

**THE ABILITY OF ADVANCED TRANSPORTATION TECHNOLOGIES TO
FACILITATE THE ATTAINMENT OF URBAN AIR QUALITY STANDARDS**

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SUMMARY

This research investigated the ability of advanced transportation technologies to reduce vehicle emissions. The specific technologies analyzed were advanced transportation management systems (ATMS) and advanced driver information systems (ADIS).

The results of this research are constrained by the assumptions and conditions as stated in their calculation. Table A-1 (see next page) is a synopsis of the relevant conditions and assumptions that were made for the determination of each technologies ability to reduce vehicle emissions. These assumptions and conditions were considered "average" values for urban populations of one million or greater.

The analyses of this research suggest that "advanced" arterial traffic control can reduce vehicle hydrocarbon emissions by 8% and carbon monoxide emissions by 13%. These numbers indicate that an arterial ATMS has considerable benefits to offer in terms of reducing areawide vehicle emissions. The analyses also suggest that "advanced" freeway traffic management and control, given the appropriate travel characteristics, can be an effective means to the improvement of urban air quality. Given the assumed "average" travel characteristics, freeway incident and traffic management was found to have a limited ability to reduce areawide vehicle emissions. However, with travel characteristics as found in the San Francisco/Oakland metropolitan area, a freeway traffic management and control system was found to reduce areawide hydrocarbon emissions by 2% and carbon monoxide emissions by 4%. The analysis of ADIS (navigation and route optimization) indicated that this technology has a significant ability to reduce vehicle emissions. If 100% of an urban area's vehicle fleet were to have ADIS features, it was calculated that there is a potential for an 11% reduction in hydrocarbon emissions, a 14% reduction in carbon monoxide emissions, and a 7% reduction in nitrogen oxide emissions. With a "reasonable" percentage of the vehicle fleet having in-vehicle devices, e.g., 10%, the reductions in areawide hydrocarbon and carbon monoxide emissions are approximately 2%.

The analyses of this research allow further insight into the potential benefits that advanced transportation technologies can offer. The attainment of these benefits are simply dependent upon the implementation of the appropriate technologies.

Table A-1. Relevant assumptions and conditions utilized in the calculations of this research.

Technologies	Relevant Conditions and Assumptions
Arterial Traffic Management and Control	<ol style="list-style-type: none"> 1. The total signalized arterial system is assumed to account for 60% of areawide vehicle hours traveled. 2. The "before-condition" assumes that one-half of the signalized urban intersections are interconnected with old timing plans. 3. The "after-condition" assumes the installation of an advanced computer control system at half of the signalized intersections (same locations as in 2. above). It is also assumed that an additional 25% of the signalized intersections are interconnected and have optimized signal timings. 4. After implementation of the advanced computer control system a negligible induced travel is assumed.
Freeway Traffic Management and Control	<ol style="list-style-type: none"> 1. It is assumed that in the typical metropolitan area one-third of all vehicular travel is on freeways, one-third of this travel is during the peak periods, and 20% of the freeway VMT experiences congestion. Since these travel characteristics are not representative of all metropolitan areas, this research attempted to quantify the benefits for urban areas with "unusual" travel patterns. The case example used was the San Francisco/Oakland metropolitan area. 2. The "before-condition" assumes that there is no form of freeway incident and traffic management in the urban area. The "after-condition" assumes that an areawide/comprehensive freeway incident and traffic management system is implemented. 2. It is assumed that an areawide freeway incident and traffic management system will reduce travel time by 16.5% for those experiencing congestion. 3. The calculations of this research only considered the benefits of freeway incident and traffic management during the peak periods. The benefits to derive through off-peak incident management were not quantified in this research. 4. After implementation of the advanced freeway incident and traffic management system a negligible induced travel is assumed.
Advanced Driver Information Systems	<ol style="list-style-type: none"> 1. It is assumed that 6.4% of all VMT and 12% of all VHT in urban areas can be saved through route optimization and navigation. 2. The calculations in this research assumed that 10% of the vehicle fleet would have in-vehicle devices by the year 2000. This research also considered the benefits that are possible if 100% of the vehicle fleet were to have in-vehicle devices. 3. This research did not quantify the benefits to be derived through route advisement in congested situations.

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INTRODUCTION

Background

The Clean Air Act Amendments (CAAA) of 1990 will have a significant impact on the planning and implementation of future and ongoing transportation programs and practices. In fact, the objective of attaining federal air quality standards may become the governing factor in future transportation investment decisions. This becomes reality when one looks at the new sanction language of the 1990 CAAA.

In times past, highway sanctions were only employed for the failure to submit, or making a reasonable effort to submit, a State Implementation Plan (SIP). As of the 1990 CAAA, sanctions can now be triggered when the Environmental Protection Agency (EPA) disapproves a SIP, or the state—including metropolitan planning organizations—fails to submit any requirement of the act. This is to say, highway sanctions can now be employed for both planning and implementation failures. These provisions allow the EPA to have a tighter rein on future transportation planning decisions by their ability to effectively strike upon each state's and metropolitan's Achilles' heel—their pocketbooks.

It is clear that environmental protection is destined to be one of the relevant issues in future transportation decision making. For this reason, it is desirable to determine the effectiveness of available resources for reducing vehicular emissions. Simple transportation system management (TSM) actions have been established as effective solutions to recurring congestion. Although there has been few meaningful attempts to measure the air quality effects of TSM actions, their favorable affects on congestion can only cause a parallel affect on air quality. Since the burden of reducing emissions, at present, is focused on nonattainment areas, the use of simple TSM actions for reducing emissions may not be applicable. It would not be unreasonable to expect that nonattainment areas (i.e., large metropolitan areas) have already implemented the classic TSM actions. Consequently, large metropolitan areas are in a position where they must look to advanced technologies to meet emission requirements. These advanced technologies, known as Intelligent Vehicle/Highway Systems (IVHS), are expected to protect the environment through improved mobility and transportation productivity, and the maximization of existing transportation facilities and energy resources. It is this claim that has been addressed in this report.

Objective

The primary objective of this research was to identify advanced transportation technologies that can significantly reduce vehicular emissions. Upon the identification of these technologies, an estimate to their emission reduction potential was calculated.

Scope

This research examined the ability of advanced transportation technologies to reduce vehicular emissions. The analysis included the technologies and ideas under the broad areas of Advanced Transportation Management Systems (ATMS) and Advanced Driver

Information Systems (ADIS), where ADIS is one aspect of the Advanced Traveler Information System (ATIS) ideal.

A quantifiable benefit has been reported for each technology. In cases where the technology has been implemented, a "measured" benefit has been reported. Since a considerable amount of the technologies are in the conceptual stage, it became necessary to generate an estimate of the benefits by use of variables or surrogate variables that influence vehicle emissions. With these variables and an appropriate modelling procedure, a forecast was derived for the emission reduction potential.

THE ROLE OF TRANSPORTATION IN URBAN POLLUTION

Pollutants of Concern in Urban Areas

There are seven (7) air pollutants that occur in high concentrations (microscopically) and have become the focus of a nationwide effort to be controlled (1):

1. PM-10 (small particulate matter)--Small particulate matter is not considered a major transportation-related pollutant.
2. Sulfur Dioxide (SO_2)--Sulfur dioxide is produced through coal and oil burning. Sulfur dioxide contributes to acid rain and is not considered a major transportation-related pollutant.
3. Carbon Monoxide (CO)--Carbon monoxide is produced from the incomplete combustion of organic fuels. CO inhibits the blood's ability to carry oxygen and is considered a major transportation-related pollutant.
4. Volatile Organic Compounds (VOCs)--VOCs are a group of chemicals (e.g., hydrocarbons) that react in the atmosphere with nitrogen oxides to form ozone or nitrogen dioxide NO_2 . VOCs are considered a major transportation related pollutant.
5. Nitrogen Dioxide (NO_2)--Nitrogen dioxide is a secondary pollutant of motor vehicle emissions. Nitrogen dioxide is formed from the chemical reaction of nitrogen oxides and VOCs in the presence of sunlight and heat. Nitrogen oxides are formed by high temperature combustion processes (e.g., automobile engines). Nitrogen dioxide produces acid rain and is considered a major transportation-related pollutant.
6. Ozone (O_3) (i.e., Smog)--Ozone is a secondary pollutant of motor vehicle emissions. Ozone is formed by the photo-chemical reactions of VOCs and NO_x . Ozone and nitrogen oxides are the principal and best understood smog constituents. Ozone causes respiratory infections, is toxic to plants, damages many materials, and is considered a major transportation-related pollutant.
7. Lead (Pb)--The concentration of lead in major metropolitan areas is being diminished by the use of fuels that are non-lead based. Lead is considered a major transportation-related pollutant, per-se.

