameplate at $19,600, and European and others at $22,000.

Vehicle Age and Ownership Periods

Delphi Study panelists estimated that the average age of passenger cars in the United States will increase from 7.9 years in 1992 to 8.5 years in 2003, and that the length of ownership by new car buyers will grow from 5.5 to 6.0 years over the same time period.

Vehicle Sales Smart Vehicle Features

Panelists estimated the following total U.S. passenger new-car market, domestic and import, penetration rate (in percent) for the following “smart” vehicle systems for 2003:

Near-object detection (back-up warning)	3
Adaptive cruise control	7
Collision warning (front, rear, and side radar)	5
Night vision enhancement	5

Radio call for help locator	10
Automatic toll collection	5
Navigation	5
In-vehicle message system	10

CAFE Standards

The Delphi panel members expect that the CAFE standards that can be reached by the different manufacturer groups by 2003 are:

Traditional domestic	32 mpg
Japanese - foreign and domestic	35 mpg
European - foreign and domestic	30 mpg

The expectations provided by the Delphi panelists give us some insight into what the future of factors affecting intelligent transportation system technology might be. If we aggregate the expectations pertaining to these factors, we can suggest the following scenario of the future. This scenario would have increasing vehicle and fuel prices and average age of vehicles on the road causing a dampening effect on the increase in demand for new vehicles, somewhat offset by a growing population needing cars and a modest increase in real disposable income. One indicator of this trend will be the increasing average age of new-car ownership. The new cars sold will be more energy efficient, safe, and environmentally friendly, although only a very small portion of them would be equipped with “intelligent” technology, perhaps because of the cost of the new technology. Because of the higher cost of cars and fuel, those people needing transportation may buy less expensive cars or switch to other, less expensive, modes of transportation. However, there would not be a decrease in vehicle miles of travel if the effects of higher fuel and vehicle prices are counter-balanced by the greater fuel efficiency of new vehicles and an increase in population.

Travel Trends

In 1992, 98% of the vehicle miles of travel (VMT) in the United States were on the highway. (U.S. Department of Transportation 1993) Between 1983 and 1990, VMT in the United States grew by

40%. Causes for this increase were distributed among the following factors by the percent noted: population increase (13%), person trips per capita (18%), mode shift (16.6%), vehicle occupancy (16.6%), and trip length (35.9%). Much of the increase in trip length was due to longer work trips which increased by 29% over the seven-year period. (U.S. Department of Transportation 1992). To the extent that work trips continue to grow in the future as they have in the recent past, there will be definite implications for increased congestion in the non-traditional work-trip commute areas.

Implications of Factors for Intelligent Transportation Systems

Table 5 contains a listing of the IVHS User Services. (IVHS America, 1994). It includes twenty-eight technologies that may be offered over the next several years. For the purposes of presentation in this paper, they are aggregated into their service groupings and presented in Figures 2 and 3, respectively, along with some of the societal and economic factors that may affect them or be affected by them (in a positive, negative, null, or uncertain way). These figures represent a preliminary and speculative attempt, without specific analysis, to synthesize the forecasts of several groups and individuals into influence charts. These charts are not meant to represent the ultimate "truth" on the relationship between societal factors and transportation systems, but rather are offered as discussion starters. Although the charts do not address the locational issues, it is important to recognize that every impact of an intelligent transportation system is felt at the local level. At the same time, it is necessary to consider regional, national, and international impacts that may occur. Note that the first row of Figure 2 shows the expected penetration rates of various intelligent transportation technologies into the new-car fleet. These are based on the expected penetration of one or more of the technologies in the user service group as estimated by the Delphi study panel members. The charts show a wide range of types of relationships, and future research aimed at establishing and quantifying these relationships is necessary.

ANALYTICAL METHODS TO ADDRESS SOCIO-ECONOMIC ISSUES

There are many analytical methods available to address the societal issues attendant to the deployment of an intelligent transportation technology. Albers and others (1994) presented several of these at the 1994 SAE International Congress and Exposition. He and others on a subcommittee of the Societal

Table 5

IVHS USER SERVICES

Travel and Traffic Management	**Commercial Vehicle Operations**
Pre-trip Travel Information	Commercial Vehicle Electronic Clearance
En-Route Driver Information	Automated Roadside Safety Inspection
Traveler Services Information	Commercial Vehicle Administrative Processes
Route Guidance	On-Board Safety Monitoring
Ride Matching and Reservation	Commercial Fleet Management
Incident Management	Hazardous Material Incident Notification
Travel Demand Management	**Electronic Payment**
Traffic Control	Electronic Payment Services
Public Transportation Management	**Advanced Vehicle Safety Systems**
En Route Transit Information	Longitudinal Collision Avoidance
Public Transportation Management	Lateral Collision Avoidance
Personalized Public Transit	Intersection Collision Avoidance
Public Travel Security	Vision Enhancement for Crash Avoidance
Emergency Management	Safety Readiness
Emergency Vehicle Management	Pre-Crash Restraint Deployment
Emergency Notification and Personal Safety	Automated Vehicle operation

Source: IVHS America (1994)

FIGURE 2 - SOCIO-ECONOMIC FACTORS AFFECTING INTELLIGENT TRANSPORTATION SYSTEMS

+ Positive Impact - Negative Impact o No Impact ? Uncertain	**Advanced Vehicle Safety Systems**	**Emergency Management**	**Commercial Vehicle Operations**	**Electronic Payment**	**Public Transportation Management**	**Travel & Traffic Management**
Liklihood of (%) Penetration (2003)	3-10	10		5		5
Population Growth	o	o	+	+	+	+
More Elderly	o	o	o	?	+	+
Highway Constraint	o	o	+	+	+	+
Regulation	+	+	+	?	+	+
Drunk Driving	o	o	o	o	+	+
Ergonomic Changes	o	o	o	o	?	?
CAPE	o	o	+	+	+	+
Clean Air Regulations	o	o	+	+	+	+
VMT Increase	o	+	+	+	+	+
Poor Highway Maintenance	o	+	?	?	+	?
Little Coordination Across Institutions	-	-	?	?	-	-
Litigation	-	-	-	-	?	-
Energy Price Rise	o	o	?	+	+	+
GNP Growth	+	+	+	+	?	+
Increasing Age of Fleet	o	-	?	?	?	?
Increase in Car Price		-	?	+	+	?

FIGURE 3 - SOCIO-ECONOMIC FACTORS AFFECTED BY INTELLIGENT TRANSPORTATION SYSTEMS

Advanced Vehicle Safety Systems	**Emergency Management**	**Commercial Vehicle Operations**	**Electronic Payment**	**Public Transportation Management**	**Travel & Traffic Management**	+ Positive Impact - Negative Impact o No Impact ? Uncertain
-	-	o	o	+	+	Access by Disadvantaged
-	-	o	o	?	-	Affordability
o	o	+	+	+	+	Air Pollution
o	o	?	+	?	?	Crime
?	o	+	+	+	?	Congestion
+	?	?	?	?	o	Cyclists
o	o	o	o	+	o	Health Care
+	?	o	o	+	-	English as Second Language
o	o	o	-	+	o	Intermodal Access
o	o	o	-	+	+	Isolation
-	-	?	-	?	-	Legal Issues
o	o	o	-	+	o	Neighborhood Viability
o	o	+	+	-	o	Noise Pollution
-	-	?	-	-	?	Non-Users of System
				?	?	Privacy
o	o	o	o	?	+	Recreation
+	+	+	o	?	o	Safety

Implications Task Force of IVHS America are in the process of compiling an inventory of such methods. It is expected that the inventory will be completed by the end of 1994. Among these methods are decision analysis, conflict resolutions techniques, focus groups, Delphi studies, futuring, scenario development, influence diagrams, scanning and monitoring the environment, econometric analysis, epidemiological techniques, and expert systems. These methods have been used widely in many sectors of the economy, but not extensively in the transportation systems analysis arena. Other methods, such as the "direct legitimacy approach" rely on direct system user input. (Hauer 1994) All these methods represent fertile ground for exploratory research for application of methods and the opportunity to incorporate into the planning process the societal issues with a rigor that exceeds simple acknowledgement and discussion.

FUTURE RESEARCH NEEDS

In order to begin to address the societal and economic factors that interact with the transportation system, there is an abundance of work that must be done. First, the issues that are not considered to be technical issues must be identified and categorized in some logical way. Second, some attempt must be made to quantify the impact of those factors on the transportation system and the effects of changes in the transportation system upon them as well. To do this properly, an identification of the available analytical techniques needs to be made followed by demonstrations of their applicability to the societal / economic arena in transportation systems analysis and planning. Some will prove to be useful, while others may not. There is every reason to pursue this line of research, and few reasons not to begin now.

SUMMARY AND CONCLUSIONS

This paper represents an identification of many of the societal and economic issues attendant to transportation systems, a summary of several efforts to forecast the future pertaining to transportation systems and the environment surrounding them, an effort to link them together in a relational way, and a call for attention to be focused on addressing this issue as analytically as possible as early as possible in the planning for the implementation of intelligent transportation technology.

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INTELLIGENT VEHICLE/HIGHWAY SYSTEMS (IVHS): ECONOMICS AND ENVIRONMENTAL POLICY

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ABSTRACT

This paper considers the environmental impacts of IVHS from an economic perspective. It discusses the potential public and private benefits of IVHS technologies and the role of the public sector in the development of smart cars, smart streets and smart transit. It concludes that some IVHS technologies can promote ***technological*** efficiency but that ***economic*** efficiency requires the use of policies that target the externality costs associated with automobile use.

1. INTRODUCTION

Intelligent Vehicle Highway Systems (IVHS) am intended to offer a variety of technological solutions to the nation's growing surface transportation problems.2 IVHS are a set of potential, new technologies designed to alleviate congestion and, in effect, increase road capacity, primarily by re-routing and smoothing traffic flow. Currently, IVHS activities are in various stages of research and development, operational testing and deployment (FHWA and FTA 1992). Federal legislation has allocated well over $100 million annually to these projects and eventual cost of IVHS deployment may reach the hundreds of billions of dollars (Horan and Gifford undated).

The public sector has traditionally accepted responsibility for transportation infrastructure investment because of the public services provided. However, although IVHS deployment involves large infrastructure investments, including traffic surveillance and communications systems, the benefits provided will be both private and public to varying degrees. In addition, because successful deployment of IVHS technologies require the financial base, marketing capabilities and technological expertise found in the private sector, a partnership is developing between the public and private sectors for the purpose of achieving IVHS deployment (FHWA

1992). These facts raise policy questions concerning the role of public sector involvement in IVHS deployment.

This paper discusses the potential, public and private benefits of IVHS technologies and discusses the role of the public sector in the development of smart cars, smart streets and smart transit.3 The stated purpose of IVHS is to effectively expand roadway capacity, allowing more people to use the roads and travel faster than before, a public benefit. But the surface transportation system as a whole imposes large public costs, including congestion and environmental externalities, that might be exacerbated by the increased automobile use that IVHS is expected to encourage. This paper addresses the policy implications of IVHS implementation, particularly with respect to environmental quality.

The next section discusses two concepts in the economics of transportation that are relevant to this discussion: externality costs and latent demand. Section 3 draws on this discussion as well as theoretical research about the travel behavior implications of IVHS technologies and empirical evidence about travel behavior to assess the public and private benefits of smart cars, smart streets and smart transit. It asks whether public sector investment is appropriate for the IVHS technologies considered here. Public sector investment is appropriate when public benefits are sufficiently large relative to the cost of program implementation. As we consider IVHS implementation, we must also address the external costs associated with the potential increase in automobile use. Section 4 focuses on environmental policies for transportation and discusses their relationship to IVHS policy. Section 5 summarizes the key points of the paper.

2. ISSUES IN TRANSPORTATION POLICY

The Social Cost of Driving

According to economists, the problem with automobile use is that automobile users do not pay for the time delay and environmental costs they impose on others. The costs of automobile use can be divided into two categories: private costs and public (external) costs. Private costs are those actually borne by the driver and consist of gasoline costs, parking fees, road tolls, wear and tear on the automobile and the opportunity cost of travel time. External costs include congestion costs (the increased time spent by others on the road as a result of the marginal increase in congestion created by an additional car), air, water and noise pollution, increased risk of traffic accidents and increased deterioration of the roads. The sum of private and public costs is the full social cost of driving. Individuals weigh their own, private costs against the benefits they anticipate from driving to determine how much driving they will do. Because their driving produces external costs, the result is a market inefficiency where total social costs exceed total (mostly private) benefits. A recent estimate suggests that time delay costs alone exceed ***$22*** billion annually (Hanks and Lomax 1991).

Latent Demand

The question of how IVHS will affect the social burden of environmental and congestion costs is a complicated one. IVHS is targeted at the congestion problem and is intended to decrease travel delays. This effect decreases part of the privately-borne cost of driving and promotes automobile use, increasing both vehicle miles traveled (VMT's) and number of trips. This is a phenomenon known as latent demand.

Latent demand refers to the additional, unanticipated vehicles that appear on new roads because people switched routes, modes or travel times, or because they decided to take trips they had previously not taken. Latent demand is present when congestion is severe enough to deter people from taking trips using their most preferred routes, modes or times of day. When new road capacity becomes available, these people switch to their more preferred trip plans and might even cause congestion to return to its previous level.[4] Note however, that although travel times may not improve, more people are taking more convenient trips than before. This is an economic gain that should not be ignored when evaluating plans to increase road capacity. From an environmental quality perspective, however, more cars, which might be traveling at the same slow speeds as before, generally means more emissions.

A full assessment of the costs and benefits of using IVHS to reduce congestion therefore requires an understanding of the extent to which latent demand will offset travel time gains. Most reports of latent demand have been based on ***expust studies.*** For example, Sherret (1975) found that after the Bay Area Rapid Transit (BART) opened in the San Francisco Bay Area, 8,750 transbay trips were diverted to BART, but 7,000 new automobile trips were generated. Using the ***stated preference*** approach to estimating latent demand, Kroes et al. (1987) found that latent demand in western Holland would add 27% to the existing evening peak hour traffic.

To date, Henk (1989) seems to have provided the most comprehensive study estimating and predicting latent demand for the state of Texas. Using data from before and after new roads were introduced in 34 selected study sites in Texas, Henk (1989) finds that the existing volume to capacity ratio (an indicator of the severity of congestion) and nearby population density positively affect the magnitude of latent demand. For example, in his study, a percentage increase in volume to capacity increases latent demand by around 90 vehicles. Latent demand can be as high as 13.8 times the population density depending upon whether the new road crosses a natural barrier, is a freeway and is radial rather than circumferential.

It is impossible to make a general assessment of how much latent demand IVHS would induce because latent demand is clearly a location-specific phenomenon. However, Henk's (1989) model and the BART example suggest that in areas where congestion is particularly severe, latent demand is likely to be high enough to offset a large percentage of the travel time gains created by new road capacity.

3. ECONOMIC IMPACTS OF IVHS

This section summarizes the main types of IVHS technologies and evaluates the primary expected impacts based on the incentives created. A convenient way to review IVHS technologies is to refer to three general categories: "smart cars," "smart streets," and "smart transit." Smart car technologies refer to privately owned technologies that are installed in individual automobiles such as Advanced Traveler Information Systems (ATIS) and Advanced Vehicle-Control Systems (AVCS). ATIS are intended to provide the driver with real-time information about traffic conditions and optimal route-planning. AVCS are intended to provide automatic steering and braking controls that allow closer following distances and faster speeds. Smart streets refer to Advanced Traffic Management Systems (ATMS) which are infrastructure-based monitoring systems intended to be used for traffic smoothing and accident detection. Smart transit technologies include real-time transit schedule information and high-tech fare cards which are intended to make transit systems more attractive relative to automobiles.

Smart Cars

Smart cars are intended to reduce congestion by providing people with real-time information about road conditions and better vehicle control systems. Implementation of ATIS involves large infrastructure investments in traffic monitoring and communications systems as well as individual information dissemination units which may take the forms of at-home telephone subscriber services or in-vehicle technologies. AVCS are primarily in-vehicle technologies.

Some ATIS owners, upon learning of congested conditions, will presumably choose to travel using alternate routes, modes or times of day, or maybe even forgo their trips altogether. The intended result is that overall travel times are reduced. Arnott, de Palma and Lindsey (1991) have shown, however, that this might not be the case. They use a general equilibrium framework to consider how providing information to travelers will affect expected travel times and find that there are many potential outcomes depending on the number of travelers receiving information, how they react to information, how they expect others to react and how reliable the information is. One possible outcome, for example, is that when people learn of congested conditions, they postpone their trips only to cause congestion when they all get on the road at a later time. Arnott, de Palma and Lindsey (1991) also find that the per vehicle, private benefits are greatest when information is provided to only a few individuals and private benefits decrease as the number of individuals receiving information increases. When all individuals are equally informed, travel times can even increase.

It is important to point out that during periods of recurring congestion people will have already optimized their trip routes and timing to deal with congestion. In other words, people will have already sorted themselves out so that those who experience the highest costs from congestion have found ways to alter their routes or timing and those who are more willing to bear the congestion costs stay on the congested roads during these times. Adding new information to this long-run equilibrium might not alter the amount of congestion that exists.

It is estimated that as much as 60% of congestion is non-recurring (Lindsey 1989); but non-recurrent (incident-related) delays occur because highways are overloaded to start (Hall 1993). Traffic diversion therefore requires surplus capacity on nearby alternate routes. During congested times, this capacity might not be available. Al-Deek and Kanafani (1993) show that although guided traffic is better than unguided traffic in situations of non-recurring congestion, the benefits associated with traffic diversion are mitigated by the congestion that is bound to form on the alternate routes. In fact, they suggest that there are little, if any, benefits associated with guiding traffic during peak periods, the most important periods to target.

The results in the literature seem to suggest that smart cars are most effective in situations where only a few individuals have them. If this is true, then there will be few public benefits associated with smart cars and the marketplace can take care of optimizing total net (private) benefits. Drivers who see potential benefits exceeding the costs will purchase the technologies.5 The purchasers of smart cars will be those who place the highest values on time, and as more smart cars appear and benefits diminish, purchases will slow down. The result should be an optimal allocation of smart car technologies that maximize net private benefits. Because smart car technologies offer primarily private benefits, they should be produced and sold as private market goods that may have a small public benefit associated with them.

Some might argue that although it is practical for the private sector to provide individual units of smart car technologies, it is still public sector responsibility to provide the traffic monitoring infrastructure (see FHWA 1992). This, however, is not the case. If the private benefits of smart car technologies exceed the full cost of implementation, then private firms will find it profitable to invest in infrastructure as well as equipment development. If they do not find it profitable, then it would be a poor investment for the public sector as well. The potential public benefit does not appear to be large enough to warrant government subsidization of smart car technologies.

Smart Streets

ATMS are sometimes called "smart streets." They include technologies for on-road surveillance and control of traffic flows through signal synchronization and ramp-metering systems, among other things. Preliminary testing of these systems has found time savings in several cities. For example, estimated improvements from ramp metering systems have shown increased speeds of 35% with increased throughput of 32% in Minneapolis-St. Paul and reduced travel times of 48% with increased throughput of 62-86% in Seattle (Federal Highway Administration 1989, cited in Shiladover 1993). The automated traffic surveillance and control system (ATSAC) in the City of Los Angeles has measured improvements of 13.2% in travel times, 14.8% in average speed and 35.2% in fewer stops (Rowe, Okazaki and Hu 1987, cited in Shiladover 1993).

As mentioned earlier, improving traffic flows will induce latent demand which, over time, might counteract the congestion and emissions benefits measured in these examples. Still, there are benefits associated with getting more people where they want to go at the times of day they prefer.

Because ATMS are intended to accomplish travel time reduction by traffic re-routing and smoothing, one of their side effects might be a reduction of VOC emissions ***per VMT. The*** anticipated result is that we have more cars traveling at faster and less-erratic speeds, perhaps producing fewer emissions per VMT than before. Unfortunately, we do not yet fully understand the relationships among VMT's, number of trips (cold starts), speed and emissions so we cannot unequivocally say whether or not emissions or other automobile-related externalities increase or decrease as a result of ATMS implementation (Sperling et al. undated). Smart streets appear to promote system efficiency, a public benefit, but the overall externality impacts, especially environmental impacts, remain an empirical question.

It is useful here to distinguish between technological and economic efficiency. Technological efficiency refers to the engineering aspects of a system rather than the allocative aspects. If there are bottlenecks in the system, then there are potential gains associated with alleviating these bottlenecks. These gains are separate from the question of whether we have too much traffic to start We do not promote economic efficiency by maintaining the bottlenecks and allowing excessive travel times to discourage people from driving.

ATMS are meant to target technological efficiency, and when evaluated on this basis, they seem to potentially offer substantial, public benefits, warranting public sector investment. In light of the potential increase in automobile use these technologies encourage, however, it will become even more important to pursue policies that target environmental externalities.

Smart Transit

Smart transit is intended to improve the attractiveness of transit primarily by providing real-time information to travelers about transit schedules. This should reduce wait times which are known to be considered negative attributes of transit. Smart cards will offer riders convenient payment methods without having to carry exact change. Smart transit is often used as the primary example of how IVHS will help diminish transportation's negative environmental impacts. The idea is that increasing the attractiveness and accessibility of transit increases its use and decreases automobile use and VMT's.

Unfortunately, expectations in this regard are probably overly optimistic.6 It is clear from the results of research on mode choices that transit is considered an inferior option compared to the automobile for most transportation users. Most transit systems presently make up less than 2% of the mode share in their respective cities. Inducing a significant reduction in automobile use would require a more than tripling of transit use in such cities, a difficult goal to achieve.'

Because the primary benefit of smart transit is reduced transit wait time, we can look at empirical models of mode choice that include transit wait time or transit headway time (the scheduled time between transit vehicle arrivals; wait time is often assumed to equal one-half of the headway time) in order to get an idea of how smart transit could increase transit ridership. Tram (1980) for example, estimates mode choice and vehicle ownership for work trips in the Bay Area using a multinomial, nested logit model (McFadden 1973,1978) and includes separate variables for transit headway and m-vehicle times. We can estimate an elasticity representing the percentage change in the probability of choosing transit with respect to a percentage change in transit headway time (Train 1986, p. 40). This elasticity is a function of the probability of choosing transit, the transit headway time and the estimated coefficient on transit headway. Using Train's (1980) estimation results, we find that the elasticity is -0.21 when the transit headway time is 10 minutes. For example, the probability of choosing transit increases 2.1% when headway time is reduced from 10 minutes to 9 minutes (a 10% change). Transit use in the Bay Area sample is estimated to be 19% of work trips (an unusually large mode share), so a 2.1% change in the probability of transit use would increase the transit mode share by 0.4%.8 Note that if we applied the same elasticity to a low-transit-use city, the magnitude of the increase in transit use would be much smaller than this. Reducing transit wait time through smart transit will increase transit use but not by amounts large enough to significantly reduce VMT's.

Nevertheless, improving transit, if coupled with a policy that provides a disincentive to drive, can offer substantial benefits. Price elasticities for automobile use have been shown to range between -0.1 and -0.5 (Goodwin 1992, Oum, Waters and Yong 1992). Improving the attractiveness of transit could increase the magnitudes of these elasticities by offering more viable substitutes for the automobile. Smart transit could be an important policy complement to environmental pricing.

Summary of Results

Table 1 summarizes the potential public and private benefits anticipated from investments in smart cars, smart streets and smart transit and the appropriate role of public sector investment.

This section has argued that the three broad categories of IVHS will have differing economic and environmental impacts. Smart cars will primarily offer private, time-savings benefits and should therefore be developed and sold in the private sector without public support Smart streets will offer public benefits by allowing more people access to the roads at peak times, but in the absence of countervailing pricing policies, might negatively affect the environment by increasing VMT's and number of trips. Smart transit will offer marginal public benefits, including environmental benefits, by encouraging transit use instead of automobile use. The effectiveness of smart streets and smart transit could be enhanced by policies that discourage automobile use. Some potential policies are mentioned in the next section.

4. IVHS AND ENVIRONMENTAL POLICY

The stated purpose of IVHS is to effectively expand roadway capacity through the use of technology. This is indeed an important goal given the high and growing costs that congestion imposes on society.[9] But because the surface transportation system as a whole harms the environment, this stated purpose seems to be directly at odds with the environmental goal of reducing emissions.[10] Even if IVHS does not adversely affect the environment, it is probably not the most effective policy for pursuing environmental improvement. A basic notion in economics is that the best way to pursue a policy goal is to target that goal directly (Baumol and Oates 1988). In the case of transportation policy, we seem to have two opposing goals: to move people as efficiently as possible given the present transportation infrastructure (technological efficiency) and to reduce transportation-related externalities (economic effkiency).