Transportation Related Pollutants

Of all the major air pollutants that are transportation-related, the most sought after to control are ozone and carbon monoxide. Carbon monoxide is a direct result of motor vehicle travel. Ozone (O_3), on the other hand, is a secondary pollutant of motor vehicle emissions. To actually understand how transportation contributes to urban ozone, one should understand how O_3 is formed. The elements that make up ozone are hydrocarbons and nitrogen oxides. The sources of these elements are as follows (1).

Sources of hydrocarbons (HC):

1. automobile emissions,
2. petroleum refineries,
3. chemical plants,
4. dry cleaners,
5. gasoline stations,
6. house painting (oil-base paints), and
7. print shops.

Sources of nitrogen oxides (NO_x):

Combustion of fuel for transportation, utilities, and industry.

Ozone is formed by the photo-chemical reaction of VOCs (HC) and nitrogen oxides. Motor vehicles account for about half (50%) of the ozone precursors, VOCs and NO_x, in the United States urban areas (1). Since motor vehicles contribute the majority of the necessary pollutants that make up ozone, it makes sense that ozone is considered a transportation-related pollutant. The actual extent of CO and the precursor elements VOC and NO_x caused by transportation are staggering when one looks at the United States large metropolitan areas. Table 1 depicts the magnitude that transportation contributes to urban pollution.

Areas that exceed CO, O₃, and NO₂ air quality standards contain roughly 75% of the U.S. population and include 88% of the metropolitan areas with populations over 200,000 people (1). The magnitude of this problem in terms of public health has been the issue that has prompted a concern on how these pollutants are to be reduced.

Major Provisions of the CAAA of 1990

The new air quality law addresses three types of pollution:

1. Ozone (Smog)*,
 2. Carbon Monoxide (CO)*, and
 3. Particulate Matter (PM-10).
- (*indicates a major transportation related pollutant).

The law also establishes provisions defining when and how the federal government (EPA) can impose sanctions for noncompliance to the CAAA of 1990. The term "sanction" has been defined as actions taken against a State or local government by the Federal government (EPA) for the failure to plan, implement, or produce an "acceptable" SIP. Examples include withholding of highway funds and a ban on construction of new facilities.

Different classifications of non-attainment are given for each area depending on their amount of pollution. An area is considered in "non-attainment" if its air quality is not as good or better than the National Ambient Air Quality Standard as defined in the Clean Air Act. An area may be an attainment area for one pollutant and a non-attainment area for others.

Table 1. The Magnitude that Transportation Contributes to Urban Pollution (1).

City	Pollutant	Percentage of emissions caused by:	
		Motor Vehicles	Non vehicular sources
Los Angeles	CO	91	9
	HC	52	48
	NO _x	53	47
San Francisco	CO	89	11
	HC	46	54
	NO _x	55	45
Philadelphia	CO	98	2
	HC	43	57
	NO _x	32	68
Denver	CO	89	11
	HC	82	18
	NO _x	40	60
Wash. D.C.	CO	100	0
	HC	76	24
	NO _x	74	26
Baltimore	CO	98	2
	HC	76	24
	NO _x	31	69

This table illustrates the distribution of CO, HC and NO_x emissions among motor vehicles and nonvehicular sources in selected cities during the mid-1970s

A classification is given in Table 2 for the level of non-attainment to ozone standards. Figure A of the Appendix lists the cities in each of these classifications.

For areas of moderate ozone pollution and above, a 15% VOC (HC) reduction within 6 years is necessary. Serious areas and above, after the initial 6 years, need an average of 3% VOC reduction per year until attainment of air quality standards.

A classification is given in Table 3 for the level of non-attainment to carbon monoxide (CO) standards. Figure B of the Appendix lists the cities in each of these classifications.

The 1990 CAAA does not make provisions for a quantifiable reduction in carbon monoxide levels. The 1990 CAAA, however, does require the areas defined as "serious" to compensate for yearly growth in CO emissions through traffic control measures (2).

Methods to Reach Attainment

The provisions of the CAAA-1990 have allocated for alternate fuel use, increased standards on individual vehicle emissions, and other restrictions to help in the attainment of the set urban air quality standards. Among other things, the amendment has set the following mobile source restrictions and regulations.

1. Tailpipe Standards: Further reductions on the parts-per-million emission of HC, CO, and NO_x. The useful life has also been extended to 100,000 miles for these emission's standards.
2. Reformulated Gasoline: Beginning in 1995, the 9 worst areas must reformulate gasoline such that minimum oxygen content and VOCs percentages are met.
3. Non-road Engines: EPA will regulate any non-road engine that contributes to urban air pollution. At a minimum, EPA will control locomotive emissions.
4. California is required to sell a minimum of 150,000 "clean cars" by the year 1996 and 300,000 per year by 1999. These "clean cars" will emit extraordinarily low levels of pollutants in comparison to previous vehicle emission rates.

The above standards and restrictions, although not exhaustive of the mobile source provisions of the CAAA, will have a significant impact on the level of pollutants in our urban areas (2).

The amendment also makes provisions for 10 categories of transportation control measures that are expected to help in reducing vehicle hours and miles traveled through demand management strategies and "supply-side" improvements (3).

Table 2. Classifications for non-attainment to ozone standards (2).

Classification	Attainment to be reached in "x" years
Marginal	3 years
Moderate	6 years
Serious	9 years
Severe	15 - 17 years
Extreme	> 20 years

Table 3. Classifications for non-attainment to carbon monoxide standards (2).

Classification	Provision
Moderate	VMT forecasts in SIPs and Automatic contingency measures
Serious	TCMs to offset growth in emissions/VMT trips. Explain TCM rejections, provide comparable reductions, implement economic incentive/TCM programs.

These defined categories include the following.

1. Trip Reduction Ordinances
2. No-Drive Days/Driving Restrictions
3. Employer-Based Transportation Management
4. Transit Improvements
5. Parking Management Programs
6. Park and Ride/Fringe Parking
7. Work Schedule Changes
8. Road Pricing and Tolls
9. Area-Wide Rideshare Programs
10. Traffic Flow Improvements

It is hoped that through the reduction of emissions at the source, travel demand management, and more efficient use of present transportation facilities, the air quality standards set by the Environmental Protection Agency can be met and maintained. It would be foolish to believe that one single action can bring about a solution to a problem of this magnitude. Although this paper addresses the small aspect of improving the "supply-side" of transportation facilities through IVHS technologies, it is by no means intended that one assume that IVHS will give the complete solution. It is going to take teamwork to solve the problems that face transportation today—there is no room for tunnel vision.

REDUCING EMISSIONS—A SYSTEM MANAGEMENT PERSPECTIVE

In the past, considerable attention has been given to this nation's energy consumption. Not unlike urban pollution problems, the majority of this nation's consumption of fossil fuels is due to transportation. The threat of running out of needed energy as quickly as 30 years down the road has spurred research in energy conservation. With pollution being a growing concern in this nation, it only makes sense to use parallel research on energy conservation in determining the best methods to reduce vehicular emissions. This is possible because of the speed dependent relationship between the average vehicle's emission rate and gallons of gasoline consumed (See Table A of the Appendix). Simply put, since there is a direct relationship between a vehicle's gasoline use and their emission rates, it is possible to use research in energy conservation for making inferences on air quality issues.

In the development of strategies to reduce the energy consumption of urban transportation systems, a two-sided approach is essential (4). The dual approach includes:

1. Reduction of vehicular travel quantity, especially single occupancy automobiles; and
2. Improvement of the efficiency of vehicular travel, i.e., reductions in the vehicle hours of travel will in turn reduce the vehicle emissions per mile traveled.

The first approach is often given the broad title of "demand management." Although travel demand management will not be addressed as a means to reduce emissions in this paper, it is a necessary component to any strategy that is expected to increase the efficiency of a transportation system. Because enhanced traffic flow quality for energy and emission reductions often will bring about induced travel, some form of demand management is necessary. Without some countermeasure, the benefits of the increased quality of flow can be exceeded by the increased travel demand, thus creating a situation that is worse than the initial condition. For this reason, demand management must be an integrated part of any program designed to increase the efficiency of the transportation system.

The second approach, the improvement of the quality of flow, is often underemphasized as a means to reduce fuel consumption and improve air quality. As already stated, latent demand is often a case for questioning the validity of this approach to actually reducing vehicle emissions. However, with coordinated efforts of both approaches, a positive result would most likely occur.

The interrelationship between supply and demand strategies is depicted in Figure 1. This figure shows that changes in the quality of travel will bring about a change in the average travel time, Δt . A change in the quantity of travel, in turn, brings about a change in the vehicle miles traveled (VMT). The objective is to achieve a reduction in total travel time (TTT) while maintaining a constant amount of VMT. With the event of a change in TTT and VMT, a change in the total vehicle emissions and fuel consumed can be calculated. Figure 1 also indicates that an equilibrium exists between the results of the two

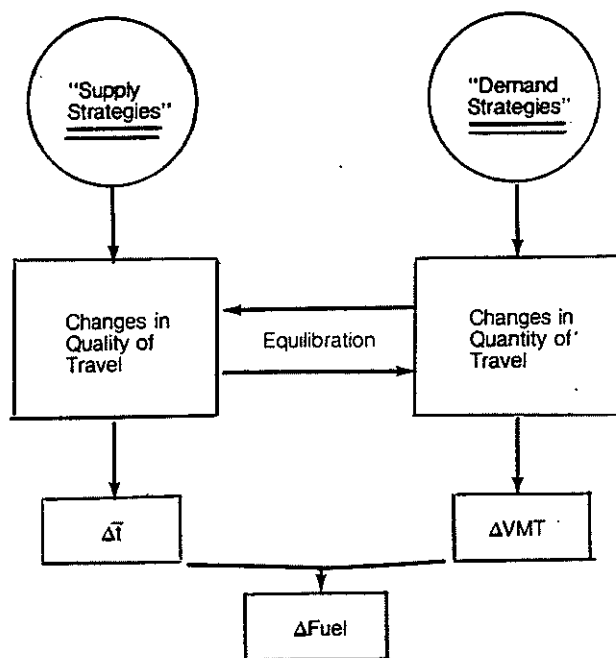


Figure 1 The Energy Effects of Transportation System Improvements (4).

strategies. It is this delicate equilibrium that must be controlled if one is to truly achieve a reduction in fuel consumption and vehicle emissions. This equilibrium process is complex, and a detailed discussion is beyond the scope of this report.

The approaches to be investigated through this research include surface arterial and freeway management improvements, as depicted in Figures 2 and 3. These figures show the affect of increased VMT/hr on the TTT. An important point about these figures is the "before-after" lines for each type of improvement. The improvement of an arterial signal system shows a benefit throughout the entire range of vehicle flow rates, whereas freeway surveillance and control systems only show a substantial benefit at high VMT/hr rates. This point will be expanded upon in the discussion of each method's representative practices and benefits.

- Surface Arterial Efficiency**
- Traffic Signal System Improvements
 - Signal Removal and Flashing
 - Right Turn on Red After Stop

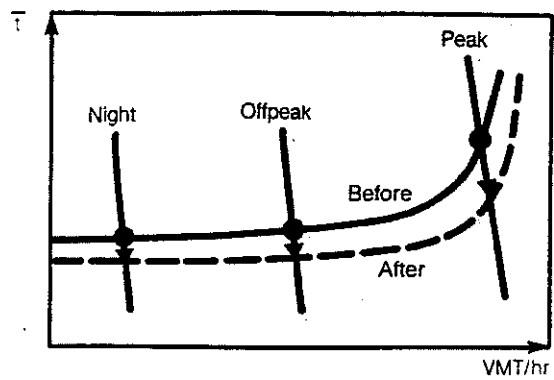


Figure 2 Impacts of Arterial Improvements on Travel Times (t) versus VMT/hr (4).

- Freeway Efficiency**
- Surveillance & Control
 - Incident Management Systems
 - Advanced Driver Information Systems

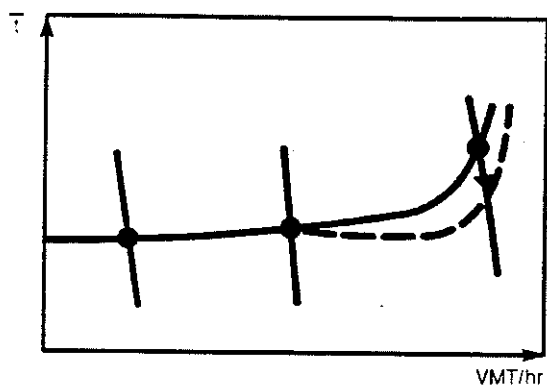


Figure 3 Impacts of Freeway Improvements on Travel Times (t) versus VMT/hr (4).

VEHICLE EMISSION CALCULATION METHODS

The premise of this analysis is that reduced travel time equates to reduced gasoline consumption, thus reduced vehicle emissions (assuming an insignificant increase in VMT). This premise is upheld by Figure 4, which illustrates the increase in fuel consumption versus the increase in mean travel time. In the sense of this analysis, reduced travel time is due to reductions in delay, rather than increases in running speeds. The relationship of the emission/gallon rates for a given average speed is found in Table 1 of the Appendix.

In the past, the total gallons of fuel consumption have been modeled as a function of the total vehicle miles traveled (VMT) and the total vehicle hours of travel (VHT). It has been shown that for most urban automobile trips, fuel consumption (F) correlates linearly with VHT and VMT (4). This relationship is as follows:

$$F = 0.0425 \text{ VMT} + 0.60 \text{ VHT}.$$

If one wishes to determine the net change in fuel consumption given a change in vehicle hours and vehicle miles of travel, the estimating relationship would be:

$$\Delta F = 0.0425 \Delta \text{VMT} + 0.60 \Delta \text{VHT}.$$

This method, although not precise, can give a good estimate of the percentage change in fuel consumption, which in turn can give an estimate of the percentage change in emissions. Although this equation was derived from the population of vehicles in the late 1970s to early 1980s, its use as a crude measure of potential benefits in this research is considered adequate. (Note: Exhibit A of the Appendix also illustrates a modelling procedure that equates average travel speed to vehicle emissions. This procedure of modelling has the limitation of not taking into account the factor of vehicle miles traveled. Since the model for determining fuel consumption has taken provisions for both VMT and VHT (where VHT is dependent on the variable of average speed), it was determined that this model should be used for making inferences. The modeling method depicted in Exhibit A is included for the reader's review.)

The analyses of the potential benefits of advanced transportation technologies are based on calculations "per one million of urban population." It is not an unreasonable assumption that the technologies to be discussed within this paper are most likely to be considered by urban areas with populations over one million, at least in the short run. Although traffic characteristics vary from urban area to urban area a typical urban population of one million is expected to generate annual VMT of 5 billion, and annual VHT

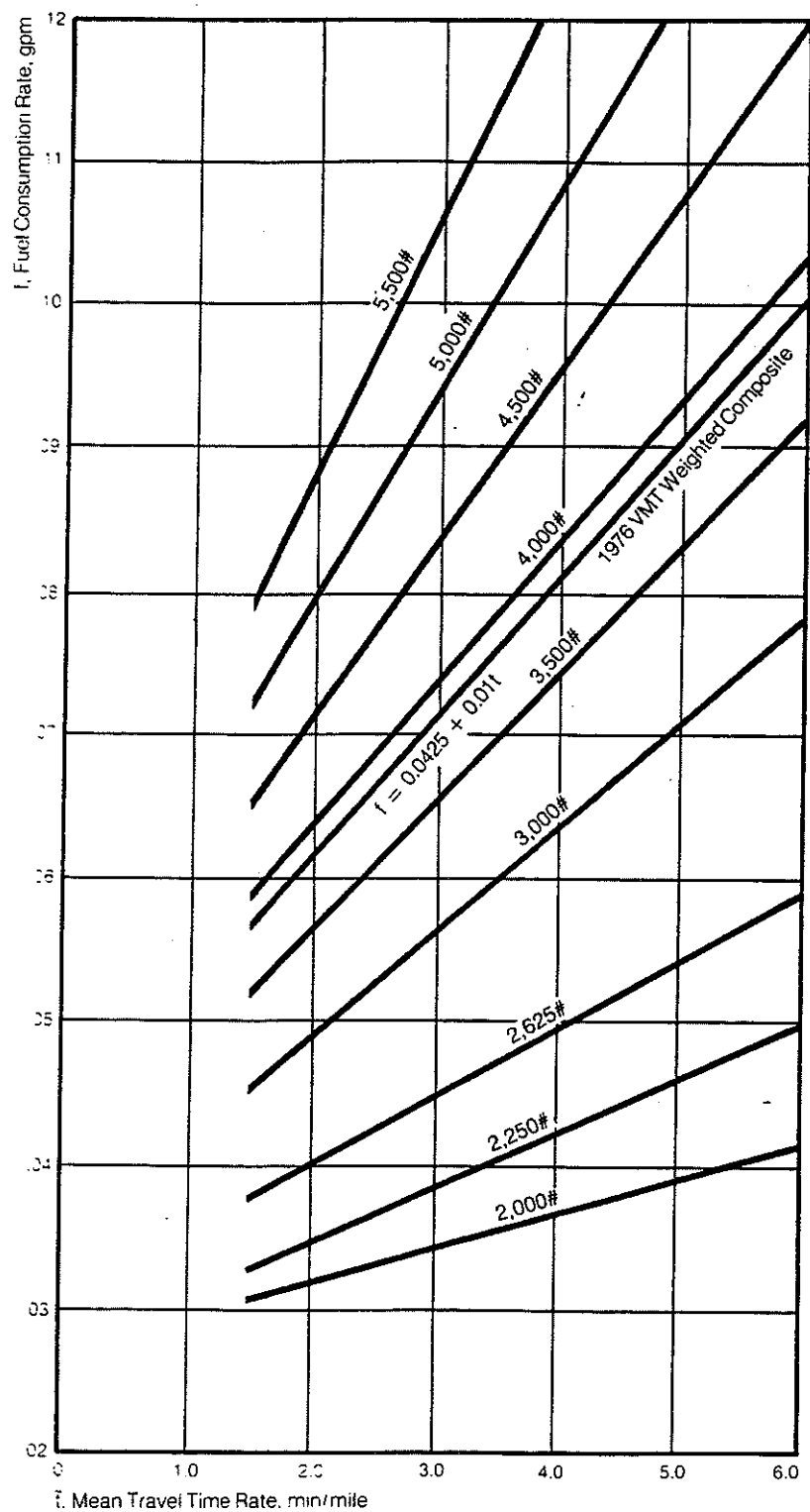


Figure 4 Fuel Consumption Rate as a Function of Mean Travel (4).