Ideally, the notion of moving people as efficiently as possible would incorporate both goals simultaneously. Efficiency implies least cost, and if we forced people to pay the full cost of driving, we would indeed obtain an efficient solution that balances the benefits associated with automobile use with the full social costs, including congestion and environmental externalities (Baumol and Oates 1988). But the present system is far different from this economically ideal world. People do not pay the full cost of their driving and it is not clear that they will do so anytime soon.[11]

In our non-ideal world, it makes sense to pursue the goals of technological and economic efficiency using a mix of policies where each goal is targeted directly using the appropriate mechanism. Following this prescription, it can be argued that some IVHS technologies show promise in promoting technological efficiency (reducing travel times or increasing throughput) while other policies such as congestion pricing or emissions testing can be used to combat the serious environmental problems created by the system as a whole, promoting economic efficiency. In other words, the idea of getting more people where they want to go faster than before is a public benefit.12 The fact that at present, people are not paying for the costs they impose on society when they drive generates a large public cost. These costs must be addressed using appropriate policies, especially as we consider introducing IVHS technologies which might exacerbate some of these costs.

There is a growing literature evaluating emissions-related policies including reformulated gasoline, enhanced inspection and maintenance programs, alternative fuels, congestion pricing, gasoline taxes and accelerated vehicle scrappage programs (Alberini et al. 1993, Geoghegan et al. 1994, Harrington, Walls and McConnell 1994, Krupnick 1992, Krupnick, Walls and Hood 1993, Walls 1992). Harrington et al. (1994) find that, in general, policies that rely on economic incentives, such as emissions rate-based vehicle registration fees, and target high emissions rates, such as vehicle inspection and maintenance programs, are more cost-effective than technology-based policies, such as alternative fuel vehicles and California emissions standards.

If we are interested in targeting automobile-related emissions we must design policies that create the appropriate incentives. The cost-effectiveness of a program depends crucially on the abiity of a program to target high-emitting vehicles, especially those that are heavily used. In addition, to maximize benefits, it is important to focus on critical areas, at critical times of day, during critical seasons. It may be impossible to develop one program to satisfy all of these criteria at once, but it is clear that certain programs are more likely to create the appropriate incentives for high-emitting vehicle owners. For example, Hanington et al. (1994) recommend an emissions rate-based vehicle registration fee coupled with a VMT-based fee, which would focus both on emissions rates and amount of vehicle use and encourage owners of these vehicles to maintain them properly and/or drive less.

Pricing policies such as gasoline taxes and congestion pricing are advocated by economists because they directly target externalities by increasing the privately borne costs of automobile use. Gasoline taxes, however, do not focus on congested areas and times and therefore might result in more diffuse emissions and congestion reductions that might not bring large marginal benefits (Krupnick et al. 1993). Congestion pricing is primarily intended to reduce congestion costs but also has the benefit of reducing the higher VOC emissions associated with congested conditions. Recent empirical work by Geoghegan et al. (1994), Mohring and Anderson (1994) and Repetto et al. (1991) has shown that optimal congestion fees can substantially reduce congestion and emissions costs and produce significant public benefits.

It is beyond the scope of the present paper to review the aforementioned environmental policies in detail. They are mentioned here as policies that directly target emissions and can be used in conjunction with certain system efficiency-enhancing MIS programs. It should also be noted that IVHS technologies can be used to facilitate implementation of some of these environmental policies. Advanced Vehicle Identification (AVI), for example, can facilitate road tolling for congestion pricing. AVI might also be used in association with remote emissions-sensing devices to fully automate an emissions rate-based pricing scheme.

5. CONCLUSIONS

The purpose of IVHS is to effectively expand roadway capacity through the use of technology. Based on preliminary test results and theoretical reasoning, it appears that the programs with the highest potential for improving public benefits are ATMS. Preliminary tests show potential for improving system efficiency by increasing throughput and possibly, reducing travel times (depending on the amount of latent demand induced). ATMS, like most IVHS technologies, will encourage automobile use so that total VMT's will increase, making it possible that congestion will return to its original level. But the external costs associated with VMT's and congestion should be addressed using policies targeted directly at these problems.

Smart transit technologies are said to enhance the attractiveness of transit and encourage its use over the automobile. Based on mode choice estimation results and existing mode shares, however, it is not clear that these technologies alone will achieve significant reductions in automobile use. But when combined with pricing policies that discourage automobile use, smart transit might be appropriate and even necessary, depending on the cost of implementation.

Smart cars seem to offer mostly private benefits. These technologies should therefore be developed and sold in the private sector without public participation in their development.

The approach taken in this paper is to consider IVHS technologies in a broad sense. Within the categories discussed, there are specific ideas, not mentioned here, that might warrant special consideration, such as smart vanpools or smart communities. There might also be complementarities associated with particular combinations of technologies.

The purpose of the present paper is to discuss IVHS in a policy context, looking at public and private costs. IVHS will not solve all of our transportation problems and might even exacerbate some, especially environmental costs. We must therefore begin to think comprehensively about an overall transportation policy mix that addresses both system inefficiencies and economic inefficiencies.

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Table 1: Potential Benefits of IVHS and Role of Public Sector

IVHS Technology	Description	Potential Public Benefits	Potential Private Benefits	Appropriate Role of Public Sector
smart cars	- Route guidance (to avoid congestion) - automatic vehicle controls	- Small reduction in congestion and travel limes - Uncertain effect cm total VMT's and emissions	Large travel time savings by avoiding congestion	Leave all investments to private sector
SmartStreets	Infrastructure-based systems to control and smooth traffic	More road capacity that allows more people to travel when and where they want	Latent demanders get access to roads	Invest when public benefits are greater than implementation costs
Smart Transit	- Real-time transit schedules - Easy payment methods	Very small improvement in congestion aud emissions	More convenience for transit users	- Invest only where potential transit ridership might substantially increase - Consider as complement to a pricing policy

ENDNOTES

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2 See Downs (1992) and Small et al. (1989) for discussions about trends in transportation use, congestion, environmental costs and infrastructure constraints.

3 Unfortunately, because IVHS technologies are new and untested, it is impossible to make a reliable quantitative assessment of the economic and environmental impacts of IVHS. Instead, many researchers have evaluated aspects of the IVHS program on a qualitative basis, or hecommended research directions or methodologies to aid in making quantitative assessments in the future (Horan and Gifford undated, Shiladover 1993, Underwood and Gehring 1992). This paper performs a qualitative analysis.

4 In the long run, people may choose where to live or work based on new road capacity, so the full extent of increasing road capacity may not be seen until many years after implementation

5 The high cost of smart cars will prohibit most people from purchasing them. This has led to concern about equity issues. This concern is valid when the public sector is subsidizing development and production, but would not be an issue should ATIS become a purely free-market good.

6 Shiladover (1993) for example, suggests that smart transit could improve greenhouse gas emissions by 10% to 30%.

7 Furthermore, an inordinate increase in ridership might require larger transit operations which might impose increased environmental costs in some cities.

8 The elasticity decreases as the headway time decreases, so multiplying the 0.4% effect by 10 minutes would overestimate the amount of transit use resulting from a complete elimination of wait time. Thus, 4% is an ***upper bound*** of the increase in transit mode share.

9 Congestion has been estimated to be roughly equal to one-third of the total social cost of driving (Small 1992, p. 84)

10 The nation's surface transportation system presently contributes 70% of carbon monoxide (CO), 39% of nitrogen oxides (NO_x), and 30% of volatile organic compound (VOC) emissions (USEPA 1992). In urban areas that violate the National Ambient Air Quality Standards (NAAQS) the shares of automotive emissions are even higher.

11 There has been increased interest in the idea of congestion pricing which would charge drivers for the congestion externality they impose. The Inter-modal Surface Transportation Act (ISTEA) of 1991 includes funding for congestion pricing pilot projects. At present though, there is only one pilot project underway (in the San Francisco Bay Area) and it may be years before implementation occurs.

12 Small (1992, pp. 36-45, 77) suggests that travel time for work trips is typically valued at 50% of the wage, or approximately $4.80 per hour for the U.S. in 1989. This information, in association with a location-specific estimate of latent demand, can be used to approximate the public value of increasing road capacity and possibly reducing travel time in a particular location.

INTELLIGENT TRANSPORTATION SYSTEMS

Building Consent for Post-Cold- War Transportation Initiatives

By Peter Roudebush and Harry Mathews

Introduction

Its the Summer of 1945, you call a friend in a small town in Vermont (Summer population 3000), and your call is transferred to where he is having dinner, because the town telephone operator is everyone's friend and often has been told or has heard where her subscribers are planning to be. Today, if you call Area code 617-951-1433 in Boston, you'll hear "Good Morning, you have reached the Boston Society of Architects "(population 11, not all full time). " "This is our user-friendly voice mail system. Please bear with me and I'll guide you where you wish to go. If you have a rotary or crank phone hold on, we can handle that too. If you know the extension of the person you want, push that extension now and I'll vanish. If you don't know their extension, push the pound or star key."

Does voice-mail answering really help your business? Does this technology save you and your client time and money? Is the value of that time more or less commensurate with what you would pay a receptionist? Should your business communications be entrusted to a machine or to someone answering the telephone?

The telephone operator who connected the caller with my father was doing something everyone thought normal in 1945. The country was at war. Everyone was helping one another (and the country) in a time of stress. People were planting their own vegetables; car-pooling to save gas; and helping one another cope with every imaginable problem. Today this feeling of cooperation seems to have disappeared. Many people seem to think, it can only exist in time of war. I am about to describe a way those feelings were evoked in peacetime around a transportation planning event which occurred twenty years ago. This may be a model for achieving consent for intermodal transportation systems today.

The planning event took place in Boston in 1971, and became one of the intellectual cornerstones of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). The Boston Transportation Planning Review (BTPR) was an enormously successful transportation planning experiment in public participation, which spontaneously conceived a locally initiated Metropolitan Area Intermodal Transportation Plan.

The BTPR was successful because its open public participation was integrated with broad interdisciplinary professional expertise. This allowed the public and the experts to explore transportation investment options together in detail. This enabled informed debate and the creation of common solutions. The review formulated holistic solutions no single person nor group could have conceived independently as accurately or as richly. It was not only a planning exercise, but an educational experience. Its results instilled deeply felt confidence on the part of everyone who participated. Participants sincerely felt their recommendations fully addressed their mandate carefully and accurately. The BTPR set the agenda for transportation planning for the Boston region for the next twenty years and has been followed with little controversy ever since.

The BTPR found out where Boston's constituency wanted to be led, and organized a plan leading in that direction. I will describe this process in more detail. It indicates one way seamless intermodal transportation could be achieved today. Such systems depend upon being made and run by people **wanting** to have them, wanting them to work, and wanting to work together to conceive, implement and operate them. The BTPR did that. But this kind of planning is not unique; similar techniques are now being used by major international corporations. These same techniques are helping businesses and manufacturers planning and building a myriad of post-Cold War facilities, tools and systems for a sustainable future.

The Boston Transportation Planning Review

In 1969, Massachusetts officials were having trouble acquiring public consent for an Interstate Highway "Inner Belt" for the Boston Region. Governor Francis Sargent instigated a review of the situation. The resulting BTPR, directed by Alan Altshuler, was designed with the help of Lowell Bridwell, former Federal Highway Administrator and representatives of state agencies, cities and towns, and interested citizens of the region. The review addressed a full spectrum of cross disciplinary criteria and interests including economics, social, environmental, historical, and landuse values, and urban as well as transportation design.

The BTPR's participatory process was very carefully constructed, and even began as the design for the study was being devised. Participation was made central to the actual planning taking place and made an integral part of it. No one was barred from participating. A special "Community Liaison" work element was separately funded to emphasize this and to help translate the concerns of interested citizens in case their contributions were not clearly understood by the professional team.

Citizens and experts saw their suggestions incorporated into the plan or amended as work progressed, perceived differently or accomplished through other means. Everyone who worked with the plan as it evolved were thus able to understand its implications. As a result, everyone connected to the plan - citizens, professionals and politicians - genuinely felt its product represented their own informed and considered opinions, hard work and self criticism. Their interaction generated mutual respect and even sometimes admiration. Ideas emerged which transcended groups or persons; it was extraordinary what wit and imagination came from voices which theretofore had been silent, including those of staid, well-seasoned engineers, who thought it not their place to make suggestions, nor that they might ever have an opportunity to do so even if they had a good idea.

Participants viewed themselves not as decision-makers, but as advisors to the Governor and the body-politic, providing technical and political information and feedback to and from citizens and government at all levels, defining ranges of possible decisions, the Governor, The Congress, the FHWA and FTA, the legislature and city mayors could take. "Alternative Program Packages' were carefully developed and evaluated, considering carefully everyone's interests. Because the process was ***inclusive*** and open, no one's agenda was excluded, nor were solutions based upon lack of information. Unknowns were treated in an informed manner leaving as many future options open to future decisionmakers as possible.

A clear statement emerged from the plan: that the people in Greater Boston wanted to reduce traffic congestion by using public transportation more and highways less to access the City. The plan, accordingly, schematically designed the systems to accomplish this objective in a thoughtful, detailed, specific, richly informed and well documented way.

Doubts persist about whether the BTPR was predisposed against Interstate Highways. The Inner Belt plan was openly evaluated along with other transportation alternatives, and its supporters were listened to very carefully. What emerged was recognition of the problem inherent to Interstate Highways in urban areas. In the country, building highways with four times the capacity of the traffic on surrounding streets is possible, but in cities, highways built to that same criteria, immediately fill to capacity. Urban Interstate highways are instantly too congested to serve for evacuation; its unimaginable how they could practically be constrained to work in an emergency. In non-emergencies, they increase congestion, because they allow more vehicles to use them than can access local streets. BTPR participants found so many more opportunities emerging from their mutual interaction, they put defense criteria in context, and went on to seek more rewarding solutions.

The BTPR recommended Massachusetts transfer some of the Interstate Highway funds apportioned to the Boston Region to transit instead of highway purposes, and that no additional highway capacity be built into the region's radial commuter road network. It recommended building a Third Harbor Tunnel to take through traffic out of the heart of downtown. This allowed north/southwest through traffic to connect directly with the Massachusetts Turnpike. It also recommended depressing a section of elevated highway built in the mid-1950's, which severs Boston's Business District from its historic waterfront, called the Central Artery. In the 1980s, even before the depressing the Central Artery had been approved, anticipation of the Project inspired a major economic renewal of the buildings surrounding the Artery corridor.

The principal transportation benefit of depressing the Artery was a rail link, to be built as part of it, between the two railroad systems serving north and south of Boston. This filled in the only missing track in rail service along the Atlantic Coast from Florida to Maine, and allowed commuter trains to traverse the city instead of terminating at separate stations. It opened new regional markets for labor and business activity by increasing City accessibility via public transportation, and made the use of interconnecting bus, transit and commuter rail systems dramatically more attractive through reduced transfers.

While the rail link didn't guarantee people would leave their cars at home or in suburban stations, it provided an attractive and affordable alternative means of travel into and out of Boston, and helped people walk to destinations in a restored historic waterfront through an environment designed for pedestrians. The rail link allowed highways serving Boston to be constrained, if the public wanted to reduce congestion, without sacrificing affordable accessibility to those who chose to enter or leave by rail.

The BTPR planning event and its resulting intermodal plan were so powerful, its recommendations were pursued with confidence. The excitement which had been created in Boston soon brought national attention and special focus to implement the plan temporarily eclipsing attention to other areas across Massachusetts.

Because the federal government had not yet approved ISTEA, the Central Artery Project became an Interstate Highway improvement under FHWA rules in 1983. I will say more about the Interstate Program in a moment. Under these rules, the design grew to carry three times more traffic. The rail link was dropped, because it was perceived to be in competition, and the project doubled in cost. As people found themselves less clearly associated with it and concerned about values they felt were being dismissed, the project further began to accumulate a staggering list of additional costs to “mitigate deficiencies”.

Last year, Massachusetts Governor William Weld formed a Task Force to determine whether the rail link could be returned to the Project. After three months, that Task Force found it could, and that rather than interfering with the Artery, it made it consistent with ISTEA and could possibly help its construction. Congress approved $4 million to start the rail link’s environmental impact statement, and the Massachusetts Legislative Transportation Committee approved $60 million in state funds to match federal preliminary funding. A full Legislative approval is pending approval of funds to help people all across the state. A Rail Link Caucus for members of the Massachusetts Legislature attracted the participation of 183 of the state’s 200 legislators last year, who recognized the rail link both as good politics and as good business.

There is strong business support for building the Central Artery Project and the Rail Link. Congestion constraints will be necessary to achieve mandated compliance with the national Clean Air Act Amendment. Constraining some of the traffic, built into it for defense reasons, may enable some of the Project’s costs, disruption and contention to be reduced. This could update the Project to make it even more consistent with national transportation policy and the BTPR master plan. It could also speed its implementation.

Disillusion and Cold War Spending Policies

That same summer of 1945, when you might have reached my father with Georgette's help at a friend's house in Vermont, America dropped the bomb on Hiroshima. It was as if I took a revolver from my briefcase, and fired it at the ceiling. The bomb captured permanent world attention in a single day. The waves caused by this explosion are still being felt now, fifty-years later, and are unlikely to subside any time soon.

That August day in 1945 changed an age of almost delirious optimism into one of almost equal cynicism within the space of fifty years. The dreams of unrestrained power and wealth resulting from a new age of machines had turned from good to evil. The powerful conviction that man's inventiveness could lead to whole new paths of life and great societies was shattered. Moral judgment and authority, the very foundations of American Democracy, were sorely and severely challenged. 200,000, mostly innocent people died in five days, and 150,000 more were to die in the next five years.

The excitement of discovery, and the energy gleaned from new sophisticated machines had started a race for world supremacy among industrial nations at the turn of the century. By World War II, most of this energy was focused on war preparations to control who would oversee its power. People had been preparing for or waging war for 30 years. Everyone had sacrificed time, energy, and money in the spirit of the nation's best interests and national defense, and had helped build the tools to win it. Then, that August day showed these same tools could unwittingly annihilate all life on Planet Earth.

It stopped World **War** II. The initial response at home was pure panic. We built bomb shelters, so some of us at least, would survive if a bomb landed on the United States. The "Doomsday Project" at the Pentagon, to sustain the country's leadership in the event of nuclear war, is only now being phased out.

The price of war had already taken its toll, the country was recovering from a severe depression, and money was scarce. Congress enacted a series of focused, single purpose, military-like programs to reinspire national reinvestment. These included massive federally subsidized and controlled programs in transportation, urban renewal, housing, banking, health and social security, everyone of which proved unsustainable.

Popular misconceptions about Cold War economic policies abound. Some of these programs might have been more sustainable had they focused upon longer-term objectives, but it was considered mandatory to regain government respect and quickly revive credibility, thus people's attention was riveted on short-term engagements. These inspired a wave of short-term profit taking, and nearly bankrupted the American economy.

Marketers, for example, made products specifically designed to wear out more quickly, on the theory that would persuade customers to repurchase. This idea quickly opened the doors to foreign competition. The oil industry created a cartel with automakers, steel producers, rubber, asphalt and concrete plants which regulated what could be sold and soon controlled highway construction. It was convinced this was how progress was made. It thought interconnected businesses were the wave of the future, which they might be if used less exclusively and less defensively. It mistakenly thought wealth came from keeping it from people who were not part of the cartel. The cartel thought our national defense highway system was helping our automobile industry, when in fact, it was keeping it from competing with German and Japanese manufacturers, who soon took over the industry.

Many people today believe conflict is inevitable and people can only work together in times of crisis. As a result, many people today are out-of work, profoundly skeptical, and the costs of doing business have skyrocketed. . Some wonder if all new technologies are dangerous. The Cold War with Russia may be over, but the Cold War between people here is still raging furiously.

These circumstances made fertile ground for the environmental movement. Born in reaction to short-term thinking and the consequences of that August day, it spread like red blood cells to a wound. As one might expect, it interfered with progress, and some of its soldiers still do. But it started to change our thinking to consider expediency differently, to look into long term consequences more fully, and to seek new ways of doing business.

Many people today don't understand why major public works should be stopped to preserve endangered species, while others are wondering if man isn't one of them. Neither crisis view is very useful in itself. But what the BTPR demonstrated was that both views have merit if both are pursued and refined together. As opposed to discarding views as too extreme to be important, the BTPR used opposing views to discover new solutions which sustained both action and long-term objectives more efficiently.

If we take a century-long overview of our progress this past century, we may not have progressed quite as radically as everyone expected and discovered that most of the problems and conflicts which have confounded man before persist. At the same time, our optimism and struggles to build new frontiers have driven us to discover amazing new ways to help confront these conflicts more knowledgeably, and we may be realizing for the first time that planning ahead might enable us to progress more fruitfully.

Post Cold War Intermodalism

Intermodalism is a new transportation term narrowly interpreted to mean improving the interrelationships between modes. But it is a concept which can and should be interpreted more broadly. Turning intermodalism from a challenge into an opportunity means allowing it to address not only travel modes, but the multiple social, economic, and environmental values which influence transportation choices and decisions. Many transportation research investments can be made narrowly, but will gain value and purpose if linked to other interests through cross-modal, cross-disciplinary thinking. These are considerations, which all levels of government and private industry must now address to achieve more sustainable economic systems, tools, and jobs.

I was impressed last year by an address given at the New England Museum Association's Annual Meeting by W. Richard West, the director of the National Museum of the American Indian. I think what he said about his museum can be usefully said about the transportation industry. I have therefore. with his permission, transposed some of his speech in a cross-disciplinary manner. In his speech, W. Richard West begins by quoting Robert McCormick Adams, the Secretary of the Smithsonian Institution, who wrote the following statement about the new museum:

As "This national museum (that) takes the permanence, the authenticity, the vitality and the self-determination of Native American voices as the fundamental reality it must represent, we move decisively from (an) older image of the museum as a temple with its superior, self-governing priesthood to a forum which is committed not to the promulgation of received wisdom, but to the encouragement of a multi-cultural dialogue".

A transposed statement about the transportation industry might read:

As America's transportation industry takes the permanence, the authenticity, the vitality and the self-determination of American voices as its fundamental reality, it must move decisively from an older image of the industry as a temple with its superior, self-governing priesthood to a forum which is committed not to the promulgation of received wisdom, but to the encouragement of a dialogue with all citizens.

No one will likely ever succeed in controlling solely for themselves or their group many of the multiple new inventions which continue to be made as we move into a new century. The notion that these are the dominion of a select aristocracy was shattered fifty years ago. We are now bound together, by that accident, into sustaining our existence by assuring that future inventions are not used to exclude or coerce for short-term gains, but to open more universally sustainable opportunities. The century just behind us has dealt a profoundly humbling message: the tools we invent must be used constructively and not to destroy. Outmoded systems must be replaced with constructive alternatives, not simply destroyed. The machines we have discovered are not ends in themselves, but simply tools which provide opportunities to envision progress differently. This hardly means we dare no longer act any more than it ever did before. On the contrary, the exciting work has just started.

Planning events such as the BTPR may help us reach detente in the Cold War we seem to be having with each other, and make it easier to accept change from Cold-War to new growth policies:

1. Design Sustainable Planning Systems

ISTEA calls for integrated statewide and Metropolitan Planning Organization plans.

If these plans are drawn considering the full range of social, economic and environmental values and all known externalities of each state or region, they can acquire the similar solid backing for their common wisdom the BTPR achieved. When they do, this will enable subsequent project EIS submittals to draw upon this information with confidence rather than to require repeating studies with each subsequent project application.

Consider EIS planning not as an impediment required by bureaucrats or as an invitation to disagree, but as a vital educational experience. Realize the ripples the bomb made are the harbingers of change. A statewide or MPO plan may make smaller ripples, but its decisions will influence what happens for better or for worse, for the next fifty to one hundred years. This means making decisions which support long and short-term opportunities, and using all available resources to act as wisely as possible. This means not discarding information or rules, but thinking constructively beyond them. It means cross-disciplinary thinking; acting the way Georgette did, using personal knowledge to connect people to new ideas or new ways to look at old ones beyond the information now listed in most books.

2. Design Sustainable Transportation Systems and Tools.

Population characteristics are changing. Unlike what was fashionable during the Industrial Revolution, industrialized countries are having smaller families. We recently discovered we were overfishing George's Bank. The view that economic health is necessarily linked to increasing everything must change and the benefits of longer-term qualities in smaller quantities must begin to be appreciated.