of 200 million. Using the equation given earlier, this equates to an annual use of 332.5 million gallons of fuel for a city of one million. It is these figures that will be utilized in deriving the benefits of advanced traffic management systems and advanced driver information systems, which will accompany actual measured and cited benefits of implemented projects. It is important to recognize that these figures and modeling procedures were obtained through the document, "Energy Impacts of Urban Transportation Improvements (4)."

ADVANCED TRANSPORTATION MANAGEMENT SYSTEMS

Introduction to ATMS/State-of-the-Art in TMS

Not unlike counterpart projects of the IVHS ideal, ATMS' goal is to improve the efficiency of our transportation systems for the reduction of congestion, delay, fuel consumption, air emissions, accidents, and the improvement of mobility and economic growth (5). The ATMS area has two primary objectives. The first objective is to apply available technology and strategies to present traffic management systems. The second objective is to advance the state-of-the-art in traffic management by research, development, testing, and evaluation (6). The objectives of ATMS, in this manner, have a fundamental difference in comparison to other areas that make up the IVHS program. The difference being its desire to expand upon existing systems and technology, rather than developing a completely new approach to traffic management. An article in the November 1990 ITE Journal entitled "Intelligent Vehicle/Highway Systems—A Feeling of Deja Vu" exemplifies this fact. In this article, the author points out that many of the concepts of ATMS are not new, and were under investigation as far back as the 1960s. This time around, however, there is a convergence of technology, attitude, and public acceptance which is IVHS' driving force. For these reasons, to truly understand the direction of ATMS, one must have an understanding of the state-of-the-art in TMS. Before we can hope to put the term "advanced" on the term traffic management systems, we must first raise the level of awareness of present traffic management systems and their benefits.

Present traffic management systems (TMS) can be put into two classifications, arterial traffic surveillance and management systems, and freeway traffic management and control systems. A freeway traffic management and control system consists of one or more of the following characteristics (7):

1. Roving tow or service vehicles,
2. Motorist aid call boxes, citizen band radio, cellular phone,
3. Incident management teams,
4. Detectors in the mainlines to monitor volume,
5. Ramp metering devices,
6. Motorist information systems,
7. Traffic diversion, and
8. Alternate route identification.

The surveillance, control and information system typically consists of ramp and highway traffic detectors, changeable message signs, closed circuit television surveillance at recurring problem areas, a communication system, and a central computer control of metering and communications (7). The system of detectors allow the monitoring of traffic conditions throughout the freeway system. Driver information is furnished through changeable message signs and radio reports—highway advisory radio being an example—which allows the driver to divert from congested areas if necessary.

The arterial surveillance and management system, unlike the freeway management system, has the limitation on what can be achieved because of the high number of at-grade intersections. Regardless, the following actions—which all or the majority constitutes an arterial surveillance and management system—can be taken.

1. Intersection surveillance and monitoring by use of the following:
Loop detectors,
Coordinated and interconnected signal system, and
Closed circuit television surveillance of problem intersections.
2. Incident detection and action. Including one or all of the following:
Incident management teams,
Information system, citizen band radio, cellular phones,
Roving tow vehicles, and
Service patrols.
3. Parking control and management.
4. Traffic surveillance and metering.

The use of traffic surveillance data for the monitoring of traffic conditions with computer graphic displays, traffic responsive control, and transportation planning and system performance evaluation is the major goal of arterial traffic management systems (7).

Present traffic management systems operate on only 6% of the almost 19,000 miles of urban freeways. Of these 1150 miles of managed urban freeway, almost half of the mileage is located in the Los Angeles area (5). Although nearly all of the larger urban areas have arterial traffic signal control systems, their extent of coverage varies widely. In fact, only 20% of urban arterial signals in the United States are under the control of a centralized urban traffic control center. Of these arterial systems in place, most do not respond well to non-recurring congestion and do not control from a network perspective (5). Clearly, most urban area practice in traffic management lags far behind the current state-of-the-art. This is the problem that ATMS wishes to solve, the Advancement of Traffic Management Systems—a more appropriate description for the acronym ATMS.

Characteristics of ATMS

The advanced traffic management system has six primary characteristics that differentiates it from the typical traffic management systems of today (6).

1. The system works in real time. The system is responsive to traffic flow characteristics. The data obtained by the control center must be up to date for useful changes to be made to the transportation system.
2. The system responds to changes in the traffic flow. The ATMS will make predictions of where congestion will occur, making it one step ahead of the actual situation on the street or freeway. This prediction of congestion will be done by use of algorithms and collected origin-destination information.

3. The system includes an areawide surveillance and detection system. The areawide concept allows for truly optimal decisions to be made from an overall system perspective.
4. The ATMS integrates control of several facilities. The advanced system will include the management of arterials and freeways, including freeway ramp metering, arterial signal control, and transportation information.
5. The integration of the several facilities thus implies a collaboration of all the applicable authorities. Jurisdictional problems must be overcome; all involved must work as a team such that the user perceives a seamless transportation system.
6. The system must include rapid response incident management strategies. The strategy must include quick detection, integrated incident site tactics, and appropriate procedures (6).

The implementation of an ATMS does require investigation of technologies not yet fully developed. Real-time traffic monitoring and data management capabilities must be developed and fine-tuned. New traffic models must be created, including simulation models, corridor optimization techniques, and real-time dynamic traffic assignment. Artificial intelligence and expert systems will have to be assessed for application in incident management, congestion anticipation, and control strategy selection. Although significant research is needed, several traffic management systems around the nation have the beginnings, if not many of the characteristics of advanced traffic management systems.

Potential Benefits and Representative Practices of ATMS

Current traffic management centers have been traditionally separated into arterial and freeway control. For this reason, the investigation will consider urban arterial traffic control centers and freeway control centers separately, then investigate the available examples of freeway and arterial control integration. The analyses of the potential air quality benefits are done through each action's ability to reduce areawide VMT and VHT. The results of these maximum feasible potential values are stated in terms of impact per million urban population. This allows easy scaling of the estimates to any particular area size. The benefits shown for the representative projects are cited values obtained from documented materials. The following is the procedure and listing of the projects to be included in the analysis.

Arterial Traffic Management and Control

1. Potential Benefits of Traffic Signal Control
2. The Los Angeles Automated Traffic Surveillance and Control (ATSAC) System

Freeway Traffic Management and Control

1. Potential Benefits of Ramp Metering and Incident Management

Integrated Freeway and Arterial Traffic Management and Control

1. The INFORM corridor traffic management system, Long Island, New York State
2. The Smart Corridor Project, Los Angeles, California

Urban Arterial Traffic Management and Control

Since approximately two-thirds of all urban VMT and an even higher percentage of urban VHT are on facilities controlled by traffic signals, optimization of these facilities is expected to give a high potential for air quality improvements. The fact that traffic signal improvements provide traffic flow quality benefits throughout the entire day also makes it an attractive approach to reducing vehicle emissions (4).

Traffic signal improvements have essentially three fundamental elements. The first being the coordination of groups of signals by interconnection or accurate time based coordination. The second being a systematic optimization of signal timing parameters, including cycles, splits, and offsets. And the third being advanced traffic control functions by a master computer control, which can include dynamic traffic responsive control, on-line traffic monitoring, and increased timing plan flexibility (1). Depending on the initial system that was in operation, these three improvements can have significant impact on the traffic flow and areawide air quality.

Although an estimated 50% of all urban area signals are interconnected, and some 200 United States cities have implemented computer-based signal control, a number of these projects have been limited to the densest parts of their city. These facts indicate that even in the cities that have implemented advanced systems, their control is limited and only a portion of the full areawide benefits have been utilized.

Since the degree of improvement that a given traffic signal improvement project produces is dependent upon the previous control measures, a synthesis of traffic signal system improvement impacts was conducted by the FHWA. These results are depicted in Table 4. This table indicates that advanced computer based control will give significant improvements for the entire range of "before" conditions. The advanced computer-based control in definition would include centralized control on interconnected and coordinated traffic signals in the system. These cited improvements do not consider complete responsiveness to traffic flows (i.e., 2nd generation urban traffic control), rather, 1st or 1.5 generation urban traffic control (UTC) would be more indicative of this level of travel time improvements.

Based upon these cited improvements of travel time, it would not be unreasonable to expect 10% reductions in areawide travel time upon implementation of an areawide advanced computer-based control system (this estimate considers a well developed and maintained before condition). Based on a hypothetical urban area of one million population, Table 5 illustrates an advanced computer-based control system's potential benefits in fuel conservation. This analysis, done by Wagner (4), indicates that the implementation of an advanced arterial traffic control system can reduce motor vehicle fuel consumption by 3.5% (12 million gallons/year). If one assumes that VMT does not increase

Table 4. Synthesis of Traffic Signal System Improvement Impacts (3).

Before Condition	After Condition	Improvement in Travel Time
Pre-Timed, Non-Interconnected Signals With Old Timing Plans	Computer Based Control	25%
Pre-Timed, Interconnected Signals With Old Timing Plans	Computer Based Control	18%
Traffic Actuated Non-Interconnected Signals	Computer Based Control	16%
Pre-Timed, Interconnected Signals Managed Timing Plans	Computer Based Control	8%
Pre-Timed, Interconnected Signals Various Timing Plans	Optimization of Signal Timing Plans	12%

Table 5. Travel Time Reduction and Fuel Conservation Impacts of a Hypothetical Traffic Signal System Improvement for an Urban Area of One Million (4).

Traffic Control Improvement Project	Baseline Annual Vehicle Hours of Travel Affected (millions)	Percent Improvement in Travel Time	Reduction in Annual Vehicle Hours (million)	Reduction in Annual Fuel Consumption (millions of gallons)	Percent Reduction in Areawide Total Fuel Consumption
1. Optimize Signal Timing @ 500 Previously Coordinated Intersections	60	12%	7.2	4.3	1.3%
2. Interconnect and Optimize Signal Timing @ 250 Previously Uncoordinated Intersections	30	25%	7.5	4.5	1.4%
3. Install Advanced Computer Control System @ 500 Intersections (Same locations as in 1. above)	60	8%	4.8	2.9	0.8%
Total Program	90	16% of signalized arterial VHT 10% of areawide total VHT	19.5	11.7	3.5%

Notes: Total annual VHT for area of 1,000,000 population = 200 million vehicle hours.
Total annual VMT for area of 1,000,000 population = 5,000 million vehicle miles.
Total annual fuel consumption for area of 1,000,000 population = 332.5 million gallons.
Total signalized arterial system is assumed to account for 60 percent of areawide total VHT or 120 million vehicle hours annually.
Total system is assumed to have 1,000 signals.

with the reduction of VHT, an increase in the average areawide speed would be calculated as follows.

$$\begin{aligned}\text{Initial Average Areawide Speed} &= 5,000 \text{ million VMT} / 200 \text{ million vehicle hours} \\ \text{Initial Average Areawide Speed} &= 25 \text{ mph}\end{aligned}$$

After a 10% reduction in areawide VHT (savings of 20 million vehicle hours):

$$\begin{aligned}\text{Resulting Average Areawide Speed} &= 5,000 \text{ million VMT} / 180 \text{ million vehicle hours} \\ \text{Resulting Average Areawide Speed} &= 27.8 \text{ mph}\end{aligned}$$

The following savings in vehicle emissions can now be calculated (the following calculations use emission rates per gallon, as found in the Appendix under Table A.):

$$\begin{aligned}\text{Initial HC} &= 332.5 \text{ million gallons} \times 55 \text{ grams/gallon} \\ \text{Initial HC} &= 1.82875 \times 10^{10} \text{ grams/year}\end{aligned}$$

$$\begin{aligned}\text{Initial CO} &= 332.5 \text{ million gallons} \times 354.8 \text{ grams/gallon} \\ \text{Initial CO} &= 1.17971 \times 10^{11} \text{ grams/year}\end{aligned}$$

$$\begin{aligned}\text{Initial NO}_x &= 332.5 \text{ million gallons} \times 31.8 \text{ grams/gallon} \\ \text{Initial NO}_x &= 1.05735 \times 10^{10} \text{ grams/year}\end{aligned}$$

Emission rates after a 3.5% reduction in gasoline use and an increase in average speed from 25 mph to 27.8 mph.

$$\begin{aligned}\text{Resulting HC} &= 320.9 \text{ million gallons} \times 52.4 \text{ grams/gallon} \\ \text{Resulting HC} &= 1.68209 \times 10^{10} \text{ grams/year} \\ \text{Percentage Change} &= -8.0\%\end{aligned}$$

$$\begin{aligned}\text{Resulting CO} &= 320.9 \text{ million gallons} \times 318.5 \text{ grams/gallon} \\ \text{Resulting CO} &= 1.02181 \times 10^{11} \text{ grams/year} \\ \text{Percentage Change} &= -13.4\%\end{aligned}$$

$$\begin{aligned}\text{Resulting NO}_x &= 320.9 \text{ million gallons} \times 32.8 \text{ grams/gallon} \\ \text{Resulting NO}_x &= 1.05269 \times 10^{10} \text{ grams/year} \\ \text{Percentage Change} &= -0.4\%\end{aligned}$$

The reduction of VHT by 10% results in a fuel savings of 3.5%, an emission savings of 8% for HC, 13.4% for CO, and 0.4% for nitrogen oxides. This calculation assumed a negligible affect on vehicle miles of travel, which is not an unreasonable assumption. This is stated because signal system improvements have a lesser induced travel impact than major highway projects.

The reasons for the lower induced travel are the following (4):

1. Traffic signal improvement impacts are spread homogeneously across the entire area, therefore, the improvement is not easily detected by the user.
2. The signal improvements do not increase capacity significantly.
3. Signal improvements do not enhance the accessibility to the area.

Traffic signal improvement by advanced computer control has a significant potential to increasing the air quality of an urban area. Based on a hypothetical urban population of 1 million, CO and HC emissions can be expected to decrease up to 8%. These improvements are also attractive because of their insignificant affect on increasing VMT. Traffic signal improvements increase the air quality because of two major reasons. The first reason is that signalized arterial VMT and VHT account for the majority of urban travel, and second reason is that this form of traffic flow quality improvement reaps benefits all day, rather than just during the peak hours.

Representative Project: Los Angeles' ATSAC System

The Los Angeles Arterial Traffic Surveillance and Control (ATSAC) system is perhaps the most advanced arterial control system currently in the United States (5). Consequently, it is a good example of the "real-life" benefits of arterial ATMS.

The ATSAC system has the following features that help to make it one of the most developed systems in the nation:

- Extensive use of detectors to obtain data on traffic flow ,
- Color-graphic monitors to display real-time traffic information,
- Critical intersection control,
- 1.5 generation areawide signal timing control,
- Real-time computation of traffic flows for system performance evaluation,
- Standardized use of 170 controllers at all intersections,
- Use of fiber optic trunk communication,
- Overall control of area computers by a central supervisory computer, and
- Development of *ad hoc* timing plans for non-recurring congestion.

The current system controls 450 signalized intersections, with another 256 intersections to be operational by the end of 1991. There are currently 860 signalized intersections under

construction, and are anticipated to be functional by the end of 1992. By the year 1998, all 4000 signalized intersections in the city are scheduled to be under the control of the ATSAC system (8).

The application software used is the UTCS enhanced package developed by the FHWA. Additional features were integrated with this package, such as automation of signal timing plan upgrades (the 1.5 generation package). There are four modes of control used by the system: time-of-day, critical intersection control, traffic responsive, and manual override. The time-of-day timing plans are developed off-line by using the TRANSYT 7 model and traffic data obtained from the 1.5 generation software package. The 1.5 generation control allows the traffic operators to be alerted when traffic flows have changed sufficiently to warrant new timing plans. The software also utilizes traffic counts to update a network data base file. This 1.5 generation control is expected to reduce manual and technical labor for developing new signal timing plans. The 1.5 generation system does require more detectorization, which approaches the requirement of 2.0 generation control. However, this same level of detectorization is needed to collect enough data to identify non-recurring congestion and to utilize critical intersection control (8).

The traffic responsive control is an automation function of UTCS Enhanced. Under the responsive control, timing plans are selected by a complex algorithm that matches currently collected data with a library of timing plans that most closely fits the current flow conditions. There are provisions to "lock-in" timing plans for a minimum length of time and make it impossible to implement certain timing plans at particular times of the day (8).