Helping cities build systems so people can live healthy, safe urban lives depends upon both changing urban living habits, and building sustainable communities. Both objectives can create good business. Skyscrapers and suburban sprawl are more energy consumptive and less easily sustainable than more moderate densities. More sustainable densities vary from place to place and are less expensive to build and maintain. But above all, these densities can be built with human-scaled designs which make people proud of them and want to care for them.

W. Richard West talks more about museums, saying: "America's educational system desperately needs our assistance, and we represent remarkable bundles of human and material resources that contain substantial stores of information, knowledge, and potential educational impact. Let me be very blunt about the reverse side of this coin----I am extremely doubtful that either the public, or, for that matter the private sectors, come the next century, will be agreeable to supporting these very expensive institutions unless the public perceives that they have a far more general and democratized educational presence and impact".

Many existing transportation systems of the past were not planned for the future. It is said Boston's streets were planned by a cow. New criteria and the tools to more accurately recognize the consequences of planning decisions keep being invented. However they need a context in which to be understood and evaluated constructively. This context might be envisioned as an ongoing educational system, in which everyone participates, out of which come experiments in progress, systematically helping discover how we can treat the Earth and ourselves more gently.

Consistent with this approach are transportation tools which help to accurately educate travelers about systems choices and tools which expand their choices: cars which don't pollute, ways of using existing resources, such as rail systems more effectively, ways to preserve older buildings and build new tree-lined streets which remind us that many of the best examples of sustainable accomplishment have been around a long time. These are places which, centuries later, sustain admiration and respect. They increase in value by inspiring pride and care. They are typically full of human wisdom, human scale, delight and creativity for everyone. The more we build of these, the easier it becomes to inspire more confidence in the future.

3. Design Systems which use people and machines to do what each do best

Enormous amounts of useful planning information exists, but lots of it is seldom used. Planning has not been popular; people assume the information gathered will be used against them. The predictions of surveillance in the book " 1984" have already taken place. We have already experienced "Big Brother" surveilling us as cold, inhuman, statistics. Few people in western societies have escaped being recorded. No city, nor state in the world has not been mapped. The data is there to enable us to drive up any street in the world via computer graphic systems, ***but not yet to look peacefully into the faces of those who live there, to ask how they feel, how we could help them and what ideas they have to help us.*** At least for the moment, this can be done with better results, face to face.

Images can now be projected on a computer screen, for most localities, showing where the transportation systems, police and fire stations are, where all the traffic goes, and where the crimes and fires have taken place. That traffic and those crimes and fires can be related unbiasedly to age, income, race, sex, marriage, mortgages, social security, insurance, and health care, if we want it to. This data, ***if we want it to,*** can be used to help the people living on those streets together with people in business and government, to make constructive, creative, useful plans and market new inventions.

The binary system of computers, while remarkable in its ability to manage extraordinary volumes of complex data, remains an impoverished fool next to man whose memory of sight, hearing, smell, touch, and feelings provide hugely more information. Creativity, I think, comes from individual thought and observation made by people ***alone*** with their thoughts, derived from connections they are able to draw from individual experiences. Great ideas emerge from all levels of intellect, age, and education; most ideas go unheard. Ideas grow strength by people building upon someone's creativity, adding to it respect and value and adjusting it to help it grow. Computers can help. Our diversity is the major source of our creativity. It may be our best assurance too that creativity will always eventually be constructively used. Our diversity expands our common vision to initiate new understandings of common "realities".

Jane Jacobs, the renown observer of cities, notes that cities are, and have always been the breeding grounds of economic resurgence; the places where ideas are formed through the interactions of people talking face to face and inventing new ways of doing things. Cities behave this way because they are places where people from everywhere come to meet, where their ideas can compete and cross associate and generate new vision.

Services are needed to design and support transportation planning concepts. Clear and sustainable concepts need less support. More services are needed, the more there is disagreement. Extending this analogy, the more sustainable we make development, the more easily we can shift growth from services back to manufacturing, thereby reducing the costs of doing business and increasing wealth.

I have unabashedly quoted Richard West previously, in a cross disciplinary effort to correlate what is happening in museums with what is happening in the transportation industry. Here is another of his comments:

"Finally, I remain convinced that if we can accomplish all the foregoing, museums can be transformed into the vital forums for the exchange of cultural ideas and information and of debate that the Secretary of the Smithsonian Institution, Bob Adams, so elegantly described in my opening presentation. At that point I believe that museums, as social institutions will have the potential for assuming a role that ascends to an entirely new plane, which seems so logical, but which they have not achieved in any systematic way to date. Specifically, they will become far more important and pivotal- far more integral--to the continuing evolution of American culture. More important, they become not only the venues for debate but, perhaps, genuinely proactive instruments of the cultural reconciliation that this country appears so desperately to need."

My thesis today has been focused upon using people's words and connections the way Georgette used the telephone in 1945. Most businesses today are actively pursuing programs which involve employee participation aggressively. Most top executives agree, without employees buying into them, their plans do not work. Most everyone going to Home Depot today expect to find good products or return them for cash. With unemployment, for example, in France reaching 15 % , overseas governments must also find ways to employ more people more usefully. Planning more openly and constructively, sharing ideas, building upon their cross-fertilization and respecting contributions more freely are effective ways to reduce both the deficit and unemployment and eventually of sending new inventions like clipper ships to span the globe for new adventure.

W. Richard West concludes his speech by quoting his Deputy Director who said " And museums will become different in a way that will, in the future, seem logical and self evident. I predict we will not be able to recreate what all the fuss was all about."

"From the longer view", W. Richard West states", "however, I have confidence approaching the serene that her prediction will prove absolutely prescient. And it is that long view which the National Museum of the American Indian, by history and perhaps destiny, is constrained to take. For us it is not only an option - it is no less than a cultural imperative. "

The Transportation Industry may not envision itself as a cultural institution, nor that its options for future action are as imperative. Nevertheless, you may find sharing some of the cross-disciplinary thinking of the National Museum of the American Indian and of the Boston Transportation Planning Review worthwhile exploring further.

Thank you very much for your kind attention.

I am indebted to Harry Mathews of Arthur D. Little, who has mentored and co-authored this writing, helping compare ideas with emerging international business practices. I am also indebted to W. Richard West whose speech about the National Museum of the American Indian I have quoted so frequently, and to the following author's papers, whose words were food for thought:

Richard Barrett The World Bank	<u>Environmentally Sustainable Urban Transport</u> <u>Defining a Global Policy</u>
John B. Hopkins	<u>Discussion Paper:</u> <u>Aspects of Sustainable Transportation</u>
Unsigned	<u>Sustainable Transportation</u> <u>Proposal for a Transportation Research Board Study</u>
Arnold Howitt Alan Altshuler	<u>The Challenges of Transportation and Clean Air Goals</u>
VNTSC .	<u>Charting A New Course in Transportation</u> <u>Transportation Strategic Planning Seminars January 1993</u>

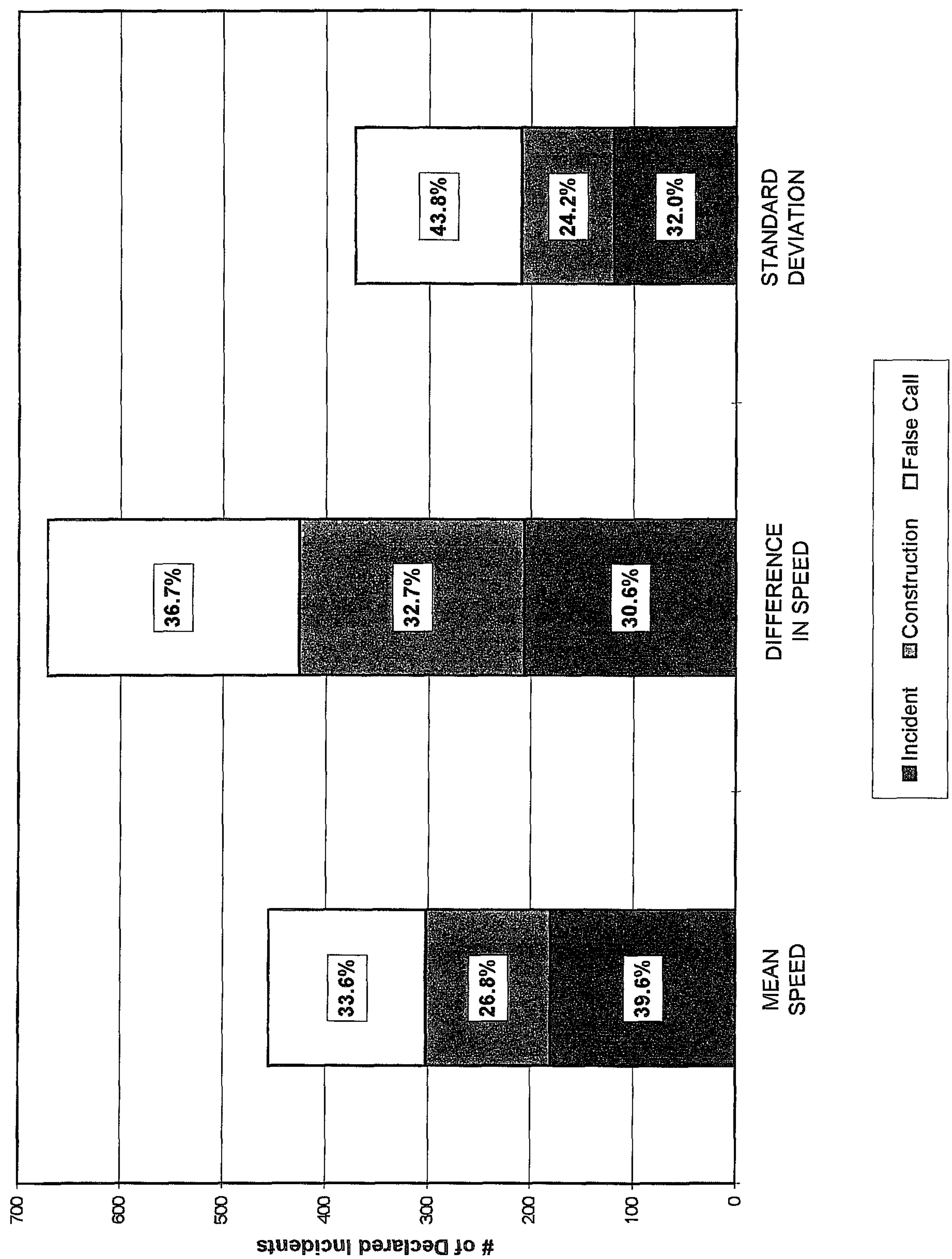


EXHIBIT 10 - REASON FOR INCIDENT

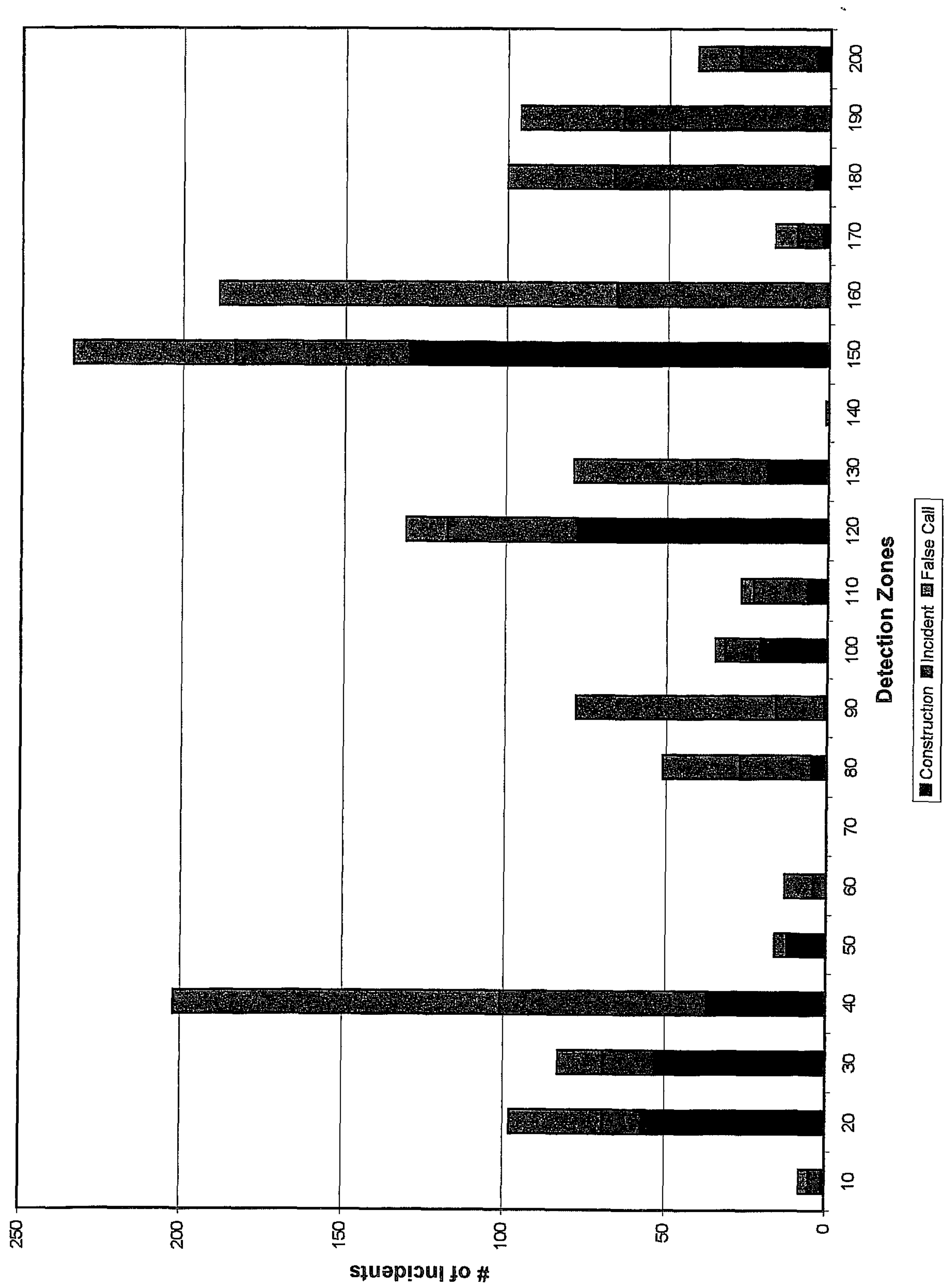


EXHIBIT 11 - REASON FOR INCIDENT BY DETECTION ZONE

cause of the declared incidents at the individual detection zones. As mentioned previously, zones 40 and 160 had some of the highest number of declared incidents, but they also had the highest number of false alarms. These two zones are located in downtown Hartford and are subject to extreme levels of recurring congestion. To further add to the number of false calls, zone 40 is in the midst of a construction zone. Due to the construction, there are reduced lane widths, and a minimal merge area for a downstream on-ramp. These factors increase the amount of recurring congestion that occurs in the area of this detection zone.

3.2.2 Combination of Algorithms

An analysis was also performed which looked at the accuracy of the different algorithms working in conjunction with one another. With the three different algorithms there are four possible combinations of algorithms as follows:

- Mean Speed & Difference in Speed (MS & DS)
- Mean Speed & Standard Deviation (MS & SD)
- Difference in Speed & Standard Deviation (DS & SD)
- Mean Speed, Difference in Speed & Standard Deviation (MS, DS & SD)

For this analysis, algorithms were grouped together if they declared an incident at a specific zone within five minutes of one another. Of the 1499 total incidents declared, only 353 involved one of the above combinations of algorithms. This low number is caused by a variety of reasons, most notably that four of the zones (zones 70, 80, 170, and 200) only use one algorithm. Other reasons include situations where only a single algorithm declared an incident, or the other algorithms were tripped more than five minutes after the first algorithm. Exhibit 12 shows in tabular format the number of occurrences for each detector zone when a combination of algorithms occurred, and the reason (i.e., incident, construction, or false call) for that occurrence. As shown in the exhibit, the accuracy for the different algorithm combinations was in the same range as the individual algorithms (55%-65%), except for the combination of all three algorithms which had a higher accuracy of 76%.

3.2.3 False Alarms

A total of 562 false alarms were declared by the system during the evaluation period, equating to an Operational False Alarm Rate (OFAR) of 37.5% for the incident detection algorithms. The operational false alarm rate is defined by the following equation:

$$OFAR = \frac{\text{number of false alarms}}{\text{number of declared alarm} \quad a}$$

	Mean Speed & Difference in Speed				Mean Speed & Standard Deviation				Difference in Speed & Standard Deviation				All Algorithms (MS, DS & SD)			
Zone	Total	Const.	Incident	False Call	Total	Const.	Incident	False Call	Total	Const.	Incident	False Call	Total	Const.	Incident	False Call
10					1			1					1		1	
20	6	2	1	3	8	2	4	2	6	3		3	7	5		2
30	8	6	2		3		1	2	1	1			10	8	1	1
40	10	1	3	6					12	1	5	6	18	8	6	4
50									2	2			2	2		
60	3			3									1		1	
70																
80	1			1	3		2	1	5		3	2				
90	15		3	12									7		2	5
100	2	2			2		1	1	1		1		3	3		
110	3	1	1	1	3		2	1	2	1	1		1		1	
120	12	6	4	2	3	1	1	1	4	2	2		16	11	4	1
130	7		3	4					3	1	1	1	3	1	1	1
140																
150	33	32	1		4		2	2	3		2	1	10	3	4	3
160	31		10	21	1		1		4			4	6		3	3
170																
180	15		8	7	7		6	1	1			1	5	1	3	1
190	9		6	3	11		6	5	3		1	2	5		4	1
200																
TOTAL	155	50	42	63	46	3	26	17	47	11	16	20	95	42	31	22
Per Cent		32.3%	27.1%	40.6%		6.5%	56.5%	37.0%		23.4%	34.0%	42.6%		44.2%	32.6%	23.2%

Exhibit 12: Combination of Algorithms

As mentioned previously, the greatest amount of false alarms occurred at two zones; zones ***40*** and 160. These two zones accounted for 223 (39.7%) of the total false alarms. Exhibit 13 shows the number of false call occurrences by time-of-day. As shown, the majority of the false calls were during the morning and afternoon peak hours. Approximately 60% of the false calls occurred during the PM peak hour and 18.5% of the false calls were declared during the AM peak hour. The occurrence of false alarms was not limited to weekdays and peak hours. Of the 562 false alarms, 66 (11.7%) of the false alarms occurred on weekends.

Another methodology that has been used for determining false alarm rates is to compare the total number of false alarms to the total number of possible alarms (i.e., execution of the algorithm) that can be declared. This false alarm rate is defined by using the following equation:

$$FAR = \frac{\textit{number of false alarms}}{\text{Total number of algorithm executions}}$$

Using this methodology, during the evaluation period there could have been a total of 6,289,920 possible alarms declared by the system. With the 562 false alarms that occurred during the evaluation period, the Hartford ATMS had an FAR of 0.009%.

In essence, a false alarm occurs whenever some disruption or other anomaly occurs in the traffic flow that "trips" the incident detection algorithm; when, in fact, the disruption was not caused by an incident. How this can occur in each of the speed based algorithms is noted below:

- ***Mean Speed Algorithm*** - This algorithm looks at the speed at an individual detection zone, and compares it to a user defined threshold. If the smoothed speed at the detection zone is below the threshold for a preset time period, then an incident is declared. In setting the thresholds for this algorithm at the individual detection zones, historical speed data taken from the system were reviewed. When setting the algorithm thresholds, it was decided to set the threshold to be no lower than fifteen miles per hour. It was felt that with the operation of the detectors, and their reliance on vehicle motion, setting the threshold lower than this limit would result in no incidents being declared. At some zones, such as zone 150, which experience significant speed fluctuations during periods of recurring congestion, the speeds will momentarily fall below the 15 mph threshold triggering the incident detection algorithm. An example of this situation, based on actual data recorded by the system, is shown in Exhibit 14.

- ***Difference In Speed*** - The operation of this algorithm compares the speed at a detection zone, with the speed at the downstream detection zone. When the speed at the detection zone is a user defined threshold lower than the speed at the downstream zone, an incident is declared. The default value for the "Speed Difference" is 15 mph and this value is modified for specific detection zones and

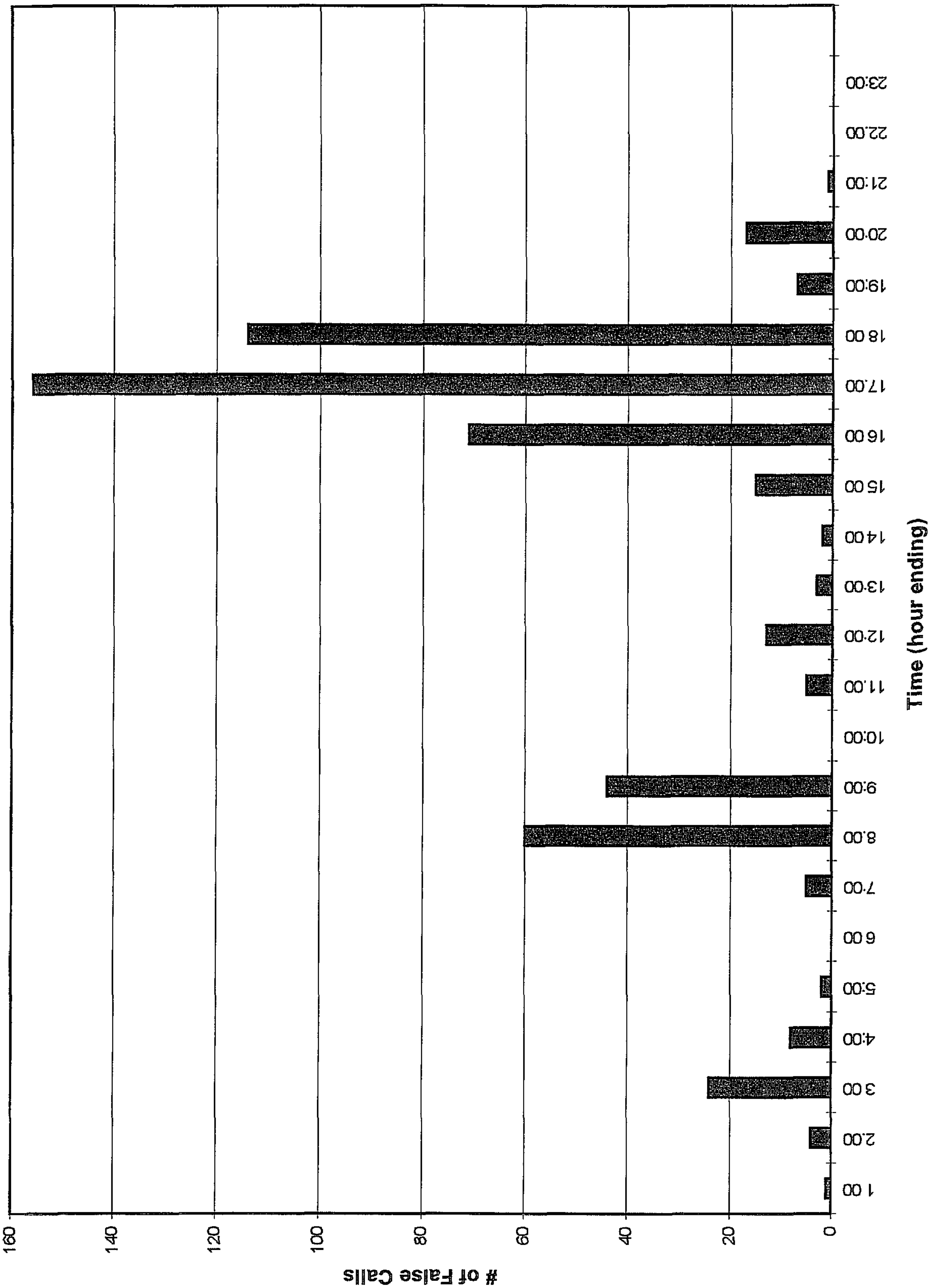


EXHIBIT 13 - FALSE CALL OCCURRENCES

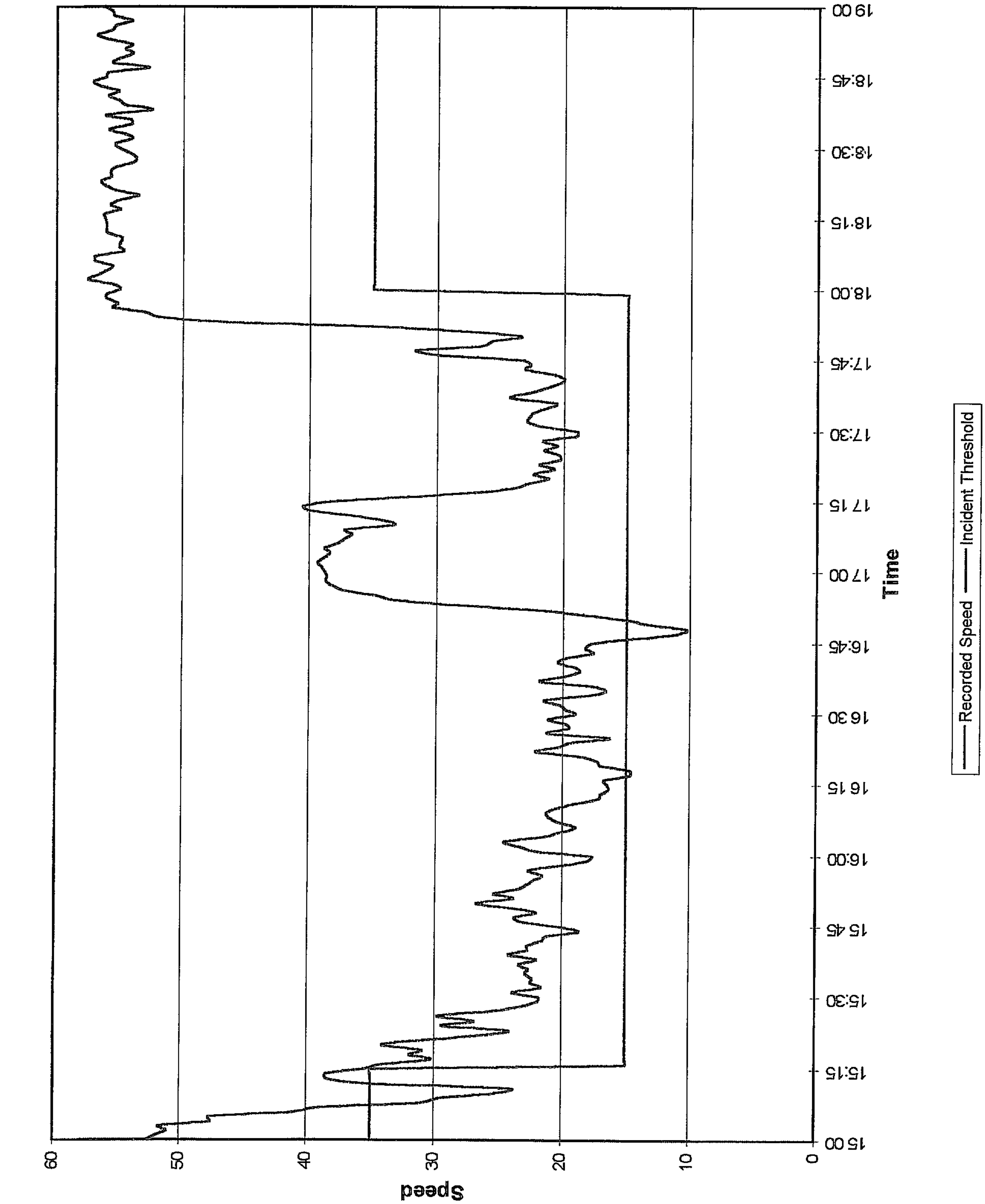


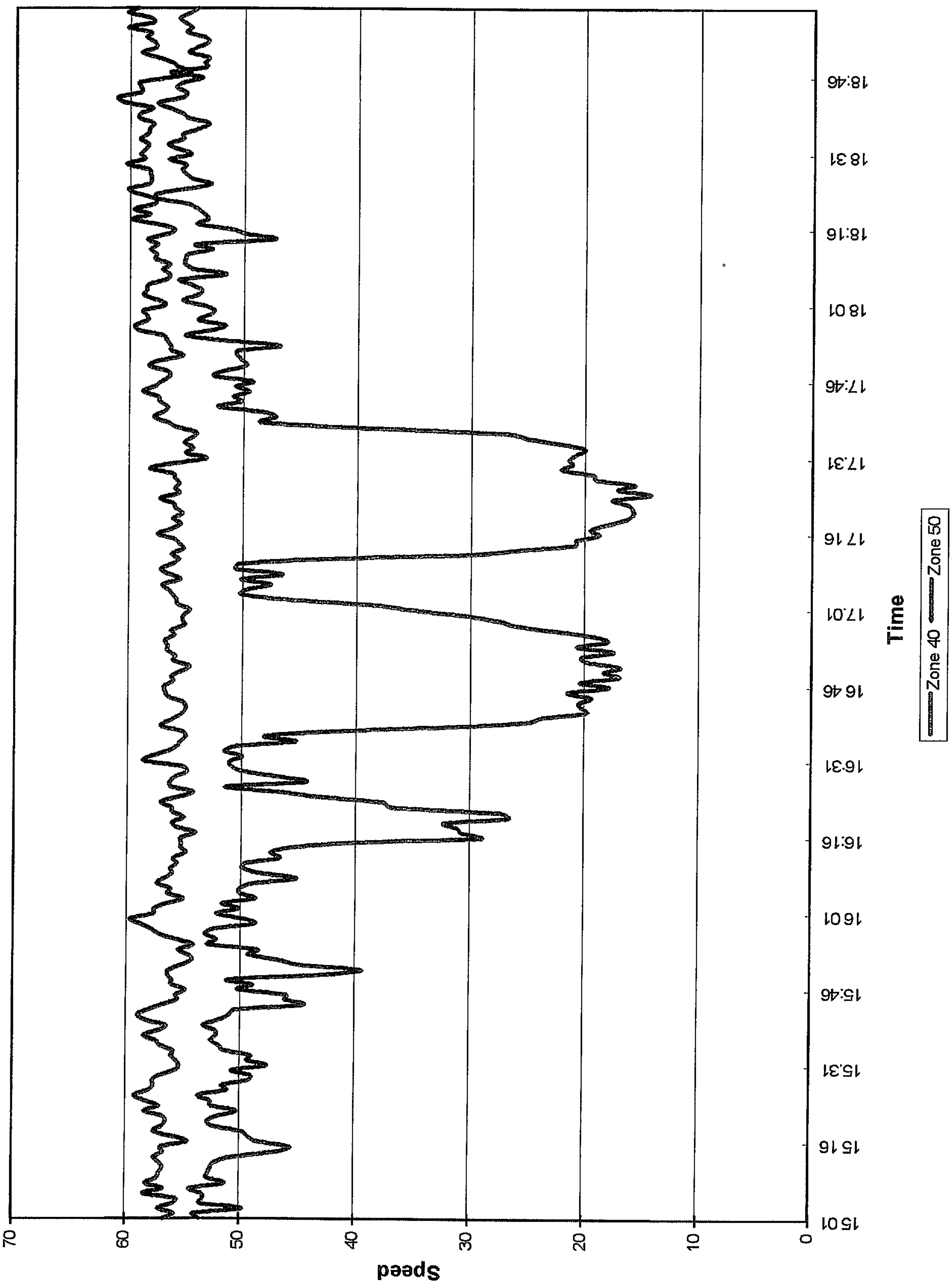
EXHIBIT 14 - MEAN SPEED ALGORITHM OPERATION

time periods based on historical data provided by the system. Considering the operation of the detectors and historical speed data, the maximum value used for this threshold was 40 mph. Similar to the Mean Speed algorithm, situations occur where brief fluctuations in speed at the detection zone, as well as the downstream detection zone, can cause the minimum speed difference to be exceeded. Zone 40 is one detection zone which experiences these occurrences. Exhibit 15 shows actual speed data from zone 40 and its downstream zone, zone 50. As shown in this exhibit, the speed at zone 50 is fairly constant, ranging from 55 to 60 mph. However, the speed at zone 40 fluctuates significantly, resulting in brief periods where the speed difference is greater than the 40 mph threshold, triggering an alarm.

- ***Standard Deviation Algorithm*** - This algorithm looks for variations in travel speeds to detect an incident. The theory behind this algorithm suggests that prior to traffic flow breaking down, there will be large variations in travel speeds, and thus a higher standard deviation. This algorithm is more difficult to set up because of the data that is being analyzed-the variation in speed instead of the actual speed as measured by the radar detectors. Through the analysis of recorded data, the basic theory of the algorithm appeared to be correct; the standard deviation typically increases before or as travel speeds are falling. However, there is no consistency in how much the standard deviation will rise, and it is extremely difficult to tie the rise in standard deviation to an incident, or recurring congestion. In reviewing the data from the system, it was found that the increased standard deviation due to recurring congestion was sometimes higher than the increased standard deviation due to an incident. Also, the increase in standard deviation occurs over a very short time frame, sometimes only a couple of minutes in length. Once the traffic flow has broken down, and speeds have settled to a low level, the standard deviation will decrease as rapidly as it increased. This makes the standard deviation a difficult value to measure, and even more difficult to apply a persistence check.

  Exhibit 16 shows a graphical plot of the speed and standard deviation at a detector zone, and illustrates the sharp fluctuations in the standard deviation. This exhibit illustrates the other peculiarities of the Standard Deviation algorithm. At the time this data was being logged, an accident occurred downstream of zone 40. That accident was reported to the State Police at 4:26 PM. The effect that accident had on the traffic is shown by the sharp decrease in travel speeds and the increase in Standard Deviation that took place at approximately 4:30 PM. However, the increase in standard deviation that occurred, which is due to recurring congestion, is greater than the increase associated with the accident.

Another possible reason for false calls is unreported or unconfirmed incidents. A vehicle pulling over to the shoulder for a few minutes to check something, a minor rear-end collision with minimal or no damage (but still resulting in the drivers stopping their vehicles to assess the damage), or similar event constitutes an "incident" in the broadest definition of the term. The result is a disruption in the traffic flow which, in turn, may be detected by the algorithm. Such incidents, however, are seldom reported to the police. Without this or other confirmation (e.g., full


Speed
70
60
50
40
30
20
10
0
Time
15:01
15:16
15:31
15:46
16:01
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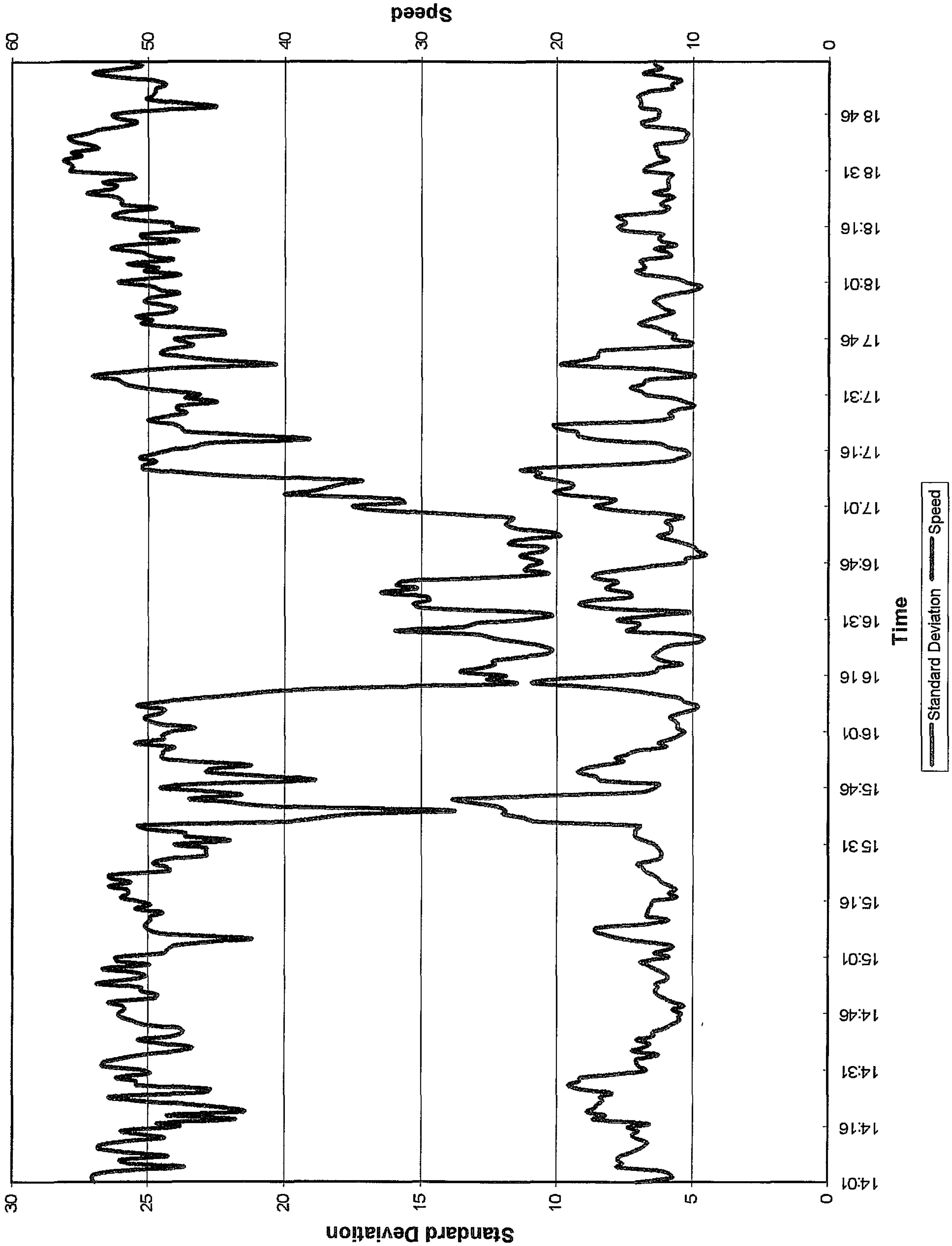
Zone 40
Zone 50


Speed
60
50
40
30
20
10
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Standard Deviation
30
25
20
15
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5
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Time
14:01
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14:31
14:46
15:01
15:16
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15:46
16:01
16:16
16:31
16:46
17:01
17:16
17:31
17:46
18:01
18:16
18:31
18:46
Standard Deviation
Speed

coverage by CCTV subsystem), they are classified as false calls. (Note - This is an appropriate representation. Incident detection is only the first step in the overall incident management process. Incidents which quickly clear themselves are not a ***major*** concern in this regard.)

3.2.4 Detection Rate

The setting of the algorithm thresholds is a delicate balance of detecting incidents by measuring disruptions in traffic flow and minimizing false calls. In a simplistic sense, one can ensure that an algorithm has no false calls by setting the thresholds at such a level that the system will only declare an incident in the most extreme circumstances. While this will reduce the FAR, it will also lead to a system which will miss the majority of incidents which actually occur on the roadway. Conversely, the thresholds can be set so that an incident is declared at the most minute disruption in traffic flow. This, however, will lead to a high FAR, and operator confidence in the system will be reduced. The previous discussions have focused on the accuracy of the algorithms with respect to the reason an incident was declared. This section discusses the success of the algorithms at actually detecting incidents which have occurred.

This analysis focused ***on*** accidents which occurred within the project area during the evaluation period. The limiting of the analysis to accidents was done to provide a measure of those incidents which are most likely to have an impact on traffic flow and are most likely to be reported and confirmed. Trying to determine the system's ability to detect construction activity would show little value because construction and maintenance activities are typically scheduled to have minimal disruption on traffic.

During the evaluation period there were 100 accidents within the project area. Of these 100 accidents, 61 were detected by the ATMS-a detection rate of 61%. The detection of an accident depends on a number of factors including the time of day, the nature of the accident, and the location of an accident with respect to a detector station. Accident information provided by the State Police for this analysis provided limited data on the nature of the accidents. The information provided included date, time and approximate location of accident between interchanges. Exhibit 17 illustrates the distribution of 39 undetected accidents that occurred on weekdays by time-of-day. As shown, the majority of undetected accidents occurred during the non-peak hours, with only two peak hour accidents being undetected by the system. During the AM (7:00-9:00) and PM (3:00-6:00) peak hours, there were a total of 35 accidents. With only two of these accidents beii undetected, the system had a detection rate of 94% during the peak periods when incident detection is most crucial.

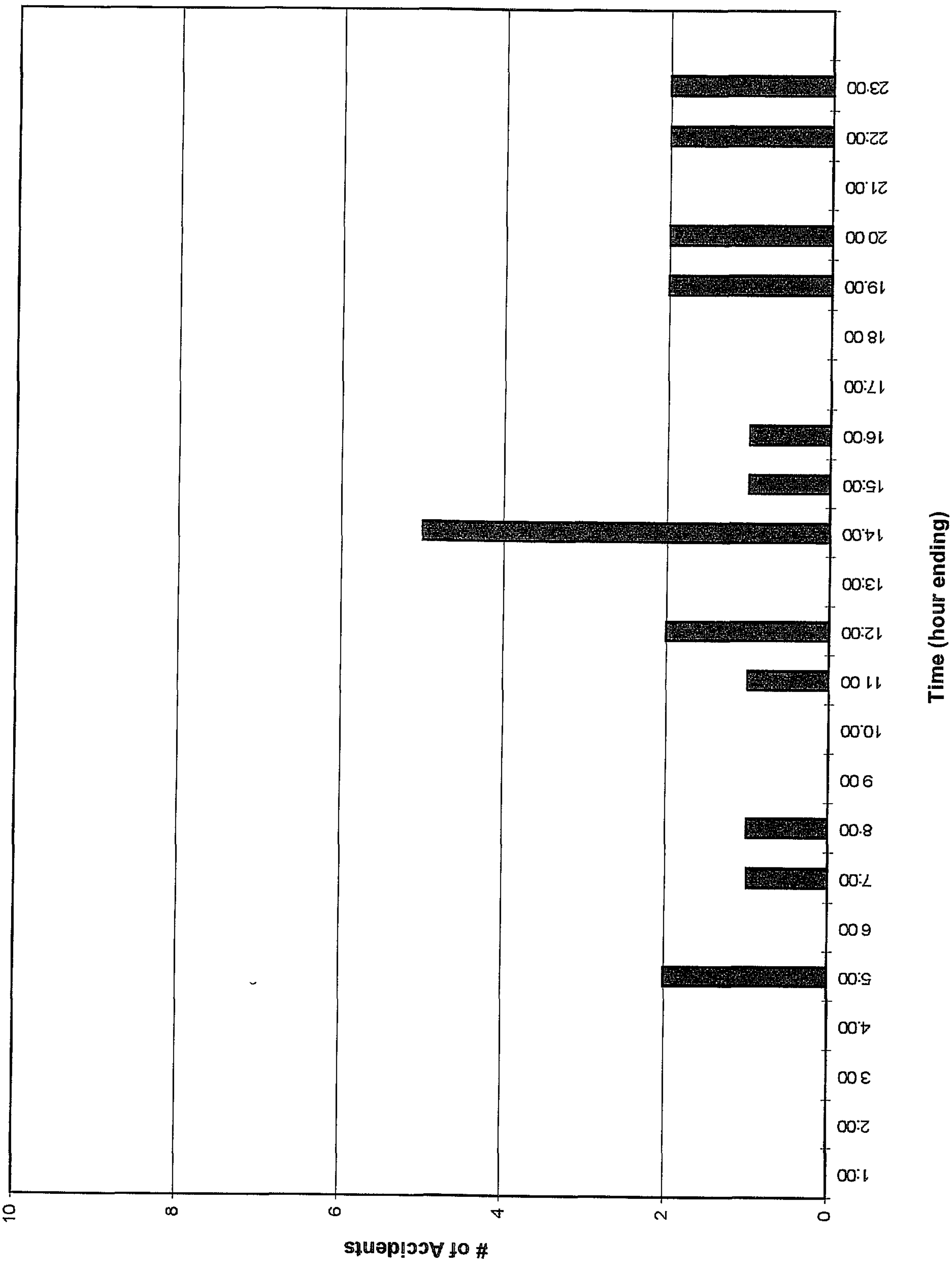


EXHIBIT 17 - MISSED ACCIDENTS - WEEKDAYS

The ability of the algorithms to detect accidents showed results similar to the accuracy of the individual algorithms. In both cases, the Standard Deviation showed the lowest potential of the three algorithms. Exhibit 18 shows the number of accidents detected by each of the individual algorithms. As shown, the Difference in Speed algorithm detected the greatest number; 46 accidents. The Mean Speed algorithm showed similar results, detecting 41 of the accidents. The Standard Deviation algorithm showed the lowest potential for detecting accidents, detecting only 25 of the accidents that occurred.

Algorithm	# of Accidents Detected	# of First Call Accidents
Mean Speed	41	18
Difference in Speed	**46**	**23**
Standard Deviation	**25**	**20**

Exhibit 18: Accident Detection

Also shown in Exhibit 18 is the number of times each algorithm was the first to detect an accident. In this analysis all of the algorithms showed similar results with the Mean Speed, Difference in Speed, and Standard Deviation algorithms being the first to detect 18, 23, and 20 accidents respectively. Interestingly, while the Standard Deviation algorithm detected the lowest number of accidents, it was the first algorithm to detect 80% of the time when it detected an accident. This is compared **to** 44% and 61% respectively for the Mean Speed and Difference in Speed algorithms. Thus, while the Standard Deviation algorithm detected the least amount of the accidents, when it did detect an accident, it was typically the first algorithm to do so.

When a combination of algorithms was used to detect accidents, only 40 of the accidents were detected. The number of accidents detected by the four different algorithm combinations are shown in Exhibit 19. The results for the combination of algorithms corresponds with the results for the individual algorithms, with the Mean Speed/Difference in Speed combination detecting the greatest number of accidents, 20.

Algorithm : Combination	# of Accidents Detected
Mean Speed : Difference in Speed	**20**
Mean Speed : Standard Deviation	**4**
Difference in Speed: Standard Deviation	**6**
Mean Speed, Difference in Speed : Standard Deviation	10

Exhibit 19: Accident Detection-Combination of Algorithms

The fact that 40 accidents were detected by multiple algorithms leaves 21 accidents that were detected by a single algorithm only. Of these 21 occurrences the difference in speed accounted for 10, the mean speed accounted for 7 and the standard deviation algorithm accounted for 4.

3.2.5 Detection Time

Through the use of incident detection algorithms, system operators can find out about incidents on the highways in a more timely fashion, and can take steps to initiate the proper ***response.*** without such a system in place, the primary means of learning about an accident is via phone calls.

Data provided by the State Police detailed when the initial phone call was received for each of the accidents. This data was compared to data from the system to determine detection times for the incident detection algorithms. The comparison of detection times only shows a comparison of when the system detected an accident to when the State Police were first informed about an accident. Detection times from when the accident actually occurred are not possible because accurate information on the actual time of the individual accidents is not available.

For all three of the algorithms the average detection time was twelve minutes after the State Police received a call regarding the accident. The detection times for the individual accidents ranged from 10 minutes prior, to 165 minutes after the State Police received a call regarding the accident. Exhibit 20 is a plot of the detection time versus time of day. As shown, accidents which occurred during the peak hours had the lowest detection times, with an average of four minutes, and in many cases, were detected by the ATMS prior to the State Police receiving a call about the accident.