To supplement the use of information from the traffic detectors, closed circuit television (CCTV) is placed at critical locations in the city. The use of CCTV allows the operator to validate the detector's indication of congestion and also helps the operator in manual override control during non-recurring incidents (8).

The benefits of the ATSAC system, although site specific, are quite impressive. The following measures of effectiveness and environmental benefits were obtained from the initial installation in the Coliseum/USC area of Los Angeles. This area encompassed 118 intersections and 396 detectors in a 4 square mile area located 5 miles from the ATSAC Control Center.

- 13.2% reduction in travel times
- 12.5% reduction in fuel consumption
- 10.2% reduction in HC emissions
- 10.3% reduction in CO emissions

On an areawide basis these reductions could be less significant. Nevertheless, upon increasing the number of signalized intersections under the control of the ATSAC system, the impact on air quality can be substantial. It would not be surprising to see citywide reductions in vehicle emissions of 5% to 10% upon the control of all 4000 signalized intersections in 1998.

An arterial ATMS can have significant impact on the improvement of urban air quality. The degree of the improvement, however, depends upon two factors. These factors are: being (1) the kind of system that exists in the before case and (2) the level and magnitude of advanced technologies to be implemented. Urban areas that have already implemented "advanced" computer-based control systems are likely to realize less of a benefit in ATMS. This is because these areas have already taken advantage of many of the components that make up an ATMS, therefore they have already realized these benefits. Regardless of this fact, ATMS can still offer even the most advanced systems significant benefits.

The Los Angeles ATSAC system, one of the more advanced systems in the nation, can realize many benefits from the research and development proposed by IVHS and ATMS. The following list is areas that ATMS wishes to develop and the ATSAC system can benefit from.

1. The use of traffic responsive or traffic adaptive control systems such as the British SCOOT system. This type of control, in comparison to UTCS Enhanced control, has shown additional reductions of 5% in total travel time. (This is under consideration for applications to the ATSAC system.)
2. The use of expert systems for identification of non-recurring congestion, and decision support functions upon identification of serious incidents. (This type of system is under development for the ATSAC system.)
3. The use and/or expansion of arterial incident management and coordination teams.
4. The integration with adjoining freeway management centers. Further network coordination will optimize freeway flow that enters and exits via the arterial streets. (This is being developed through the SMART Corridor Project.)

An arterial ATMS has tremendous potential to offer in terms of improving urban air quality. Its benefits are simply dependent upon its implementation.

Freeway Traffic Management and Control

Freeway traffic management has two objectives: (1) reduce the occurrence and intensity of recurring congestion and (2) limit the amount of delay resulting from non-recurring congestion (7). Aside from non-recurring congestion management, freeway surveillance provides benefits primarily during the 4-6 peak period commuting hours.

Recurring congestion is the result of traffic demands exceeding the free-flow capacity of freeway sections. There are two primary causes to recurring congestion:

1. unrestrained entrance ramp traffic which loads the freeway beyond capacity
2. and freeway discontinuities, created by geometric design deficiencies.

Either of these two conditions cause bottlenecks where demand exceeds capacity. The effects of bottleneck queues are slow speeds, increased travel times, and increased air pollutant emissions.

Non-recurring congestion is the cause of incidents such as traffic accidents, vehicle disabilities, spilled loads, and adverse weather. These incidents have the most severe impact during peak periods, but they can also degrade traffic flow significantly during the off-peak periods (7).

There are essentially two components to freeway traffic management. These include: (1) enhancement of ramp metering systems and (2) incident detection and management (4). The advanced extension of freeway traffic management is real-time motorist information and route guidance systems. The potential benefits of these systems will be discussed later in the paper.

Figure 3 illustrates the affects of freeway management actions on the highway network traffic supply. The actions of ramp metering and incident management have similar impacts, that is they serve to improve flow quality during peak periods. Since ramp metering cannot make free-flow conditions during the off-peak any freer, its benefits are limited to only 4-6 hours a day (4). Although freeway incidents occur in the off-peak, the real benefits to derive from incident management is during the 4-6 peak period hours. Unlike arterial traffic management, freeway management's benefits are limited to less than 25% of the entire day. This fact has a significant impact on the emission reduction potential of this type of approach.

The peak period impacts of freeway management can be quite impressive and are shown in Table 6. The table shows the percentage improvement in average area speeds. All projects, except one, incorporated some form of incident detection and management. Therefore, the results indicate the combined effect of ramp metering and incident management. With delays at ramps taken into account, the average speed of the seven projects was found to have increased by 20%. The average speed increase of 20% corresponds to a reduction in travel time of 16.5%.

Although these peak period impacts are striking, their areawide impacts can be diluted drastically. In the typical metropolitan area, only 1/3 of all vehicular travel is on freeways, and only 1/3 of this travel is during the peak periods. If one considers that only 20% of freeway VMT is congested during the peak periods, the data indicate that the impacts of freeway management improvements are felt by (4):

$$1/3 \times 1/3 \times (20\%) = 2\% \text{ of daily areawide travel.}$$

If one considers that the freeway management improvements increase speeds on an average of 20% and decrease travel time by 16.5%, then the decrease in areawide VHT is only (4):

$$1/3 \times 1/3 \times (20\%) \times (16.5\%) = 0.37\%.$$

Table 6. Impacts of Freeway Incident and Traffic Management on Average Speed (4).

Location (References)	Length (miles)	Time of Day	Average Speed, mph			Percent Improvement
			Before Ramp Control	After Ramp Control	After Including Ramp Delays	
Minneapolis I-35 W Inbound	16.6	7:15-8:15 am	33.8	45.5	43	27
		6:30-9:00 am	43.9	50.1	48.5	10
Outbound	12.7	4:30-5:30 pm	33.7	40.1	38.6	15
		3:30-6:30 pm	38.5	45.7	44.4	15
Chicago, Eisenhower Expressway Inbound	9.4	2 Hr. AM Peak	30.3	33.0	na	9
		4 Hr. AM Peak	37.7	39.7	na	5
Los Angeles, Santa Monica Fwy. Inbound	13.5	6:30-9:30 am	36.2	50.6	41.4	14
	13.5	6:30-9:30 am	36.2	50.6	41.4	14
Houston, Gulf Freeway Inbound	6	7:00-8:00 am	20.4	32.6	na	60
Los Angeles, Harbor Freeway Inbound	4	3:45-6:15 pm	25.9	40.3	37.4	44
Detroit Lodge Freeway Inbound	6	2:30-6:30 pm	27.3	36.4	32.6	19
Toronto, Queen Elizabeth Way Inbound	3.9	7:00-9:00 am (Good Conditions)	21.1	30.9	26	21
		7:00-9:00 am (Poor Conditions)	13.4	21.4	16.7	24
Average, All Data			30.2	38.9		
Average, Including Ramp Delay			30.4		36.5	20

Note: This table illustrates the percentage improvement in average speeds due to the combined effect of ramp metering and incident management during peak periods.

By the same token, increases in average areawide speeds are only:

$$1/3 \times 1/3 \times (20\%) \times (20\%) = 0.44\%.$$

Using a hypothetical urban population of one million (see Vehicle Emission Calculation Methods), the fuel and emission savings for a .37% reduction in areawide daily VHT are:

▲VHT = 0.0037 x 200 million vehicle hours, and

▲VHT = 720,000 vehicle hours.

▲F = 0.6 (720,000 vehicle hours), and

▲F = 432,000 gallons/year.

Therefore, percentage change in fuel consumed is -0.13%. Initial emissions for the hypothetical urban area of one million population are given in the discussion of arterial signal management. Emissions after a 0.13% reduction in gasoline use and a 0.44% increase in average speeds are the following.

Resulting HC = 332.1 million gallons x 54.9 grams/gallon

Resulting HC = 1.82298×10^{10} grams/year

Percentage Change = -0.32%.

Resulting CO = 332.1 million gallons x 353.4 grams/gallon

Resulting CO = 1.17339×10^{10} grams/year

Percentage Change = -0.54%.

Resulting NO_x = 332.1 million gallons x 31.8 grams/gallon

Resulting NO_x = 1.05731×10^{10} grams/year

Percentage Change = 0.0%.

The before mentioned estimates are just that, estimates, and rely heavily on some major assumptions. These assumptions are: (1) the percent of total areawide travel by the freeway is 33% and (2) the percent of peak period freeway travel subjected to congestion is only 20%. Obviously if either of these were a greater value, the impacts would favorably increase. Additionally, these estimates do not take into account the benefits of incident management during the off-peak periods. Incidents in the off-peak periods can cause substantial delays, but in comparison to the peak-period, these delays are not as frequent or severe (4). To account for this unrepresented benefit, a 1% reduction in areawide vehicle emissions would be a safe upper limit for a freeway management's potential. However, these estimates required a negligible induced travel (i.e., increased VMT). This is often not the case in actual implemented cases. In cases where VMT increases, small

reductions in vehicle emission rates may be overcome by increased volume levels, thus creating a situation of increased overall emissions.