Like the other incident detection performance measures, the time it takes to detect an accident is dependent on many different variables. These include nature of the accident, the traffic conditions at the time the accident occurred, and the location of the accident with respect to a detector location. For the accidents detected by the incident detection algorithms, the accidents which had the longest detection times typically occurred during the evening or early morning hours, or on weekends. This is the case for the accident which had a detection time of 165 minutes. This accident occurred at 00:10 AM and was not cleared until approximately 4:00 AM. The low volumes that are present during the early morning hours when this accident occurred led to a situation where it took an extended period of time for the resultant queue to extend back to the upstream detector zone. During these time periods, traffic demand is reduced, which increases the time to detect an incident. In some cases it is even possible for the incident detection algorithms to miss the accident all together if the nature of the incident and the traffic

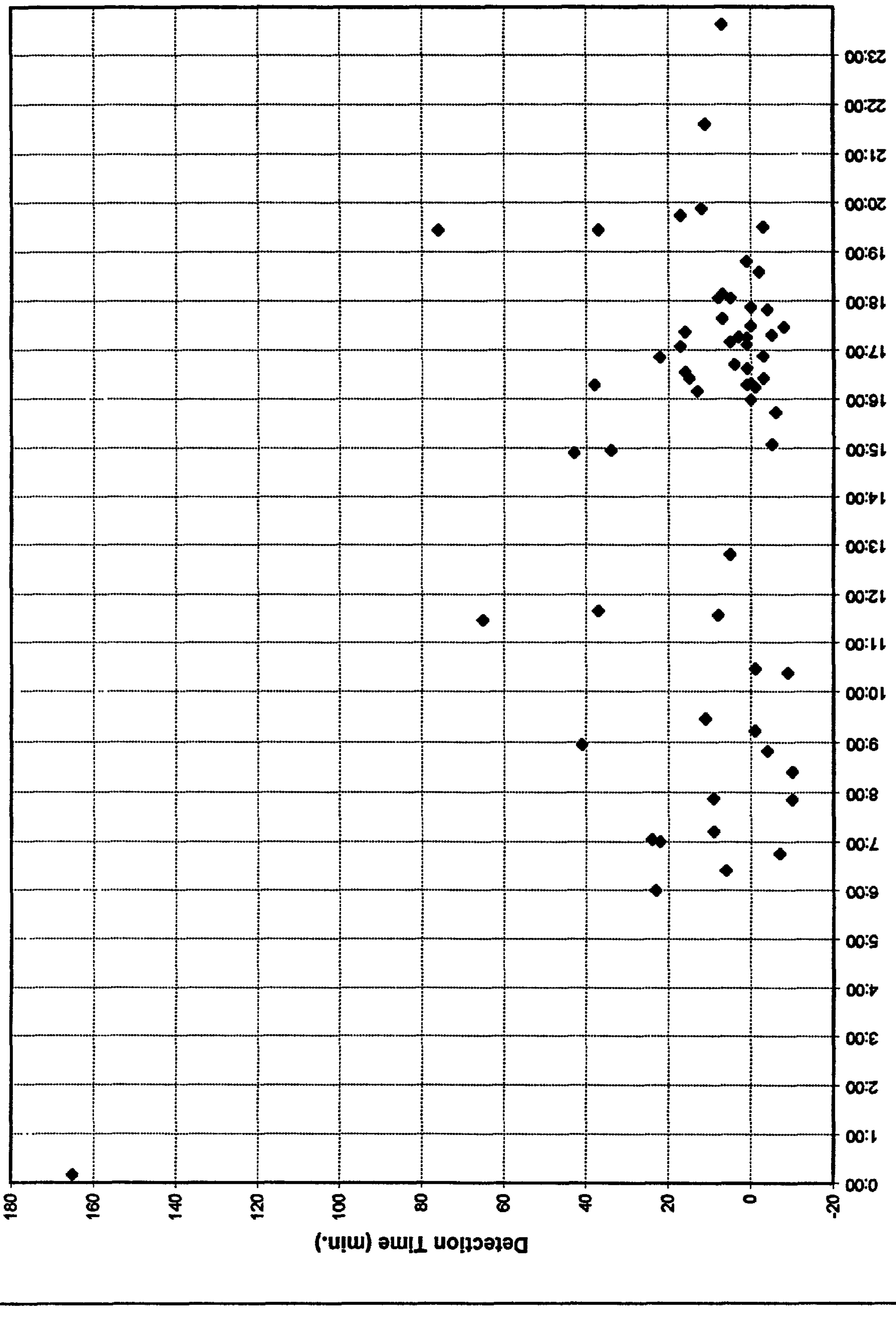


EXHIBIT 20 - DETECTION TIME (all accidents)

demand are such that the queue (i.e., area of reduced speed) from the incident never extends back to the detection zone.

Relying on a combination of algorithms to detect an accident would result in an average detection time of twenty six (26) minutes. The detection times for the combination algorithms ranged from 7 minutes ***prior, to*** 166 minutes after the State Police received a call regarding an accident.

4 CONCLUSIONS

Based on the analysis discussed above, the use of radar detectors and speed-based incident detection algorithms are very effective for monitoring traffic conditions, and detecting incidents. The accuracy of the detectors for measuring vehicle speeds provides system operators with a real-time display of traffic conditions on the highways in the project area. The real time information provided by the system has produced many benefits in addition to automated incident detection. One of the greatest benefits provided by the system is the ability to quickly inform the system operators of the extent of queues caused by accidents after the accident has occurred. This allows the operators to relay this information to the traveling public through the use of variable message signs. Some of the local television stations have also recognized the benefits of the information provided by the system and have started broadcasting from the Control Center during snow storms.

4.1 Radar Detectors

The use of radar detectors to monitor vehicle speeds, and thus traffic conditions, provides not only accurate data, but also provides data which is easily understood by the system operators, and the traveling public. The accuracy of the detectors for monitoring vehicle speeds is very high. Moreover, the aforementioned FHWA Study identified the Whelen detectors as the best at providing vehicle speed data, with the caveat that they do not detect stopped or near-stopped (less than 5 mph) traffic. The major drawback of the radar detectors is that they are only able to provide accurate speed data, and have not shown the ability, on this system, to provide accurate data on other traffic flow parameters such as traffic volume. The FHWA testing performed on the narrow beam Whelen detectors has shown impressive accuracy results with regard to traffic volume. The reason those accuracies are not being achieved in the Hartford area is unknown. It should be noted that the low volume accuracy found in the Hartford Area ATMS has not been limited solely to this system. Limited testing performed on ConnDOT's I-96 freeway management system, which uses the same detection technology, has shown similar results for volume accuracy. The ability to provide accurate traffic volume, at those sights with narrow beam detectors, would enhance the operation of the system by giving the operators information on traffic demand, and also providing data for other units within ConnDOT, such as the Bureau of Policy and Planning Department.

4.2 Incident Detection Algorithms

To draw a conclusion on the operation of the incident detection algorithms, their false alarm rates, and ability to detect accidents, a comparison to other algorithms provides the greatest measure of their operation. Incident detection algorithms have been in use for many years with poor to moderate success. In some cases, such as the INFORM system on Long Island, the poor operation of the incident detection algorithms has led to their discontinued use. Similar experiences have occurred on other systems throughout the country. In addition to the California algorithms, numerous other incident detection algorithms have been developed, or are undergoing development, to try and find the "perfect" algorithm. The "perfect" algorithm is defined as one that is easy to implement, gives no false alarms, detects every incident as soon as it occurs, and does not require extensive calibration. The speed-based algorithms developed for the Hartford ATMS, while showing very favorable results, still fall short of being "perfect".

4.2.1 Operational False Alarm Rate (OFAR)

As discussed previously, the incident detection algorithms had a combined operational false alarm rate (OFAR) of 37.5%.

The Mean Speed and Difference in Speed algorithms had similar OFARS; 33.6% and 36.7% respectively. The OFAR for the Standard Deviation algorithm was slightly higher at 43.8%. While these false alarm rates may appear to be high, they are extremely low compared to the OFAR of other algorithms. One algorithm, which is being used and continually modified, is the McMaster algorithm. This algorithm is used **by** the COMPASS system in Toronto. The algorithms used for that system are operating with an OFAR of 97.67%. This includes both alarms which were declared when there was no congestion, as well as alarms that were declared for recurring congestion. In addition to its use on the COMPASS system, testing was done using the McMaster algorithm by the University of Minnesota. This testing, which was done to evaluate the AutoScope video detection technology, showed the McMaster algorithm with an OFAR of 87%. Another algorithm used in this evaluation, AutoScope Incident Detection Algorithm (AIDA), had an OFAR of 81%. The results of the tests for these two algorithms are included in Appendix B.

Through the use of simultaneous detection on multiple algorithms, the OFAR was approximately equal to the operation of the individual algorithms. The only significant difference being with the combination of all three algorithms, which had an OFAR of 24%. This improvement in the OFAR, however, is offset by decreased ability to detect incidents which will be discussed later.

4.2.2 False Alarm Rate (FAR)

Another methodology of determining the false alarm rates **is** to compare the number of false alarms to the total number of possible alarms that could be declared. As mentioned previously, when combii all three algorithms, the FAR for the Hartford ATMS was 0.999%. The FARs for the individual algorithm6 are shown in Exhibit 21. These FAR6 show considerable improvement over other algorithms that are currently being used. On-line testing of the California algorithms resulted in a FAR ranging from 0.63% to 0.74%[2]. Another algorithm which has undergone testing is the High Occupancy (HIOCC) algorithm. This algorithm had a FAR of **4%** for on-line tests[(2)]. As shown, the speed based algorithms used for the Hartford Area ATMS perform much better than these other algorithms when the FAR is used as a performance measure.

Algorithm	False Alarm Rate
Mean Speed	0.006%
Difference in Speed	0.012%
Standard Deviation	0.008%
All Algorithms	0.009%

Exhibit 21: Algorithm False Alarm Rates

4.2.3 Incident Detection

As their name implies, the primary purpose of incident detection algorithms is to detect traffic incidents. Focusing on accidents which occurred in the project area during the evaluation period, the three algorithms used on the ATMS detected 61% of the recorded accidents. This shows favorable results when compared to data from the other systems and tests mentioned

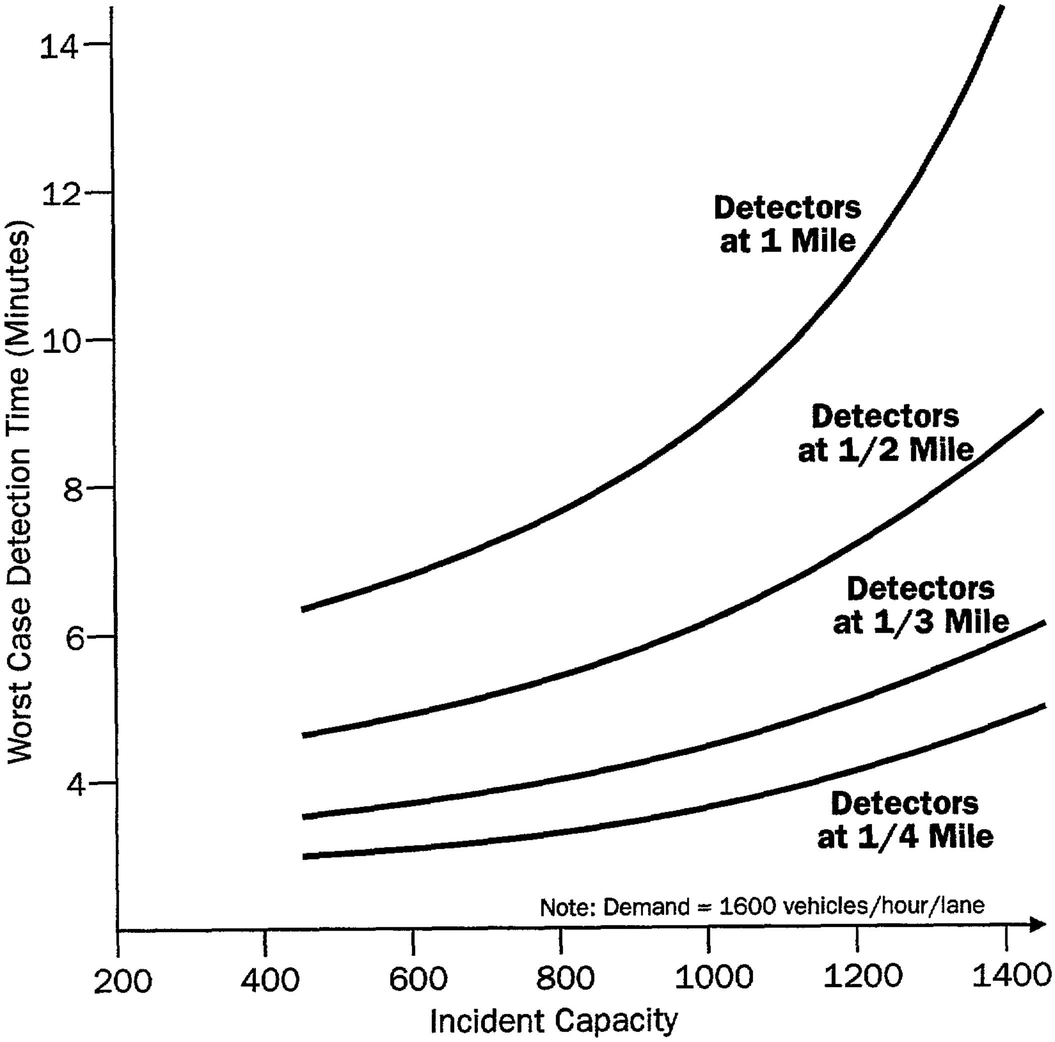
‘Ball Engineeriug, Incident Detection Issues Task A Report, Automatic Freeway Incident Detection, Draft Interii Report; October 1993 previously. On the COMPASS system, 84.7% of the incidents were detected by the system. However, the COMPASS data may be misleading because the operation of the system does not allow for automated incident detection once the incident has been detected by other means. The testing performed by the University of Minnesota showed the McMaster algorithm to detect 28% of the incidents that occurred. In those same tests, the AIDA algorithm detected 14 out of 18, or 78% of the incidents. Appendix B contains reports which detail the results of the McMaster and AIDA algorithms. In addition, on-line testing of the California Algorithm6 showed a detection rate of 41%-56%. The High Occupancy (HIOCC) Algorithm had a detection rate of 94% in on-line tests. While the results of the HIOCC algorithm are impressive, one must keep in mind that this detection rate was achieved at the expense of FAR as discussed in the previous section. The HIOCC algorithm had an FAR over 400 times greater than the speed-based algorithms.

For the individual algorithms, the Difference in Speed algorithm functioned the best, detecting 46 of the 100 accident6 that occurred. The Mean Speed algorithm was a close second, detecting 41 of the accidents, and the Standard Deviation algorithm showed the worst detection rate, only detecting 25 of the accidents.

When a combination of algorithms was used, the incident detection rate fell sharply, with the combination of the mean speed and difference in speed algorithms performing the best, detecting 20% of the accidents that occurred during the evaluation period. The combination of all three algorithms detected only 10 of the 100 accidents which occurred. Thus, while this means of detection had the lowest false alarm rate, it also had one of the lowest incident detection rates. The detection rate, however, is so low that it is not made up for **by the** improved FAR.

4.2.4 Detection Time

As discussed, the average time to detect an accident for the three algorithms was twelve minutes after a call was received **by** the State Police. This detection time, however, is more a factor **of** the detector spacing than the incident detection algorithms themselves. with the one mile detector spacing that is currently used on the ATMS, this detection time is not out of line. Exhibit 22 shows the detection time for various detection spacings and volume/capacity ratios. On a roadway functioning slightly over capacity, it will take approximately fourteen minutes to detect an accident with one mile detector spacing. This value decreases significantly as the demand increases and the capacity of the roadway is further exceeded. The Hartford Area ATMS showed similar characteristics, with those accidents which occurred during peak hours being detected by the system much quicker, and in many cases, prior to the State Police receiving a phone call about the accident.



Source:
Preliminary Design Report, Highway 401
Ministry of Transportation and Communications
Province of Ontario, Canada

Exhibit 22: Incident Detection Time

As a matter of comparison, on-line testing of the California Algorithms showed a **Mean** Time to Detect of 5.3-7.5 minutes. It should be noted, however, these on-line tests were performed **during** rush hour traffic conditions and with a l/Z-mile detector spacing.

4.2.5 Summary

Exhibit 23 provides a summary of the various performance measures for the speed based incident detection algorithms and a comparison against other algorithms which had on-line test data available.

Algorithm	OFAR	FAR	Detection Rate	Time-To-Detect During Peak Hours
Mean Speed	33.6%	0.006%	41%	9 min(a)
Difference In Speed	36.7%	0.012%	46%	10 min(a)
Standard Deviation	43.8%	0.008%	25%	8 min(a)
California(3)	NA	0.63%–0.74%	41%–56%	5.3–7.5 min(b)
AIDA	81%	NA	78%	NA
McMaster	87%–97%	NA	28%–35%	NA
High Occupancy(3)	NA	4%	94%	NA

(3) Ball Engineering; Incident Detection Issues Task A Report, Automatic Freeway Incident Detection, Draft Interim Report: October 1993
(a) With one mile spacing
(b) With l/2-mile detector spacing

Exhibit 23: Summary of Various Performance Measures

This information shows that the speed based algorithms perform very favorably when compared to other algorithms durrently in use. The speed based algorithms perform better than the other algorithms in terms of false alarm and operational false alarm rates. Based on the detection rate, the speed based algorithms are out performed by the other algorithms. However, each of the algorithms which have better detection rates also have significantly higher false alarm and operational false alarm rates. This trade-off between false alarms and incident detection is one faced by all algorithms and requires a delicate balance when setting up the algorithm thresholds. The California algorithms show a lower time-to-detect but that difference is more a result of the detector spacing that is used than the algorithms themselves.

5 RECOMMENDATIONS

While the field equipment and incident detection algorithms used on the Hartford Area ATMS show very favorable results they are not perfect, and there is room for improvement. Regarding the radar detectors, it is recommended that additional work be done with Whelen Engineering to determine if improved volume accuracy can be achieved. As previously mentioned, the Whelen detectors have shown themselves to be extremely accurate in other tests, and if so, similar results should be available to ConnDOT.

Of the three incident detection algorithms the Difference in Speed and Mean Speed algorithms showed similar results. While the Mean Speed algorithm had a lower FAR, the Difference in Speed algorithm had the highest detection rate. The Standard Deviation algorithm had the highest false alarm rate and the lowest detection rate. As discussed previously, the traffic conditions in the project area and the operation of the Standard Deviation algorithm are such that further fine tuning will probably not lead to improved results of this algorithm. While the false alarm rate could be minimized, this would be at the expense of the detection rate. Considering that the Mean Speed and Difference in Speed algorithms are present on the system, attention should be given to discontinuing the use of the Standard Deviation algorithm. Eliminating this algorithm will not have a significant impact on the ability of the system to detect incidents, nor will it cause a degradation of detection time. The benefit of eliminating this algorithm would be a reduction in the number of total alarms. By reducing the number of alarms declared by the system, operator confidence in the system can be improved.

The false alarm rates attributed to the algorithms and the overall system can also be improved by adjusting the algorithm thresholds based on weather conditions. Adverse weather conditions. Adverse weather such as heavy rain and snow affect traffic conditions and result in motorists traveling at slower speeds. These slower travel speeds can result in alarms being declared even though there are no incidents present. The ATMS currently has only one set of algorithm thresholds that are used for all weather conditions. Due to the effect that weather has on traffic flow, the system should be modified to incorporate a second set of thresholds which can be used during inclement weather. These "weather thresholds" would utilize lower speeds than the current thresholds. The implementation of these lower thresholds could be implemented manually by the operators when inclement weather is present. It could also be possible to incorporate the "weather thresholds" automatically based on sensors installed in the field. This type of operation is being implemented as part of the I-95 Freeway Traffic Management System.

It should be noted that to have such a functionality as part of the ATMS would require major revisions to the field equipment including the addition of the precipitation detectors, modifying the communications equipment and revising the communications protocols.

The operations of the Hartford Area ATMS is such that each of the algorithms operates independently, During the course of this evaluation, results were also evaluated for the various algorithm combinations. This evaluation showed that using a combination of algorithms to declare incidents did not provide a significant improvement to system performance. Thus, revising the system to rely on multiple algorithms to declare an incident is not recommended.

The detection rate and time to detect of the algorithms can be improved by modifying the detector spacing. As discussed previously, the Hartford Area ATMS was an FHWA demonstration project which had limited funding. The design of the system and the placement of the detectors was based on a variety of factors including using existing overhead structures and trying to obtain the largest area of coverage. The placement of the detectors was also affected by the presence of major roadway construction projects. A couple of locations which were recommended for detector stations were not constructed because major construction projects were underway in the area. These two criteria led to a system which has a detector spacing of approximately one mile. This detector spacing affects the detection rate and time-to-detect in the following manner:

- During light to medium traffic conditions, the queue resulting from an accident may not extend back to the upstream detector station. If the queue does not extend back to where traffic passing a detector station has to slow down, then the detectors cannot measure the reduced speeds and the accident will not be detected resulting in a lower detection rate.
- The increased spacing between the detectors results in more time being required for the queue to reach the upstream detector station (if it even extends back that far). As shown in Exhibit 22, the time to detect an accident can be reduced by approximately 4-6 minutes by using a 1/2 mile detector spacing.

To improve the performance of the system, it is recommended that additional detectors be installed to achieve a 1/2 mile detector spacing. While benefits can be achieved by providing this reduced spacing throughout the system, the following areas should be given the highest priority:

1. I-84 between High Street and Connecticut Boulevard - The preliminary design of the system included a detector station on I-84 at Main Street in Hartford. Due to the construction of a platform over I-84, this detector station could not be built. Now that the platform construction is complete, consideration should be given to installing a detector in this location. This area experiences severe levels of recurring congestion and a number of accidents. Placing a detector station at Main Street would also provide valuable information regarding traffic conditions under the platform which cannot be viewed by the system's CCTV cameras.

2. I-84 between Capital Avenue and High Street - This area has a number of entrance and exit ramps. The weaving activity that results in this area causes a number of accidents as well as recurring congestion, especially during the PM peak hour.

3. I-91 between I-84 and Jennings Road - This area also experiences recurring congestion that is the result of merging, weaving, and diverging activity associated with the interchange ramps between I-91 and I-84 and the Jennings Road ramps. During the AM peak hour, there is a difference in travel speeds on SB I-91 of over 20 miles per hour between Jennings Road and I-84. This large difference is speed illustrates the levels of congestion in this area.

4. I-91 between the Whitehead Highway and I-84 - During the PM peak hour, there is a difference in speed between these two sites of over 35 miles per hour. The congestion which occurs in this area is exacerbated **by the** presence of construction in this area which results in reduced lane widths and minimal acceleration lengths for a left hand on ramp. This area can be readily viewed from one of the CCTV cameras which provides valuable information to the system operators. Prior to installing a detector at this location, the Department may want to wait until the construction is complete to determine if a detector is truly necessary in this area.

Other areas such as I-91 south of Hartford should also be considered. While this area does not experience the congestion levels as the previous areas, it does have the largest spacing between detection zones, exceeding 7,909 feet in some instances. Adding detectors to reduce spacing to a 1/2 to3/4 mile will improve incident detection in this area.

Currently the setting of the thresholds requires personnel to review the speed data supplied by the system and then to manually adjust the threshold settings for the different algorithms at the individual detection zones. This is a very time consuming process, which needs to be performed approximately every three months. The three month value is baaed on previous work, where it was shown that travel speeds vary with the seasons, with lower travel speeds being present during the winter months. Construction activity in the project area also requires the refinement of thresholds as new long-term traffic patterns are established. The current operation of the system requires that when a threshold is changed from the default value, the operator has to change the value in a table for the specific fifteen minute interval for each day, even if the same value is going to be used for every day of the week. It is recommended that the system be revised to modify the way that the various algorithm thresholds are set. One option for modifying the threshold settings include the use of a scheduler, where through the entry of angle comman d line, the operator can set a threshold level for a given time period. A second option would be to allow the system to automatically set thresholds based on historical data collected by the system. This latter method is being used by ConnDOT on their I-95 Freeway Traffic Management System. The operation of the automatic threshold setting should be evaluated prior to its use on the Hartford Area ATMS.

APPENDIX A - Algorithm Flow Charts

APPENDIX A - INCIDENT DETECTION ALGORITHM FLOWCHARTS

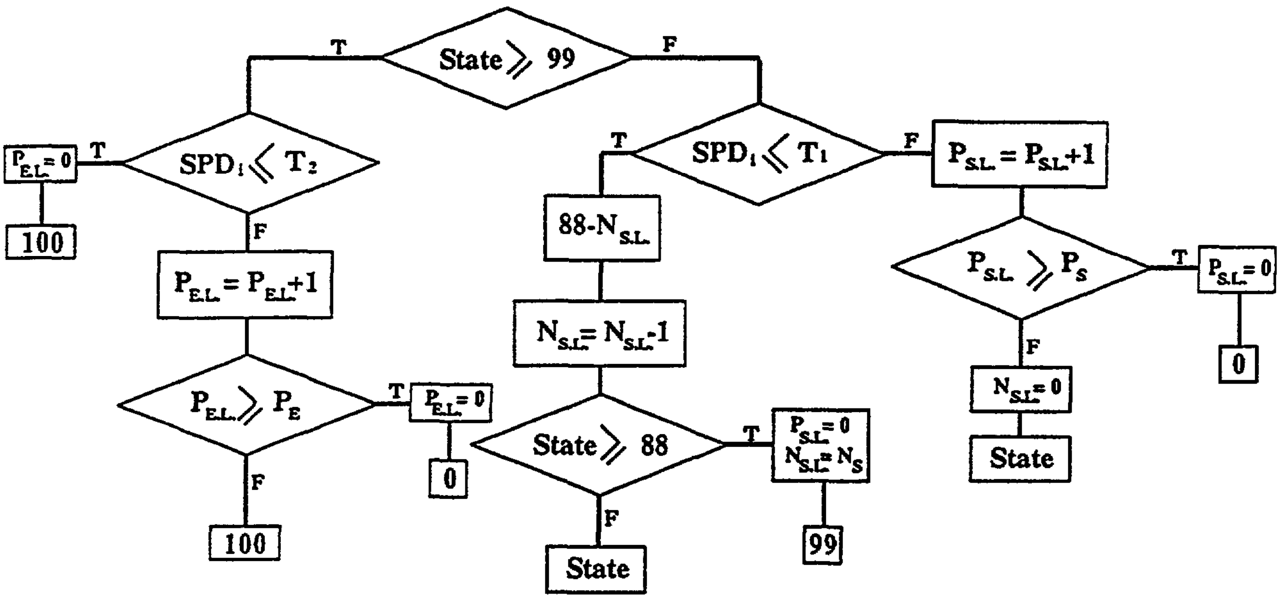
Included in this index are the flowcharts for the four individual incident detection algorithms used within CTATMS. Also included below is a list of definitions of variables and algorithm states used within the flowcharts.

Variable Name	Description
SPDi	Smoothed speed station i.
SPDi+l	Smoothed speed at station i+1, (the station adjacent and downstream of station i).
AV.SPD(i,t)	The average speed at station i for time period t.
AV.SPD(i+1, t-p)	The average speed at station i for the prior p periods.
SPDDF	SPDi+l - SPDi (Spatial difference in speed).
SPDRDF	SPDDF / SPDi+1 (Relative Spatial difference in speed).
SPDCTD	$$\frac{(AV.SPD(i+1,t-p)-AV.SPD(i+1,t))}{AVSPD(i+1,t-p)}$$ Relative temporal difference in speed downstream.
SDSPDi	Standard deviation of speed at station i.

Algorithm State Values

State	Indication
0	Incident Free.
1	Incident Terminated.
88-n to 88	Incident Tentative (see note below).
99	Incident Confirmed.
100	Incident Continuing.

Note: N represents the value of a number of operator modifiable persistence thresholds which specify the duration required from a Tentative to non-Tentative condition.



Mean Speed Algorithm

T1- Speed Start Incident.

T2 - Speed-End Incident.

Ns - Intervals Start Incident.

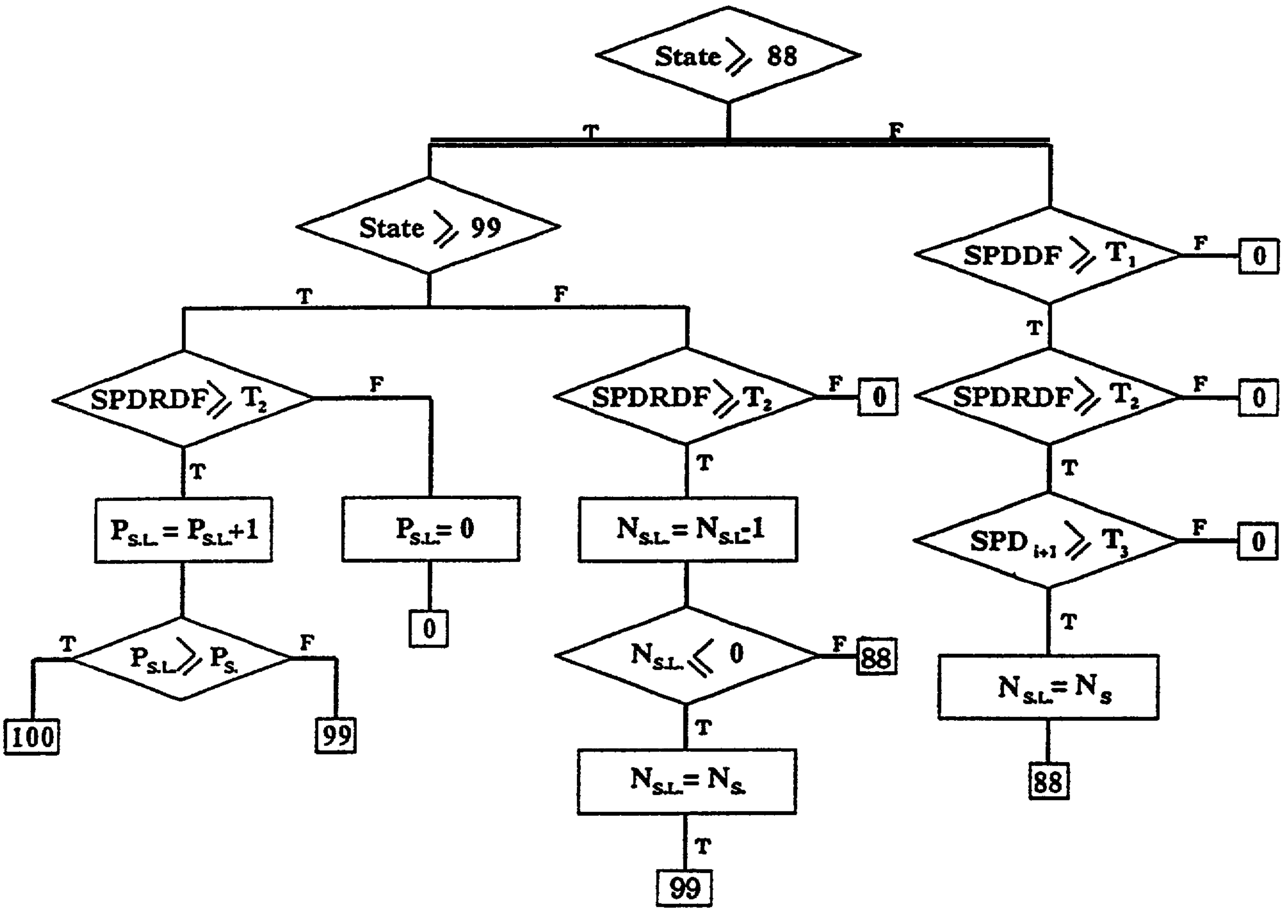
Ns1- Accumulator for number of consecutive intervals during which conditions required for incident detection were present.

Ps - Intervals End Tentative.

Ps1- Accumulator for number of consecutive intervals during which conditions required for algorithm to leave Tentative state were present.

Pe - Intervals End Incident.

Pe1- Accumulator for number of ***consecutive*** intervals during which conditions required for algorithm to leave Confirmed or Continuing state were present.



Difference in speed With Persistence Check Algorithm

T1- Spatial difference in speed.

T2 - Relative spatial difference.

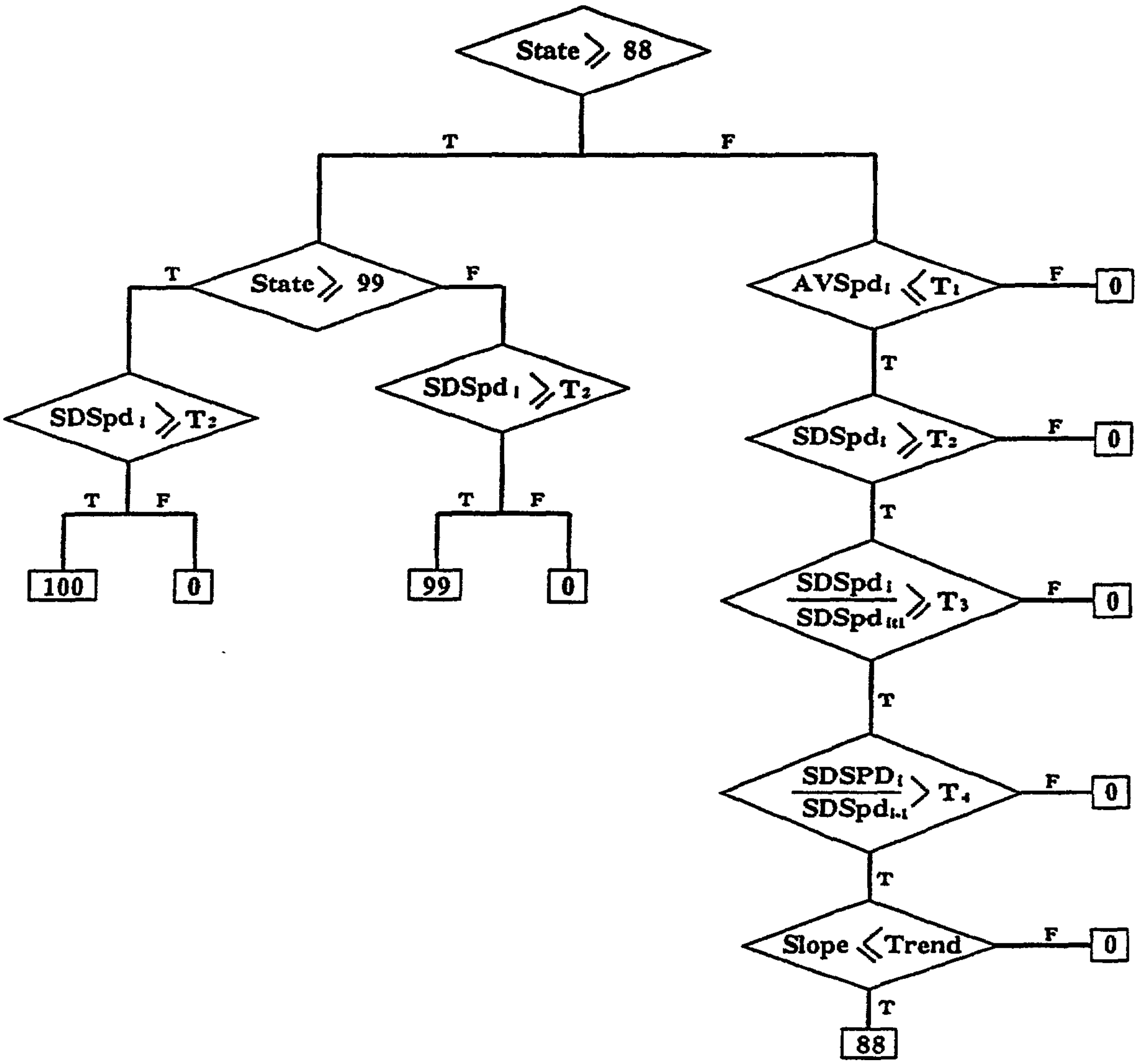
T3 - Downstream Speed.

Ns - Tentative Confirm.

Ns1- Accumulator for number of consecutive intervals during which conditions required for algorithm to transition from a Tentative to a Confirmed state were present.

Ps - Confirm Continue.

Ps1- Accumulator for number of consecutive intervals during which conditions required for algorithm to transition from a Confirmed to a Continuing state were present.



Standard Deviation of Speed Algorithm

T1- Operating Speed.

T2 - Standard Deviation Speed.

T3 - Spatial Standard Deviation Ratio.

APPENDIX B - Reports from Other Systems

Automatic Incident Detection through video image processing

by Panos G. Michalopoulos, *Department of Civil Engineering, University of Minnesota*
and by Richard D. Jacobson, Craig A. Anderson and Thomas B. DeBruycker, *Image Sensing Systems, Inc.*

Automatic Incident Detection is one of the major challenges in urban freeway operations. In spite of recent efforts worldwide, fast and reliable Automatic Incident Detection has been elusive. To a large extent this can be attributed to the limitations of existing detection devices. To overcome this problem, a new wide-area video detection system called AUTOSCOPE was recently developed in Minnesota and was installed in the field for rigorous around-the-clock testing for over two years. As a result, AUTOSCOPE was substantially improved, weatherised and expanded to multiple camera units. Subsequently an incident detection system was developed, based on AUTOSCOPE measurements, installed at a site in Minneapolis and evaluated under continuous around-the-clock, real-time operation for over four months. In parallel to this, a 39-camera, seven-mile, machine vision, live laboratory was designed on Interstate-394 for full deployment and validation of the incident detection system. In this paper the development and testing of the machine vision-based incident detection system is presented, along with the long-term AUTOSCOPE test results and plans for future improvements.

1. INTRODUCTION

Incident detection response and management is one of the major challenges in urban freeway operations requiring constant attention and considerable investment in manpower and equipment. While several methods are currently employed for detecting incidents, automatic techniques are becoming increasingly important for decreasing the detection time and increasing reliability. However, in spite of recent efforts worldwide, fast and reliable Automatic Incident Detection has been elusive. Conventional, automated techniques based on computerised algorithms are less effective than is desirable for operational use as they generate a high level of false alarms or missed incidents. Operator-assisted methods, on the other hand, minimise the false alarm risk, but also suffer from missed or delayed detections, are labour-intensive and restrict the potential benefits of Advanced Integrated Traffic Management as they require human attention for detecting incidents rather than only confirming, responding and managing them through computer-aided means.

Perhaps the major handicap of existing Automatic Incident Detection (AID) algorithms is that they are designed to operate with the limited data provided by existing vehicle detection devices. This information alone, typically volume and occupancy, has not been proven to be sufficient for effective and reliable incident detection, partly because volume is not a dynamic measurement and partly because occupancy is a surrogate rather than a true measurement of a spatial traffic flow variable, namely density. Most importantly, the measurements upon which current detection algorithms must rely are essentially taken at a point rather than over space. Since traffic flow dynamics are two-dimensional in nature (time and space) rather than one (time), it should be evident that any effort to monitor automatically a dynamic phenomenon (incident propagation) with conventional detection devices is bound to be met with limited success.

This observation leads to the conclusion that Automatic Incident Detection should be improved by extracting additional traffic flow parameters in both time and space. Based on this as well as the general need for wide-area detection, an advanced video detection system called AUTOSCOPE was recently developed at the University of Minnesota[1] with support from the U.S. Federal Highway Administration (FHWA) and the Minnesota Department of Transportation (Mn/DOT). This device is also suitable for advanced traffic control as well as detailed traffic parameter extraction for modelling, simulation and studying traffic flow characteristics. Following extensive development and testing, AUTOSCOPE was installed in the field in 1989, and was improved both by manual testing and by continuous, around-the-clock comparison with loops for over two years at several freeway and intersection sites. As a result of this experience, AUTOSCOPE was commercialised by the private sector and field-deployed for Automatic Incident Detection and intersection control*.

In this paper, long-term AUTOSCOPE test results during freeway operation are presented along with the development and field deployment of the entire incident detection system, called IDEAS (Incident Detection Evaluation through the AUTOSCOPE System), which is currently under way. In spite of the fact that IDEAS must, for the time being, rely only on single-camera input, preliminary test results over a continuous, around-the-clock, four-month period suggest an 80 per cent detection accuracy with a station alarm rate of 0.6 alarms/day. They also indicate detection of incidents within almost two miles from the detection zone even when the incidents occur beyond the field-of-view of the camera as well as in adjacent freeways

**A United States Patent has been issued to the University of Minnesota for the basic AUTOSCOPE™ technology and several foreign applications are pending. Image Sensing Systems, Inc. hold a worldwide licence to use the technology and have licensed Econolite Control Products, Inc. to manufacture and distribute AUTOSCOPE™ in North America.*

2. BACKGROUND

Vehicle detection has been the weakest link in advanced traffic applications and automatic surveillance. Although several options are available for replacing or supplementing loop detectors (the most widely used device), the use of video imaging has been widely accepted as the most viable alternative. However, in spite of major worldwide efforts to develop a machine vision system for traffic surveillance and control, a real-time, fieldable device having the capabilities and performance required for practical applications has been elusive. The major problems with other systems which were only recently resolved by the introduction of AUTOSCOPE are discussed in Reference 2.

Briefly, the system can detect traffic in multiple locations within the camera's field-of-view. These locations are specified by the user in a matter of minutes using interactive graphics and can be changed as often as desired. This flexible detection placement is achieved by placing detection lines, using a mouse, along or across the roadway lanes on a video monitor displaying the traffic scene. Since these detection lines exist only on the monitor and not in the pavement, they can easily be removed or adjusted following initial placement. Every time a car passes through these lines, a detection signal (presence and passage) is generated which is similar to the signal produced by loop detectors. Thus, the system can easily replace loops. In addition to the wireless detection, a single camera can replace many loops, thus providing true wide-area detection and becoming cost-effective. It should be noted that AUTOSCOPE does not have to be collocated with the camera: it can either be placed in the field along with the camera or at a central location where video input is received. Figure 1 depicts the system configuration.

Because of this design, AUTOSCOPE can be installed without disrupting traffic operations. Furthermore, it is not restricted to a particular detection configuration, but rather can be changed manually or dynamically as a function of traffic conditions. Finally, the wide-area view will enable the extraction of second-generation traffic parameters, such as queue lengths, delays, stops, density, etc., that cannot easily or economically be derived by conventional devices (if at all). Because of

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focused on increasing the detection accuracy, reducing the false alarm rate and developing a new speed detector that could track the position of individual vehicles in time and space.

The performance of AUTOSCOPE on the selected video-taped sequences was improved to greater than 96 per cent detection accuracy and less than 5 per cent false alarm rate. As a result, the AUTOSCOPE detection algorithms were ready for 24-hour extended on-line testing described in the next section.

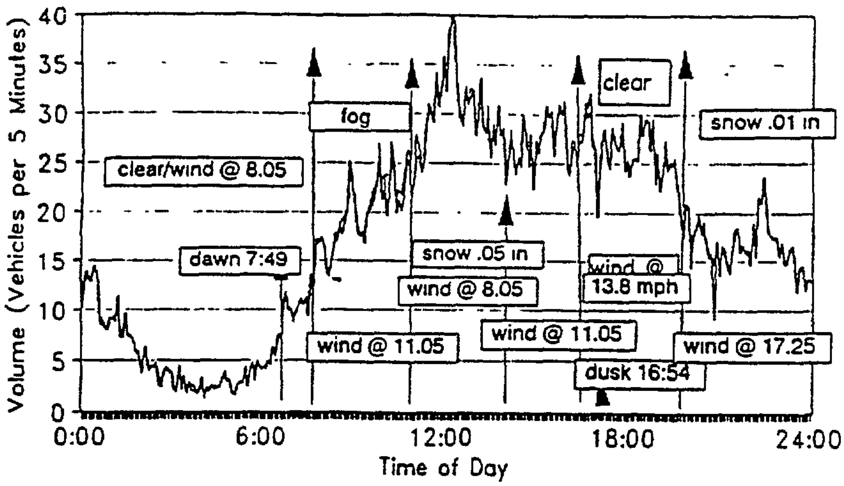
3.3. On-line testing

The objective of the on-line, long-term testing was to establish sustainable, continuous operation under real traffic and weather conditions and to ensure robustness and reliability. The tests ran continuously from April 1990 to September 1991 at both freeway test-sites described earlier using the ScopeServer. Automatic comparisons with loops were made of volume, occupancy and speed measurements on an individual vehicle-by-vehicle basis and also by 30-second intervals for 24 hours each day.

The 24-hour loop *versus* AUTOSCOPE data were used to identify recurring problems. When the disparity between the AUTOSCOPE and loop detection data became very large, the recorded video sequences were saved. The video tapes were then analysed using manual ground-truthing to identify the cause of the problems. During the tests several problems with loops were identified. The most significant involved their reliability. At random intervals loops would either stop working or they would produce totally inaccurate measurements for periods ranging from a few minutes to several hours. The other problems were relatively minor (i.e. volume error of 3 to 5 per cent during congested traffic flow conditions and speed errors of up to 15 per cent).

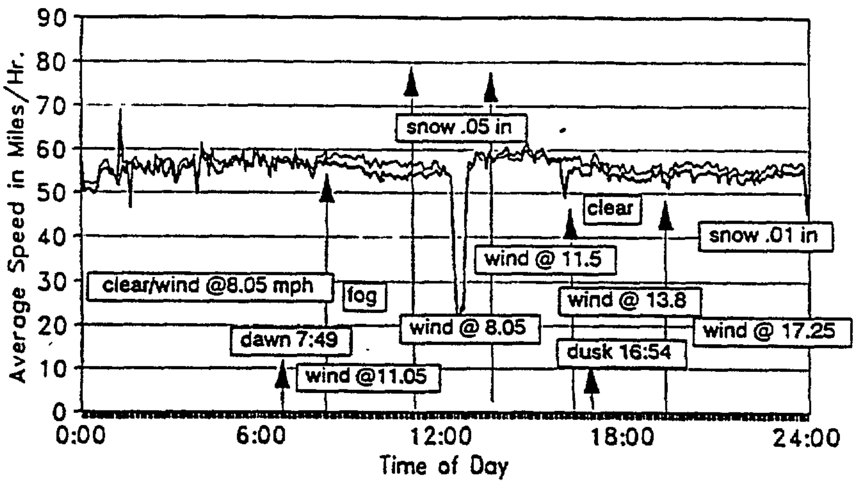
Several AUTOSCOPE problems were identified and corrected during the testing. One of the initial problems was caused by leading headlight reflections at night on wet pavement. There were specific regions of the camera field-of-view that reflected headlights directly into the camera from the road surface, resulting in the appearance of two distinct sets of headlights which led to the double-counting of cars. An attempt was made to reduce the reflected light using a polarised light filter, but very little improvement was observed. Ultimately, a set of night detection parameters was implemented which reduced the false detection rate from as high as 30 per cent to 7 per cent.

A second problem was that of distinguishing strong vehicle dynamic shadows from dark cars. Previous enhancements to AUTOSCOPE that dealt with shadows were a compromise between minimising false detections of shadows and detecting dark cars. This approach was effective at dealing with static shadows (such as tree shadows, pole shadows or dark cloud movements) and short, down-lane or cross-lane, dynamic vehicle shadows. Further testing revealed that during daylight transition periods (dawn and dusk) when the sun is low in the sky and very bright, the strong dynamic (vehicle) shadows cause false detections. An effective approach was implemented which reduced the false alarm rate from as high as 40 per cent to less than 10 per cent.



Comparisons between AUTOSCOPE and loops: Fig 3 (above), volume; and Fig 4 (below), speed.

— AutoScope — Loops



A third problem that was identified and fixed was the difference between AUTOSCOPE and loop speed measurements. The difference was attributed to an incorrect calibration of the AUTOSCOPE speed detector size. The detector lengths were corrected and an accurate field-of-view calibration procedure was introduced. Resulting tests demonstrated that speeds averaged over 30 seconds were as reliable as loops over 24-hour periods for all weather, lighting and traffic congestion levels. Furthermore, individual vehicle speed calculations by AUTOSCOPE were within 2.5 mile/h from that of loops and within 5 per cent of actual speeds. The speed analysis was conducted at ranges of operation of 150 and 350 ft from the camera with only a very slight performance degradation at the longer range.

When these problems were resolved, the AUTOSCOPE performance was thoroughly re-evaluated. Figures 3 and 4 show the speed and volume detection performance as compared to loops during two artifact-rich days of operation. As can be seen from these figures, AUTOSCOPE closely tracks the loop measurements even when weather and lighting conditions vary substantially over 24 hours.

4. APPLICATION TO INCIDENT DETECTION

Automated incident detection was selected as the first application of the AUTOSCOPE technology to enable traffic managers to concentrate on more critical operations tasks and to reduce the number of monitors required for observing traffic conditions. For the purposes of this study an incident was defined as an unplanned occurrence on the freeway that impedes traffic flow.

A number of AID algorithms can be found in the literature. Their structure varies in the degree of sophistication, complexity and data requirements. Comparative performance evaluation of existing AID algorithms was presented in a recent paper[4] where the need for more effective incident detection systems is identified. The most important include the *comparative* algorithms (California logic[5-7]), the type employing statistical forecasting of traffic behaviour (*time series* algorithms[8-10]) and the McMaster algorithms[11]. These algorithms operate on typical detector occupancy and volume outputs averaged over time intervals of 30 to 60 seconds. Another approach is employed by the HIOCC algorithms[12] that use one-second occupancy data to detect

5. INCIDENT DETECTION FIELD-TESTING

Prior to field implementation and real-time testing, the three incident detection algorithms — SPIES, McMaster and AIDA — were tested off-line using the incident database which was available as of September 1991. This testing revealed that the SPIES approach had problems caused by the significant signal noise due to traffic fluctuations during heavy congestion when vehicles accelerate and decelerate. Since it did not appear to be more promising than the other two incident detection algorithms, SPIES implementation was deferred until after the completion of the I-394 test site.

Following the off-line testing, the McMaster and AIDA algorithms were incorporated into the ScopeServer and have been running in parallel using real-time data from the 26th Street test site since December 1991. The results from the first four months (December 1991 to April 1992) of continuous around-the-clock operation are discussed next. The 26th Street test site is a very complex one as shown in Fig 6. It is just upstream of a point where I-35W splits into two freeways and a downstream exit ramp. The freeway that splits to the right has another exit ramp to a third freeway. The complexity provides an abundance of incidents, especially during the winter season.

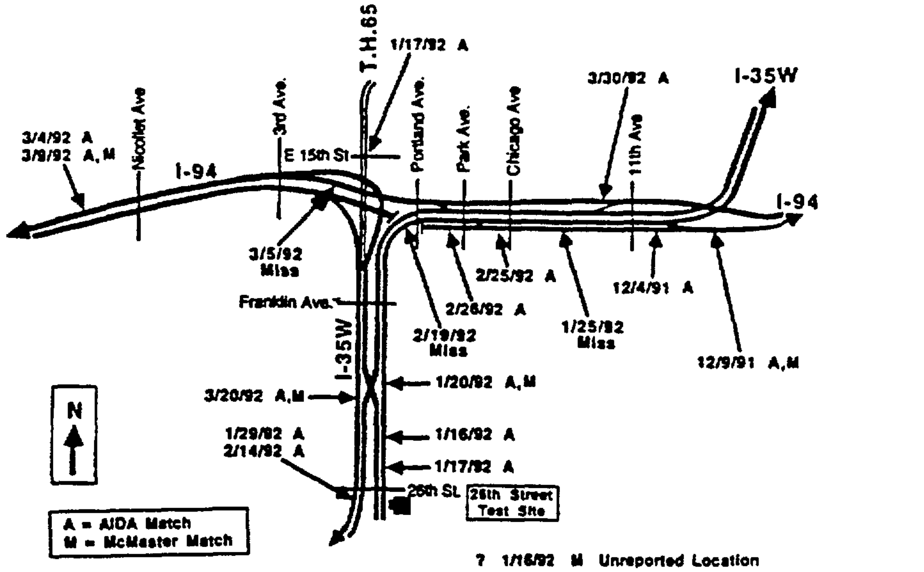


Fig 6. Incident occurrence and verification in the vicinity of the 26th Street installation.

Eighteen reported incidents judged relevant to the 26th Street location are indicated on the map in Fig 6 by dates and large arrows. All but one were taken from the TMC incident logs. An 'M' indicates a match by the McMaster algorithm and an 'A' indicates a match by the AIDA algorithm.

Overall performance summaries for the McMaster algorithm and the AIDA algorithm are given in Table I. For the four-month, 122-day period beginning 1 December 1991, the McMaster algorithm produced a total of 38 alarms resulting in a station alarm rate of 0.3 alarms per day. Five alarms matched confirmed incidents resulting in an incident detection accuracy of 28 per cent (5/18). An additional 24 per cent (9/38) of the alarms were designated likely incidents as judged by the severity of the measured traffic parameters as compared to the matched incidents. Typically, a very sharp drop in speed accompanied by a sharp rise in occupancy, characteristic of confirmed incidents, plus their occurrence during off-peak traffic hours, led to categorising these alarms as likely incidents. Some of these occurred after TMC operating hours and thus could not be confirmed, while others occurred during TMC operating hours but did not correspond to any incidents reported by TMC. Another 21 per cent (8/38) occurred during rush-hours. Finally, 42 per cent (16/38) of the alarms were confirmed to be false alarms. The majority were during late night or early morning periods, when the data were very noisy due to low traffic volumes.

The AIDA algorithm produced a total of 73 alarms during the four months of analysed data resulting in a station alarm rate of 0.6 alarms per day. Fourteen alarms matched confirmed incidents resulting in an incident detection accuracy of 78 per cent (14/18). Of the total of 73 alarms, 32 per cent (23/73) were judged to be likely incidents and another 47 per cent (34/73) occurred during rush-hours and would have required an operator to verify whether an incident had occurred. All likely incidents appeared serious enough to merit an operator's attention, whether they were caused by actual incidents or merely a heavily-congested freeway system . In either case an operator could take action to reduce traffic volumes entering the congested area via ramp metering changes. Finally, only 3 per cent (2/73) were confirmed as false alarms.

The AIDA incident alarm matches breakdown is as follows: Ten occurred during rush-hour — four accidents and two stalls during the morning rush-hour and three accidents and one spin-out during the evening rush-hour. Another four incidents were during off-peak hours — two accidents, one stall and one serious spill (bulldozer).

The AIDA alarm missed three accidents and one stall. The first accident missed occurred on 16 January 1992, at an unreported location during morning peak hours. This accident is believed to be upstream of the camera and would be more likely to be detected by an upstream station. The second accident missed occurred on I-94 eastbound on 25 January 1992 at noon and, as can be seen from Fig 6, would strictly cause a 'gawker slowdown' on I-35W. This accident would be more appropriately detected by a station on I-94. The third missed incident was a stall on the left shoulder of I-35W southbound near Portland Avenue, approximately 0.8 miles away, on 19 February 1992 at 16:15h, which only produced a 12 mile/h drop in smoothed 30-sec. interval speeds from 54 to 42 mile/h and a small increase in occupancy, 20 to 28 per cent, not enough to trigger an alarm.

Table I. McMaster and AIDA incident detection results

Month	Number confirmed incidents	McMaster: Total alarms	McMaster: Match	McMaster: Unknown cause – Likely incident	McMaster: Unknown cause – Rush hour	McMaster: Confirmed false alarms	AIDA: Total alarms	AIDA: Match	AIDA: Unknown cause – Likely incident	AIDA: Unknown cause – Rush hour	AIDA: Confirmed false alarms
December	2	13	1	4	4	4	17	2	6	9	1
January	7	12	2	2	2	6	32	5	10	16	0
February	4	2	0	0	1	1	11	3	2	6	1
March	5	11	2	3	1	5	13	4	5	3	
Totals	18	38	5	9	8	16	73	14	23	34	2

	McMaster	AIDA
Detection accuracy of confirmed incidents	28 per cent	78 per cent
Station alarm rates (per day)	0.31	0.60
Confirmed false alarms	42 per cent	3 per cent
Unknown cause alarms	45 per cent	78 per cent

vanced incident detection algorithms. The McMaster incident detection algorithm[11] which was tested here is promising, but has some limitations. For instance, the characteristic curve on which the algorithm is based is subjective, time-dependent and not easy to obtain. Furthermore, the algorithm did not perform well in inclement weather, missed incidents close to the detection station and turned on some accident alarms very late (when clearing). On the other hand, it does not generate alarms very often on recurrent congestion, a desirable feature. The AIDA algorithm has a high incident detection accuracy, a low confirmed false report rate, short incident detection times and long detection range. AIDA is still a prototype that should improve in the deployment phase, especially when it will be able to combine data from adjacent cameras and utilise spatial traffic measurements such as density and speed profile that can be made available with some additional research and development.

6. CONCLUDING REMARKS

The field installation of AUTOSCOPE™ substantially improved the performance and reliability of the earlier version which, like other devices at this stage, suffered from problems that could only be overcome by the rigorous long-term tests described. As a result of these experiments and others at intersections, the system has evolved from a research and development prototype to a commercial product. This required additional private funding to produce a fully weathersed, multiple-camera unit meeting cost-effective commercial standards. This process required Government-University-Industry co-operation.

The IDEAS incident detection system exceeded expectations not only in terms of performance, but also in terms of its capability to detect incidents based on single-camera, single-station measurements. For example, 14 of 18 confirmed incidents were detected during its first four months of operation, while only two confirmed false alarms were generated and the average daily station alarm rate was only 0.6 alarms.

Most importantly, incidents as far away as two miles were detected while the detection time ranged from −7 to +15 minutes from the reported time of the incident, depending on distance and freedom of vehicles to divert from the freeway prior to reaching the detection area. The above results are very encouraging given that the incident detection system is still experimental. Full deployment of IDEAS is currently underway at the I-394 site while plans for installation in several other freeways are being considered. The I-394 site will serve as a laboratory further to improve the IDEAS system. The I-394 installation should be completed in late 1993 and will enable fine-tuning of the alarm decision logic, use of adjacent camera information for confirming and localising alarms, development of an incident severity index, introduction of interactive learning for parameter calibration and prediction of incidents based on real-time measurements.

Video detection is not simply a replacement of loops, which will continue to serve their intended purpose for some time, but is a wide-area detection technology that can obtain more information including traffic parameters and measures of effectiveness (delays, stops, energy consumption, etc.) which have in the past been hard, labour-intensive, time-consuming and expensive to obtain. The deployment of video detection is a function of the specific application that the device is to accommodate which, in addition to incident detection, can include ramp control, large-scale database generation for IVHS applications (i.e. driver information systems and vehicle guidance), intersection control and a variety of enforcement applications. Deployment of the incident detection system developed here can use both loops and AUTOSCOPE which is important since many loops are already in place on freeways. Finally, the camera placement for incident detection is a function of the desired detection time. Since detection distances up to almost two miles have been demonstrated, AUTOSCOPE camera placement at the rate of one per mile is feasible. However, this assumes that vehicle diversion between cameras is insignificant so that the effects of incidents can reach the upstream camera within a reasonable time. To be sure, the exact placement of AUTOSCOPE depends on the geometry of the road and other existing instrumentation which will be determined in the preliminary engineering and design phase when the system is being deployed.

ACKNOWLEDGMENTS

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**Authors' Note: The McMaster algorithm in the sense described in this paper refers to the logic as described in the literature and in Reference 11, rather than to the software recently produced by its developers.*

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M3M IJ8

June 21, 1995

Mr. Jack L. Kay
President
JHK & Associates
2000 Powell Street, Suite 1090
Emeryville, CA 94608

Dear Mr. Kay

Re: Monthly System Performance Reports and ITS Privacy Issues

Attached, please final a copy of the monthly performance reports for our 3 Compass systems. I have also attached a copy of a discussion paper on ITS Privacy Issues which was prepared by our government's Information and Privacy Commissioner.

It was my pleasure to see many of you at the mid-year meeting in San Antonio. Best wishes for a safe and restful summer.

Sincerely,

P.R. Korpal
Manager (Acting)

RECEIVED
JUL 5 1995
By____________

HIGHWAY 401 COMPASS SYSTEM
RENFORTH DRIVE TO YONGE STREET
TRAFFIC DATA AND OPERATIONS REPORT
FOR MAY, 1995

	East Bound	West Bound	Total
*Monthly Average Daily Traffic (veh.)	180,768	184,704	365.472
*measured in the vicinity between Weston Road and Islington Ave			

	East Bound	West Bound
Monthly Average Peak Period Speed (km/h) AM (from 0800 to 09:00)	75	59
Monthly Average Peak Period Speed (km/h) PM (from 17:00 to 18:00)	73	55

	East Bound	West Bound
Highest Hourly Per Lane Volume	2,292	2,416
Day of the Month	10	2
Time & Day	07:00 to 08:00	08:00 to 09:00
Station Description	W OF WESTON	W OF KENNEDY
Roadway Description	EXPRESS	COLLECTOR
Station Number	401 DW0080DEE	401 DE0270DWC

	*Total Monthly Vehicle-Hours of Delay
East Bound (veh-hrs)	92,390
West Bound (veh-hrs)	122,757
Highway 401 Total (veh-hrs)	215,156
* monthly accumulated total of additional travel time experienced by all vehicles that travel at less than 70km/h	

Between Yonge & Renforth	*Average Travel (min) At 08:00	*Average Travel (min) At 17:00
EastBound Collector	22	22
EastBound Express	20	20
WestBound Collector	23	24
WestBound Express	18	22
*Average travel time calculation is based on the Highway 401 COMPASS speed data		

CHANGEABLE MESSAGE SIGN UTILIZATION	
Number of Changeable Message Signs	13
Number of Non-Default Messages Displayed	11377
Non-Default Messages Displayed per Sign per Day	28

CONFIRMED INCIDENT DATA BETWEEN YONGE STREET AND RENFORTH DRIVE (INCLUDING SHOULDER INCIDENTS)		
Total Number of Confirmed Incidents		72
Percentage Detected by System		34.72%
Percentage Manually Detected		65.28%
Incident types:	51.39%	Accidents
	15.28%	Disabled Vehicles
	30.56%	Road Work
	.00%	Debris
	2.78%	Other
Lane Blockage Types:	20.83%	Full Closure
	65.28%	One Lane
	12.50%	Two Lanes
	.00%	Three Lanes
	.00%	Four Lanes
	.00%	Five Lanes
	.00%	Six Lanes
	1.39%	Other
Total Duration of the 72 Incidents:	5,658.92	min
Avg Duration per Incident:	78.60	min
Percentage of False Alarms false alarms divided by total alarms):		29.26%
Percentage of Improper Classifications (congestion detected as incidents divided by total alarms):		68.41%

COUNTS OF OPERATOR REACTION TIME TO CONFIRM INCIDENT DETECTION ALARMS FOR THE MONTH OF MAY	Counts	Percentage
~~Less than 3 Minutes~~	~~416~~	~~48.04%~~
3 To 6 Minutes	139	16.05%
6 To 15 Minutes	131	15.13%
Above 15 Minutes	180	20.79%
Total:	**866**	**100.00%**

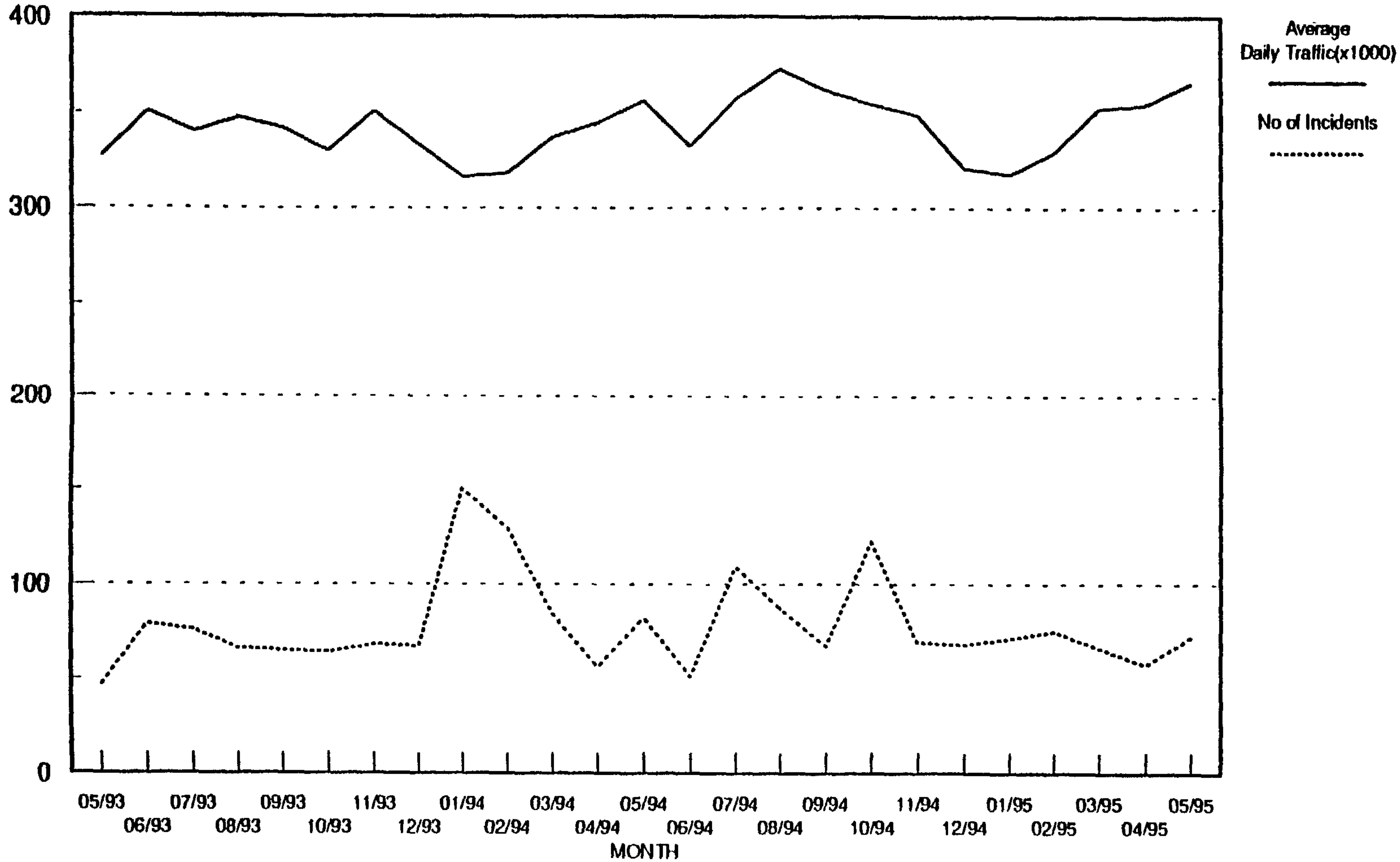
COMPASS Voice Logging Activities, MAY	
No. of Radio calls logged	N/A
No. of Phone calls logged	N/A
Total	N/A

MONTHLY FIELD EQUIPMENT OPERATING STATISTICS	
Potential No. of VDS Controller-Hours Available	90,768
Actual No. of VDS Controller-Hours Recorded	90,407
Percentage VDS Controller Availability	99.60%
Potential No. of CMS Controller-Hours Available	10,416
Actual No. of CMS Controller-Hours Recorded	10.322
Percentage CMS Controller Availability	99.10%
Note: VDS = Vehicle Detector Station CMS = Changeable Message Sign	

HIGHWAY 401 COMPASS SYSTEM

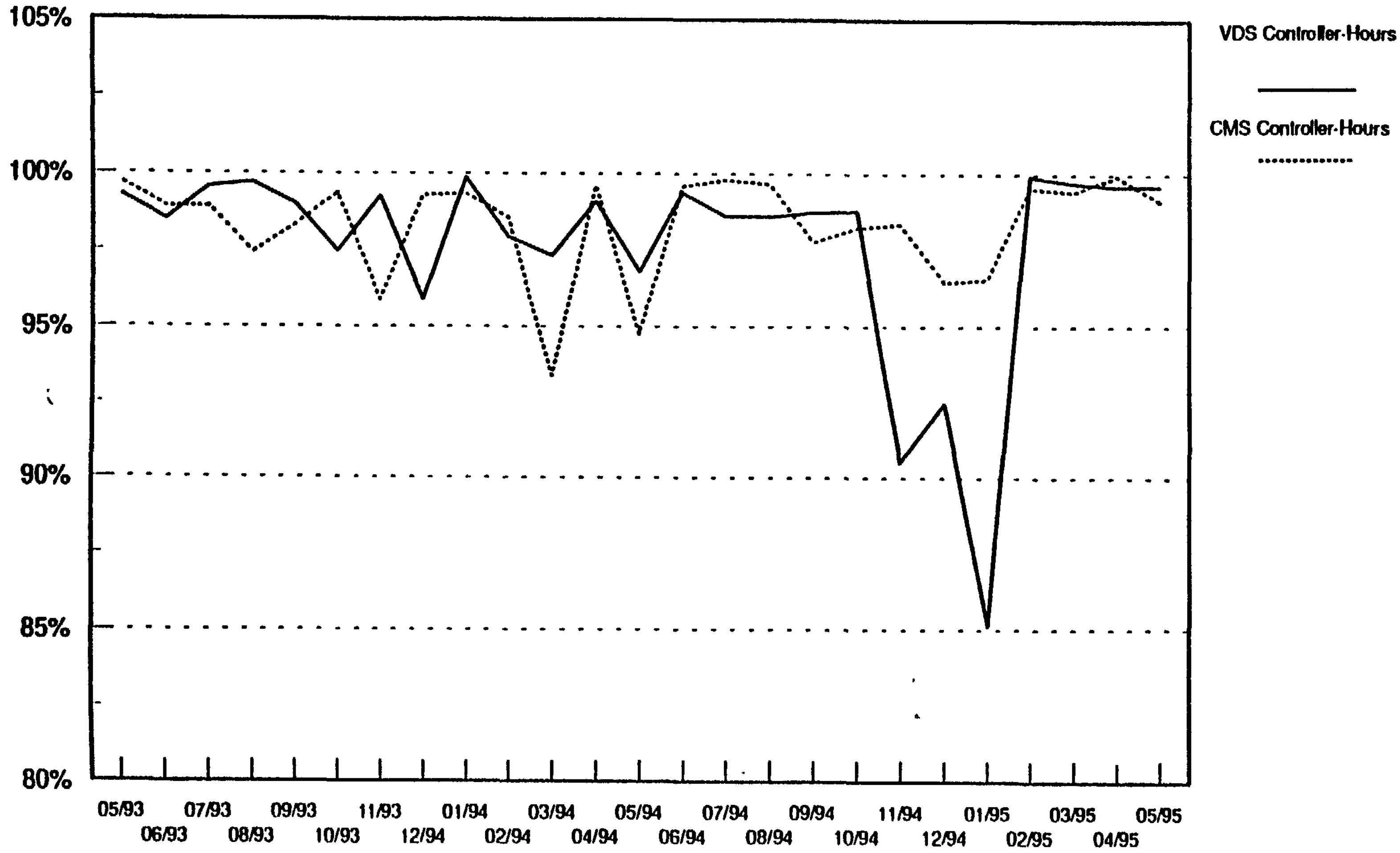
MONTHLY INCIDENTS/DAILY AVERAGE TRAFFIC

FROM MAY 1993 TO MAY 1995



HIGHWAY 401 COMPASS SYSTEM

MONTHLY EQUIPMENT AVAILABILITY
FROM MAY 1993 TO MAY 1995



Q.E.W. MISSISSAUGA COMPASS SYSTEM
ROYAL WINSOR DRIVE TO HIGHWAY 427
TRAFFIC DATA AND OPERATIONS REPORT
FOR MAY, 1995

	East Bound	West Bound	Total
*Monthly Average Daily Traffic (veh.)	84,094	77,160	161,254
*measured in the vicinity West of Highway 427			

	East Bound	West Bound
Monthly Average Peak Period Speed (km/h) AM (from 08:00 to 09:00)	60	79
Monthly Average Peak Period Speed (km/h) PM (from 17:00 to 18:00)	77	63

	East Bound	West Bound
Highest Hourly Per Lane Volume	2,264	2,359
Day of the Month	3	16
Time of the Month	07:00 to 08:00	17:00 to 18:00
Station Description	QEW EB, EAST OF ROYAL W.	QEW WB. E OF MISS.
Roadway Description	SINGLE	SINGLE
Station Number	1	Al

	*Total Monthly Vehicle-Hours of Delay
East Bound (veh-hrs)	19,409
West Bound (veh-hrs)	05,583
Q.E.W. Total (veh-hrs)	24,992

* monthly accumulated total of additional travel time experienced by all vehicles that travel at less than 70km/h

*AVERAGE TRAVEL TIME	Weekday Travel Time at: 08:00	Weekday Travel Time at: 17:00	Weekend Travel Time at: 10:00	Weekend Travel Time at: 17:00
Eastbound Royal Windsor Drive to Highway 427	29 min	11 min	11 min	11 min
Westbound Highway 427 to Ford Drive	10 min	12 min	10 min	11 min

*Average travel time calculation is based on the QEW Mississauga COMPASS speed/occupancy data

COMPASS

Q.E.W. MISSISSAUGA COMPASS SYSTEM REPORT FOR MAY, 1995

CHANGEABLE MESSAGE SIGN UTILIZATION	
Number of Changeable Message Signs	2
Number of Non-Default Messages Displayed	1484
Non-Default Messages Displayed per Sign per [illegible]	24

MONTHLY FIELD EQUIPMENT OPERATING STATISTICS	
Potential No. of VDS Controller-Hours Available	25,296
Actual No. of VDS Controller-Hours Recorded	23,505
Percentage VDS Controller Availability	92.92%
Potential No. of CMS Controller-Hours Available	3.720
Actual No. of CMS Controller-Hours Recorded	3,713
Percentage CMS Controller Availability	99.81%

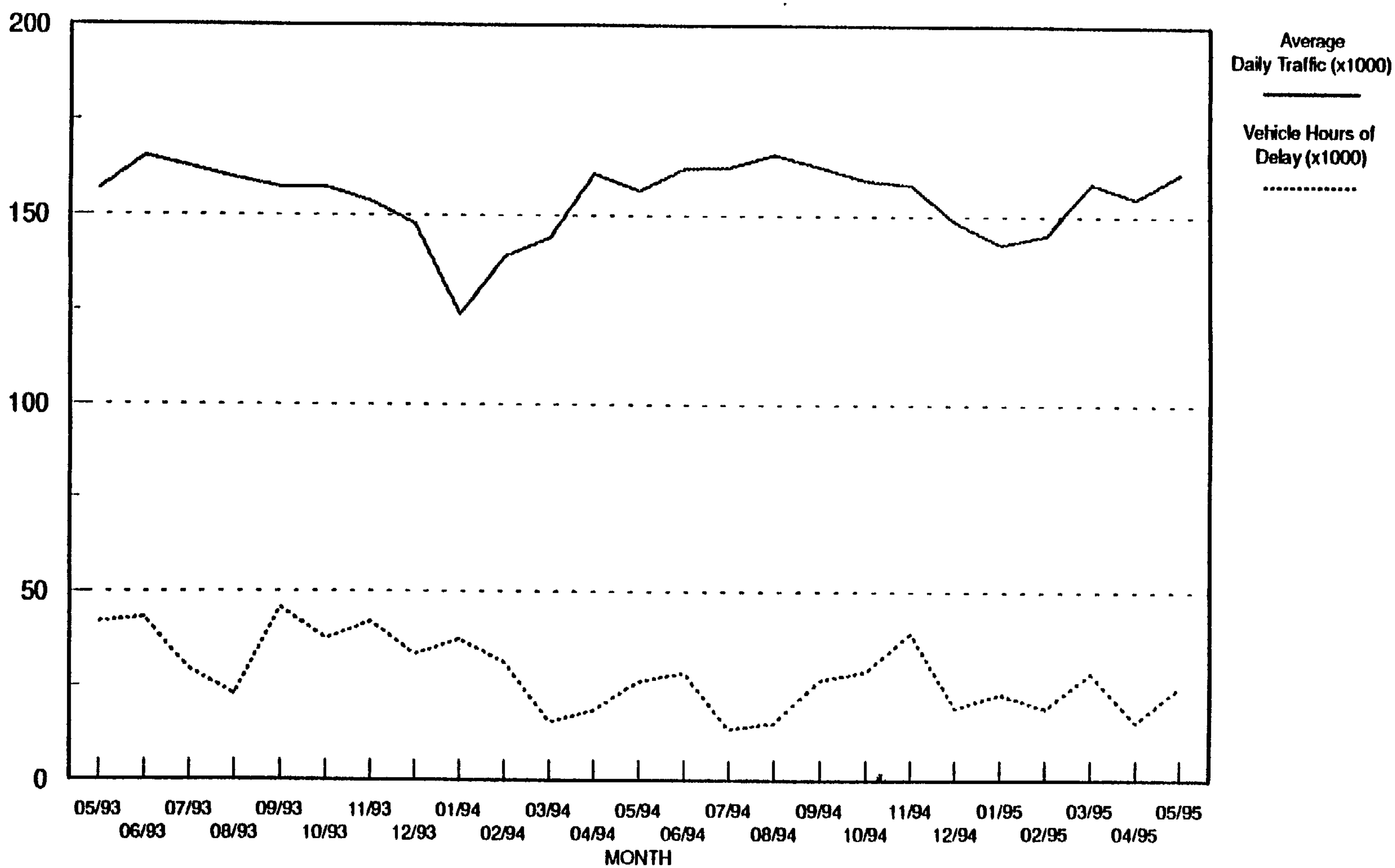
Note: VDS = Vehicle Detector Station
CMS = Changeable Message Sign

PERCENTAGE OF QEW RAMP METERING RATE UTILIZATION

ON RAMP LOCATION	RATE IN SECONDS 5.0	6.0	7.5	10.0	15.0
Ford Drive	46.30%	13.48%	20.53%	19.59%	0.11%
Winston Churchill NB	45.15%	13.74%	18.27%	22.84%	0.00%
Winston Churchill SB	45.13%	13.85%	18.18%	22.85%	0.00%
Erin Mills/Southdown	39.32%	18.72%	21.23%	20.73%	0.00%
Mississauga Road SB	16.66%	10.39%	38.70%	34.15%	0.10%
Mississauga Road NB	16.82%	9.29%	38.43%	35.38%	0.08%
Highway 10 NB	22.86%	25.54%	35.20%	16.40%	0.00%
Highway 10 SB	22.01%	25.22%	36.00%	16.77%	0.00%
Cawthra Road NB	37.43%	32.72%	25.33%	4.52%	0.00%
Cawthra Road SB	37.57%	32.64%	25.26%	4.53%	0.00%
Overall Averages	32.28%	20.15%	28.21%	19.34%	0.03%

QEW MISSISSAUGA COMPASS

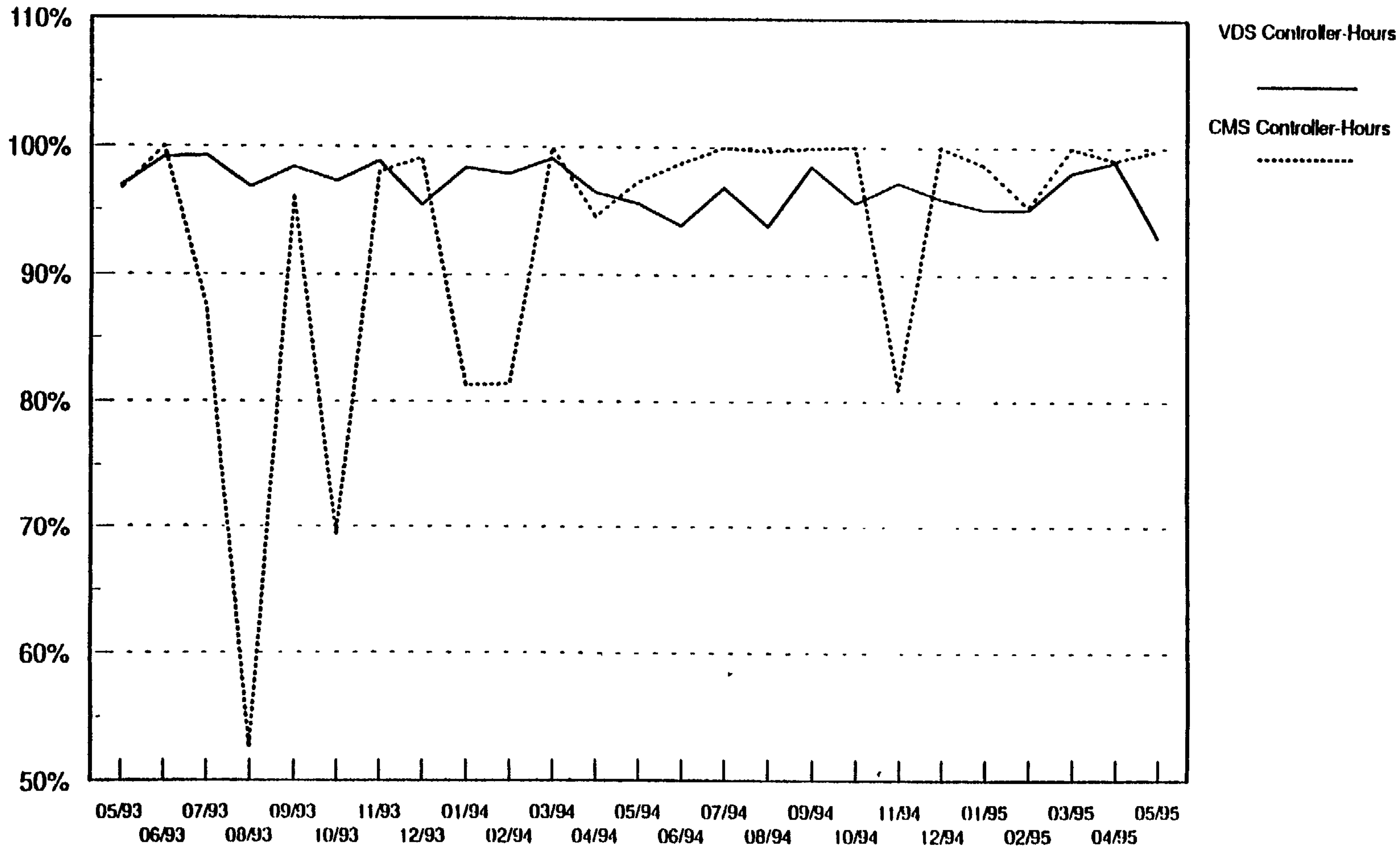
DAILY AVERAGE TRAFFIC/VEHICLE HOURS OF DELAY
FROM MAY 1993 TO MAY 1995



QEW MISSISSAUGA COMPASS

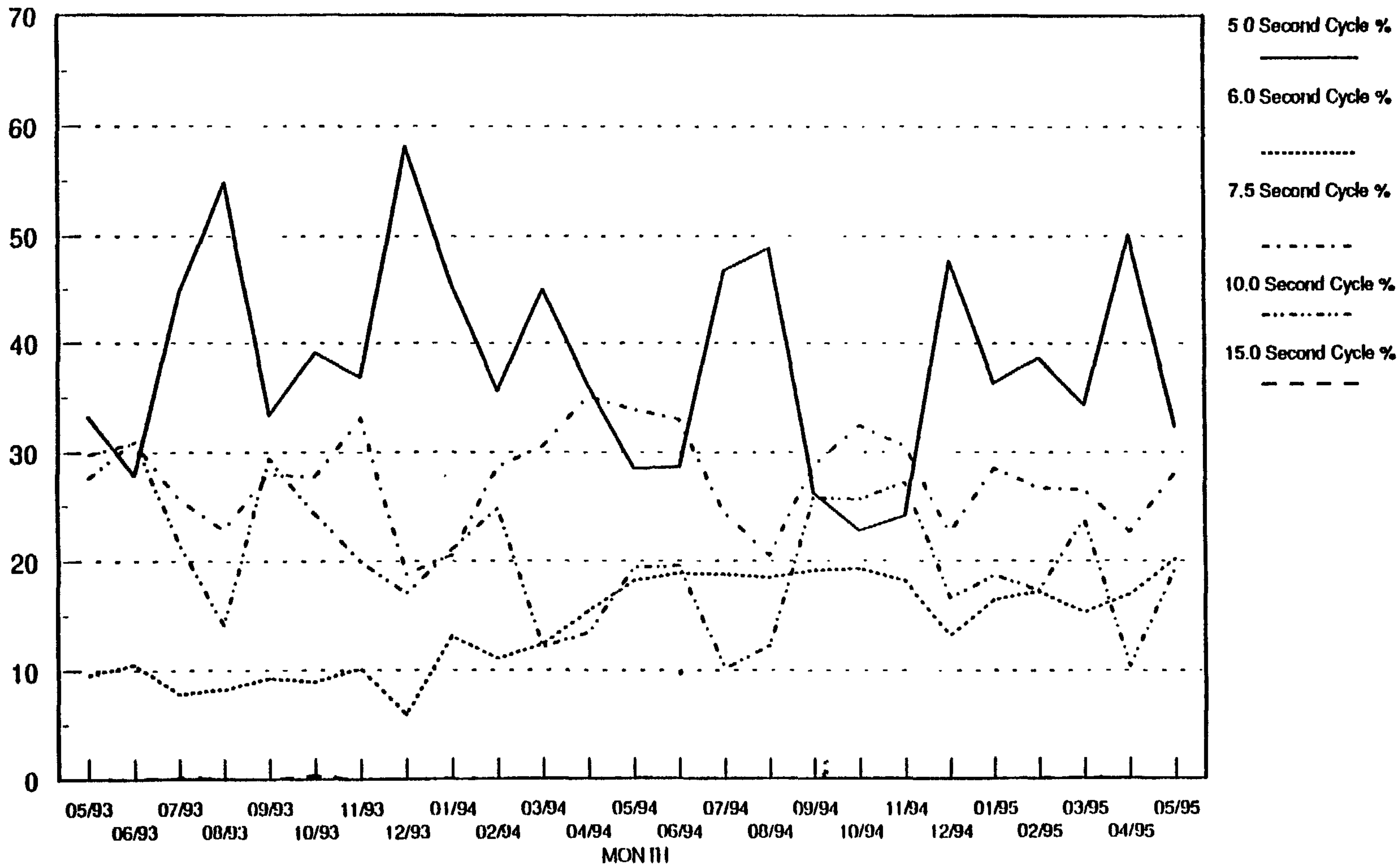
MONTHLY EQUIPMENT AVAILABILITY

FROM MAY 1993 TO MAY 1995



QEW MISSISSAUGA COMPASS

PERCENTAGE OF RAMP METERING RATE UTILIZATION FROM MAY 1993 to MAY 1995



Q.E.W. BURLINGTON COMPASS SYSTEM
BURLINGTON ST. TO FAIRVIEW ST.
TRAFFIC DATA AND OPERATIONS REPORT
FOR MAY, 1995

	Toronto Bound	Niagara Bound	Total
*Monthly Average Daily Traffic (vehicles)	46.075	53.201	99.276
*measured at top of Skyway			

	Toronto Bound	Niagara Bound
Monthly Average Peak Period Speed (km/h) AM (from 08:00 to 09:00)	85	76
Monthly Average Peak Period Speed (km/h) PM (from 17:00 to 18:00)	86	84

	Toronto Bound	Niagara Bound
Highest Hourly Per Lane Volume	1,443	1,551
Day of the Month	1	19
Time of the Month	08:00 to 09:00	17:00 to 18:00
Station Description	EASTPORT DR NB	SOUTH OF WOODWARD SB
Roadway Description	STANDARD	STANDARD
Station Number	QEWDS0040DNS	QEWDS0090DSS

	*Total Monthly Vehicle-Hours of Delay
Toronto Bound (veh-hrs)	00.012
Niagara Bound (veh-hrs)	00.176
Q.E.W. Burlington Total (veh-hrs)	00.188
* monthly accumulated total of additional travel time experienced by all vehicles that travel at less than 70km/h	

Between Burlington & Fairview	*Average Travel for Weekday 08:00	*Average Travel for Weekday 17:00	*Average Travel for Weekend 10:00	*Average Travel for Weekend 17:00
Niagara Bound	4	4	4	4
Toronto Bound	4	4	4	4
*Average travel time calculation is based on the QEW Burlington COMPASS speed/occupancy data				

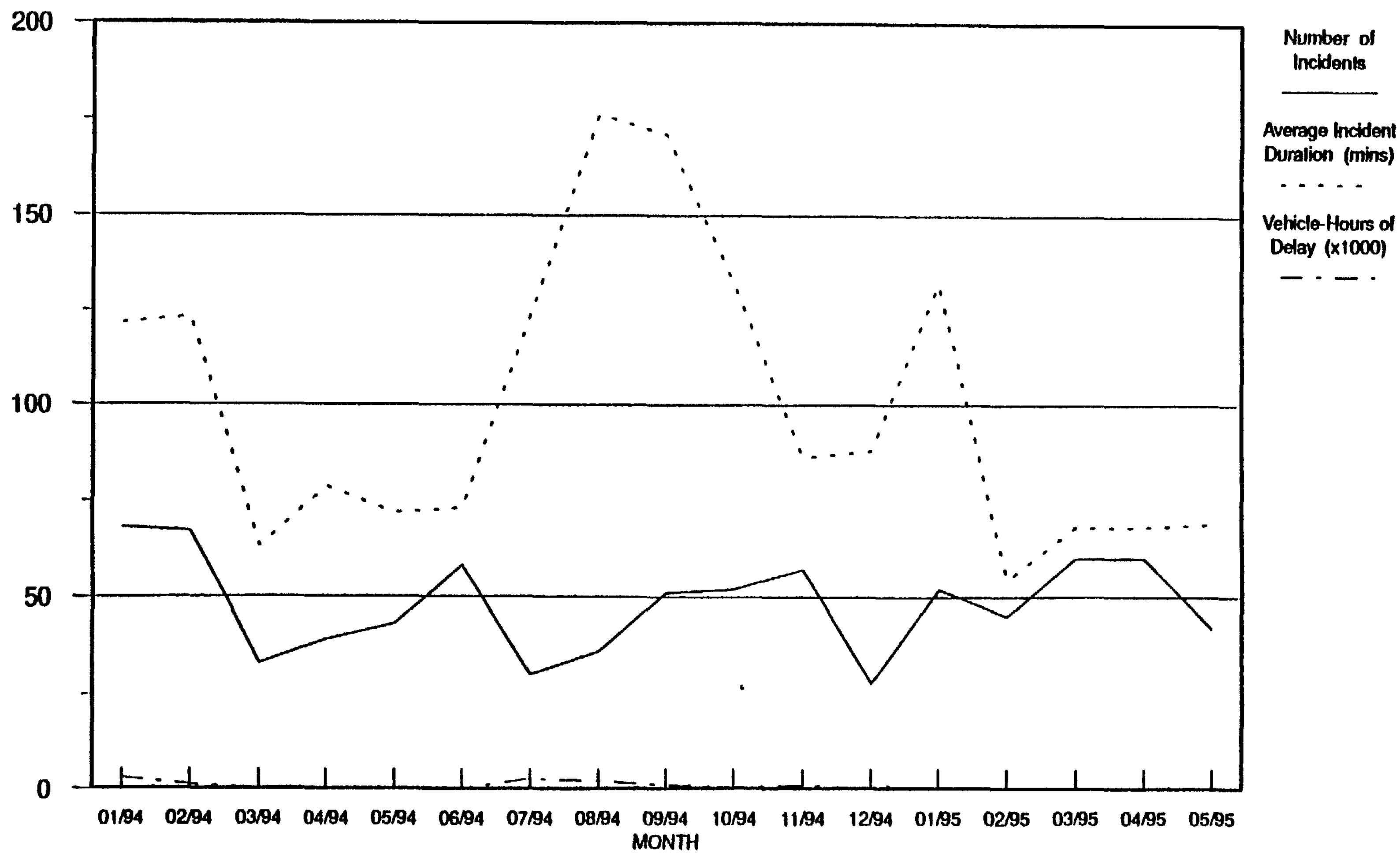
CHANGEABLE MESSAGE SIGN UTILIZATION	
Number of Changeable Message Signs	8
Number of Non-Default Messages Displayed	600
Non-Default Messages Displayed per Sign per Day	3

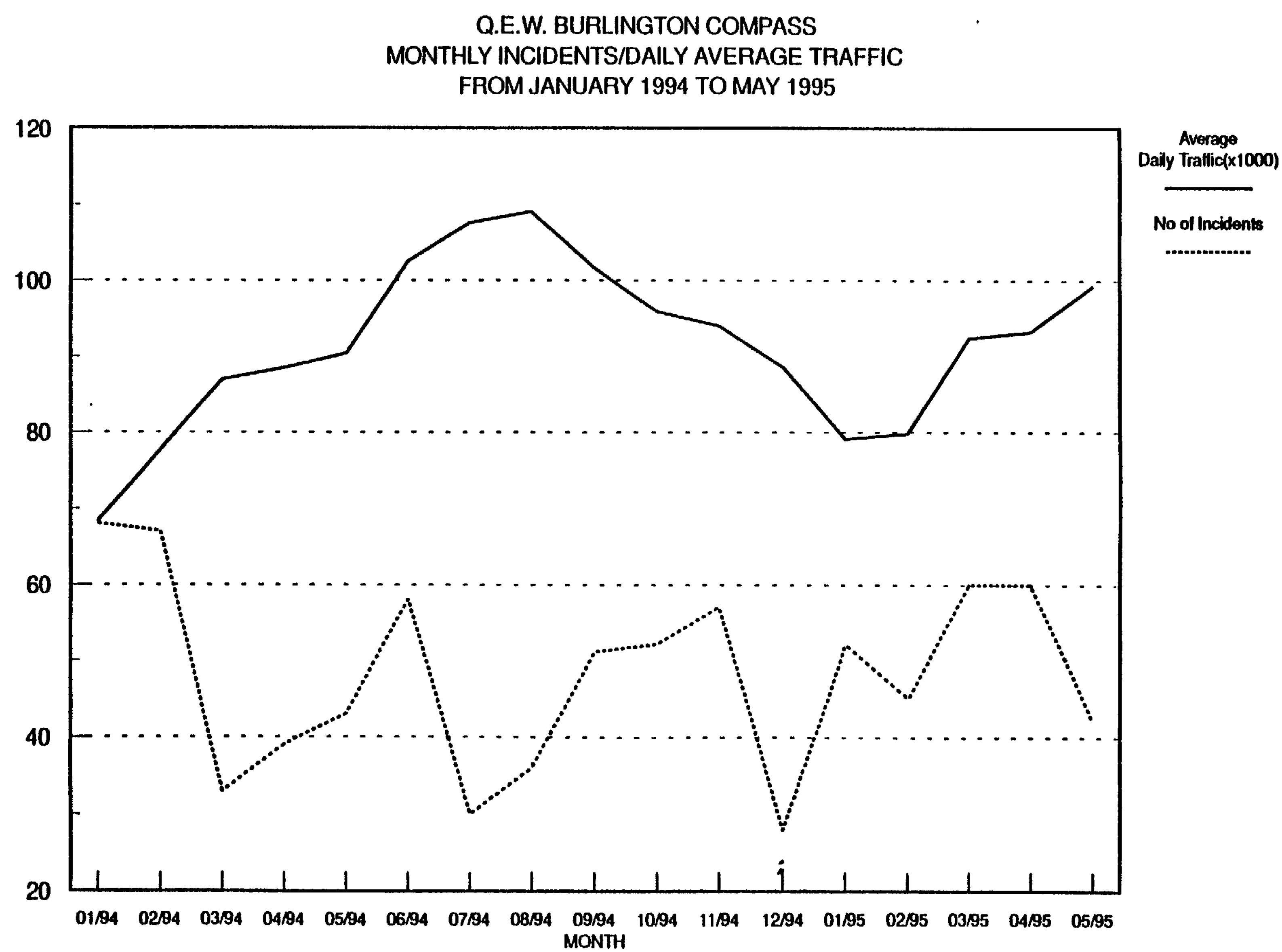
CONFIRMED INCIDENT DATA BETWEEN BURLINGTON STREET AND FAIRVIEW STREET (INCLUDING SHOULDER INCIDENTS)	
Total Number of Confirmed Incidents	60
Percentage Detected by System	5.00%
Percentage Manually Detected	95.00%
Incident types:	6.33% Accidents 10.00% Disabled Vehicles 60.00% Road Work .00% Debris 31.67% Other
Lane Blockage Types:	.00% Full Closure 31.67% One Lane 6.67% Two Lanes .00% Three Lanes .00% Four Lanes .00% Five Lanes 61.67% Other
Total Duration of the 60 Incidents:	4.095.57 min
Average Duration per Incident:	68.26 min
Percentage of False Alarms (false alarms divided by total alarms):	96.88%

MONTHLY FIELD EQUIPMENT OPERATING STATISTICS	
Potential No. of VDS Controller-Hours Available	21,600
Actual No. of VDS Controller-Hours Recorded	16,607
Percentage VDS Controller Availability	76.88%
Potential No. of CMS Controller-Hours Available	5,760
Actual No. of CMS Controller-Hours Recorded	4,438
Percentage CMS Controller Availability	77.06%
Note: VDS = Vehicle Detector Station CMS = Changeable Message Sign	

COUNTS OF OPERATOR REACTION TIME TO CONFIRM INCIDENT DEJECTION ALARMS FOR THE MONTH OF APRIL	Counts	Percentage
Less than 3 Minutes	88	97.78%
3 To 6 Minutes	1	1.11%
6 To 15 Minutes	1	1.11%
Above 15 Minutes	0	.00%
Total:	90	100.00%

Q.E.W. BURLINGTON COMPASS
MONTHLY INCIDENTS/VEHICLE-HOURS OF DELAY
FROM JANUARY 1994 TO MARCH 1995




Q.E.W. BURLINGTON COMPASS
MONTHLY INCIDENTS/DAILY AVERAGE TRAFFIC
FROM JANUARY 1994 TO MAY 1995
120
100
80
60
40
20
01/94
02/94
03/94
04/94
05/94
06/94
07/94
08/94
09/94
10/94
11/94
12/94
01/95
02/95
03/95
04/95
05/95
MONTH
Average
Daily Traffic(x1000)
No of Incidents

Q.E.W. BURLINGTON COMPASS
MONTHLY EQUIPMENT AVAILABILITY
FROM JANUARY 1994 TO MAY 1995