This analysis suggests that freeway management alone is not a viable solution to improving air quality. Freeway management is more of a congestion relief measure, rather than an energy and emission reduction measure (4). Although freeway management may not seem to significantly benefit the environment, its assets from an operational standpoint make it a justifiable traffic control measure.

Exhibit B of the Appendix illustrates extraordinarily significant benefits due to freeway surveillance and management. This example illustrates that under certain situations, freeway management can have a profound impact on areawide air quality. This indicates that generalizations often give misleading results. For this reason, decisive inferences about traffic control measures should be done on a site specific scale—the results of this research are not indicative of every urban area.

Integrated Freeway and Arterial Traffic Management

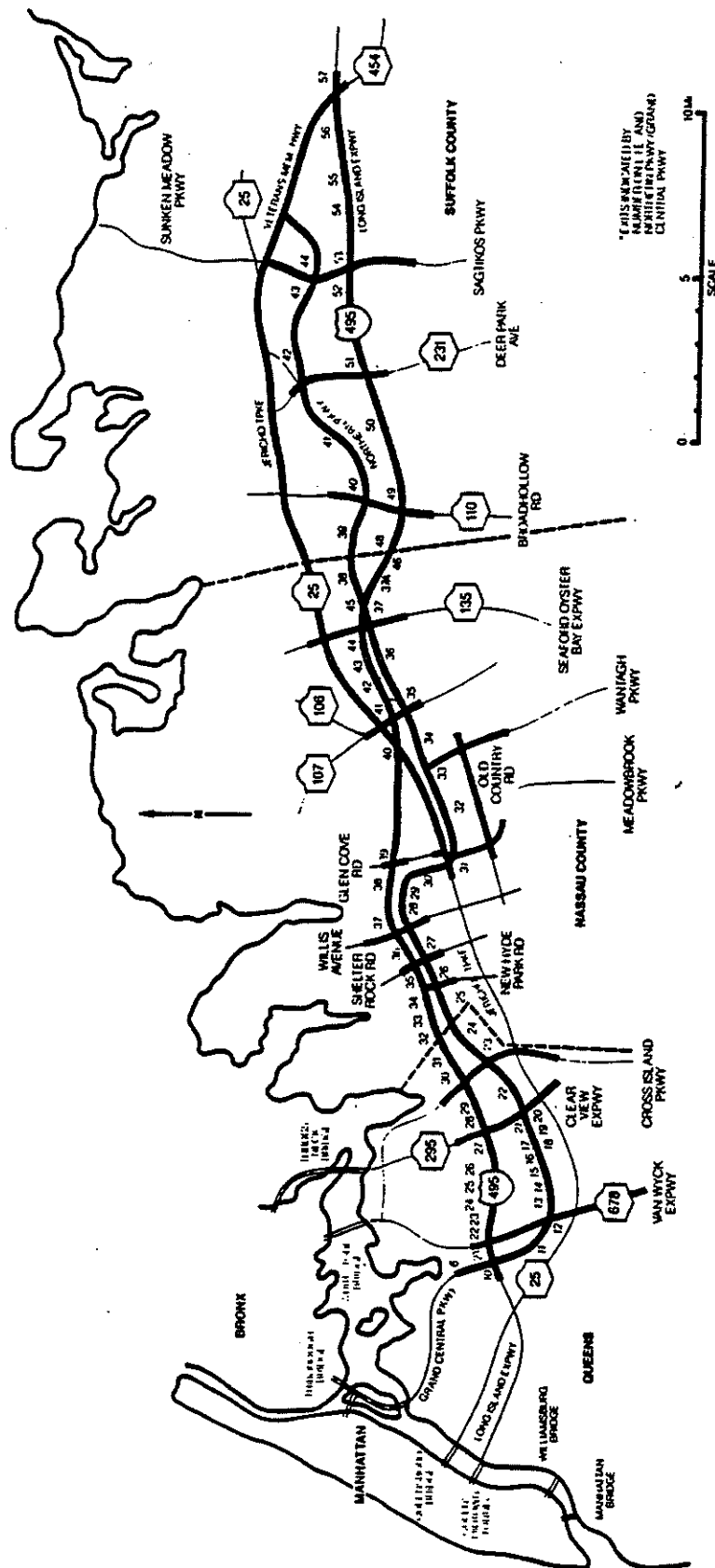
Further benefits to vehicle flow can be anticipated with the synergism of arterial and freeway control measures. The potential benefits of an integrated control system can be looked at as being greater than the summation of each individual control system's benefit. It is the premise that has motivated interest in corridor control.

Representative Project: The INFORM System, Long Island, New York State

The INFORM system is a corridor traffic management system that is located on Long Island in New York State. The corridor centers about the Long Island Expressway (I-495), which measures approximately 35 miles by 5 miles. The corridor has 130 miles of highway instrumented with system equipment and encompasses 110 signalized intersections. Figure 5 is a map that illustrates the extent of the INFORM corridor. The INFORM system incorporated the demonstration project IMIS, which was used to evaluate automated control of an urban freeway corridor (10).

An operation center, located at the east side of the system provides 24 hour, 365 days per year control of data gathering, processing, and information dissemination. The system's basic elements include vehicle detection, an operations facility, radio communication monitors, intersection control, closed circuit television (CCTV), and a coaxial cable communication system (10).

INFORM



INFORM SYSTEM OPERATIONS

Figure 5' Map of the INFORM Corridor (10).

The system utilizes over 2,400 vehicle detectors to measure and calculate traffic flow characteristics. Currently, there are 74 disk matrix type message signs in the INFORM system. The signs are used to display real-time information to the motorist, such as delays due to recurring or non-recurring congestion, or the absence of delay. Fifty freeway entrance ramps in the INFORM project corridor are equipped with metering equipment. There are presently 12 camera sites in the system. The CCTV provide visual validation of traffic flow problems and incidents. The INFORM system also has a subscription service, the Video Traffic Information Program (VTIP), which provides color computer graphics of traffic conditions. The INFORM operators monitor Citizen Band radio and police radio communications for incident detection and verification. This is critical to the effectiveness of the system because of the lack of corridor-wide surveillance by CCTV. The system controls 110 intersections with the UTCS-Enhanced traffic control software. These intersections include the Long Island expressway service roads and a few arterial routes, such as the Jericho Turnpike and Veterans Memorial Highway. The INFORM system does not control any signals in New York City (10).

The unique feature of the INFORM system, which distinguishes it from other freeway or arterial management centers, is its integration of the two management approaches. The integrated freeway and arterial traffic management system is depicted in Figure 6. All system operations are through contractual agreement with a private engineering firm. Maintenance of the system is done through contract with three private contractors.

Although the basic system elements of the INFORM system have been in use for many years, the design of the INFORM system is revolutionary because of its high level of corridor traffic management automation. The levels of INFORM's automated tasks can be separated into low, medium, and high automation as follows (10).

Low level automated tasks:

1. Data collection and communication,
2. Computation of traffic flow characteristics, and
3. Reporting of traffic flow characteristics.

Medium level automated tasks:

1. Intersection control,
2. Ramp meter controls, and
3. Equipment failure monitoring.

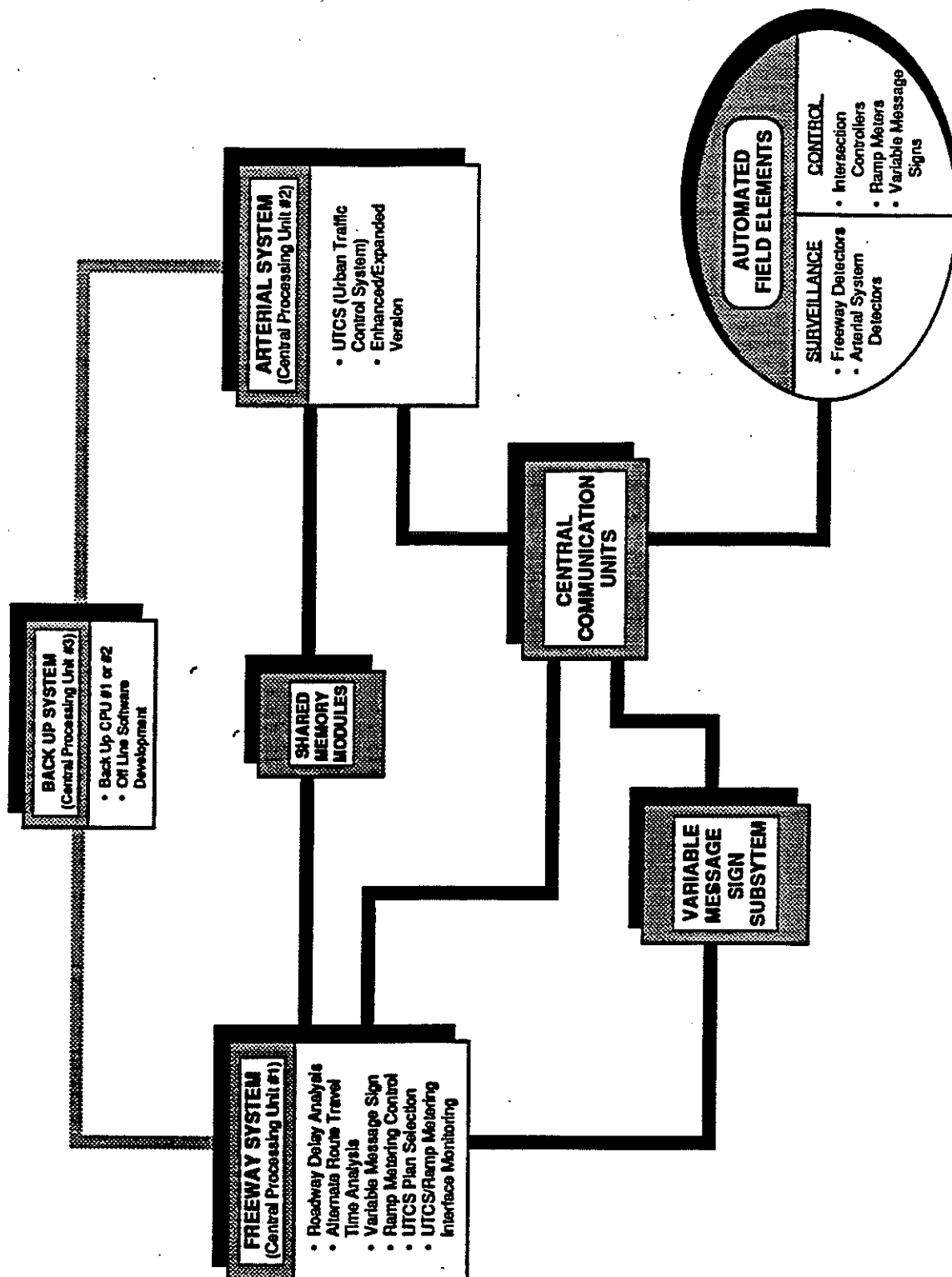


Figure 6 The Integrated Freeway and Arterial Traffic Management System (10).

High level automated tasks:

1. Variable message sign generation (the messages of delay are automatically activated based on collected speed data),
2. Intersection control (upon the diversion of traffic from the freeway, the system adjusts the affected arterial's timing plans based upon a compiled diversion database),
3. Ramp meter control (if the adjoining arterial intersections are at saturation flow or above, the nearby ramp metering rates are made more permissive to remove ramp queues from the arterial streets), and
4. Incident management and diversion strategies (traffic incidents will be automatically detected and diversion strategies will be implemented).

The actual ability to predict the potential delays as a result of an incident remains the responsibility of the operator. The automated diversion of the INFORM system is not presently being utilized. This is due to the lack of sufficient research on the diversion algorithm.

The extent of the INFORM's freeway incident management is the dissemination of information to the motoring public. There are currently 74 changeable message signs (CMS), 24 are on arterial streets and the remaining 50 are for freeway use. The CMS system works in a combination of manual intervention and semi-automatic control. The manual intervention is required for diversion messages. The system utilizes three specific types of diversion. The three types of diversion include: (1) freeway to freeway, (2) freeway to freeway via arterial, and (3) freeway to service road. The semi-automatic control of the CMS updates the messages of delay and their location.

The INFORM system, in addition to the subscription service VTIP, offers traffic information through a personal computer dial-in-service. This service enables the user to view the current messages being displayed on the changeable message signs (10).

The documented benefits of the INFORM system are limited to the ramp metering system. An analysis done two months after ramp metering implementation showed the following (5):

- 20% reduction in mainline travel times,
- 6.7% reduction in fuel consumption,
- 17.4% reduction in carbon monoxide emissions, and
- 13.1% reduction in hydrocarbon emissions.

The emission reductions shown are for the peak period in the mainline site area. The areawide percentage reductions over the entire day, therefore, would not be this significant. The areawide benefits of this project are being assessed, and will be available in the forthcoming report, "Integrated Motorist Information System Evaluation," FHWA Contract NO. DTFH61-84-C-00107.

Representative Project: The SMART Corridor Project, Los Angeles, California

Unlike the INFORM project, the SMART Corridor project is in the conceptual design phases. The basic premise of the Smart Corridor project is that a much greater benefit can be achieved by the integration of existing traffic management systems than could be achieved through their independent operation. Major control centers to be in the SMART Corridor linkage include (11):

The Caltrans Traffic Operations Center,
The Los Angeles Department of Transportation ATSAC Center,
The Los Angeles Department of Transportation Parking Enforcement Center,
The Highway Patrol Operations Center,
The Los Angeles Police Department Operations Center, and
The Southern California Rapid Transit Operations Center.

The Smart Corridor project will be approximately 12 miles long by 2 miles wide, on the south-east end of Los Angeles to beyond the San Diego Freeway (I-405). The "backbone" of the corridor is the Santa Monica Freeway (I-10). Included in the corridor are five parallel arterial streets. These streets are Olympic Boulevard, Pico Boulevard, Venice Boulevard, Washington Boulevard, and Adams Boulevard. The combined capacity of these streets approach that of the I-10 freeway, therefore, the arterial streets can offer opportunities to balance traffic flow in the corridor.

The project will implement advanced surveillance and control on the freeways. Included will be additional ramp metering, traffic responsive ramp metering software, additional changeable message signs, closed circuit television, fiberoptic communication capabilities, and Traffic Operations Center upgrade. In order to provide traffic responsive control, 1,600 additional loop detectors will be installed on the corridor surface streets. The ATSAC system will also consider use of an expert system and upgraded traffic responsive software. The improved signal timing software will incorporate saturation flow conditions in the controlling of surface street traffic. The expert system is expected to help in the identification and decision making support of surface street incidents.

The improved traffic management strategies are expected to bring the highest rewards to the project. Operational plans that coordinate the ramp and arterial signals can significantly improve the flow on the freeways and arterials. Detectorization on the freeway off ramps will prevent backups onto the mainline freeway. Freeway to freeway connector metering will also be implemented to improve traffic flow. Expansion of the freeway incident management team will allow deployment to incidents that close a lane for more than an hour; previously, incident teams were only employed for incidents that closed two lanes for more than two hours. A freeway service patrol may be implemented that assist motorists involved in minor mishaps.

A major focus of the project is the implementation of advanced driver information systems. Changeable message signs are to be installed on the surface streets to communicate street and freeway conditions to the motorist. Provisions will be made to provide highway advisory telephone access, so that the public can have easy access to timely

traffic information. The dissemination of information will also include computer bulletin boards, and teletext technologies. An important aspect of the information system will be the interactive communication with the motorist through in-vehicle navigation devices. The device being considered is the Pathfinder project, which is presently being evaluated.

The anticipated benefits due to the integration of the corridor have been done on a conceptual level, and include projection of the following:

- The total travel time will reduce by 11-15% in the corridor,
- The number of vehicle stops will decrease by 35% in the corridor,
- The delay at intersections will decrease by 20%,
- The carbon monoxide emissions will reduce by 15% within the corridor, and
- The hydrocarbon emissions will reduce by 12% within the corridor.

The above numbers indicate that the coordination of advanced traffic management systems can bring additional benefits to air quality and traffic operations.

ADVANCED DRIVER INFORMATION SYSTEMS

Introduction and Characteristics of ADIS

ADIS are vehicle features that assist the motorist in the planning, perception, analysis, and decision making processes needed to drive a motor vehicle (12). The improvement of the driver's decision making will allow further convenience and efficiency of travel. These systems will provide direct and immediate benefits to the driver, and indirect benefits to society. The benefits to society include reduced congestion, reduced travel time, reduced fuel consumption, and improved air quality. Specific types of ADIS include (5):

- on-board replication of maps and signs,
- pre-trip electronic route planning,
- traffic information broadcasting systems,
- safety warning systems,
- on-board navigation systems, and
- electronic route guidance.

The ADIS program has conveniently been divided into three stages that allow better understanding of how ATMS and ADIS will interact. These stages are as follows:

The Information Stage (1990-1995); Providing each driver with information to improve individual planning and decision making will be the primary emphasis of this stage.

The Advisory Stage (1995-2000); This stage will supplement the Information Stage by providing dynamic traffic information and advising alternate routes around congestion.

The Coordination Stage (2000-2010); This stage will see the exchange of information between vehicles and the infrastructure. The vehicles themselves will act as probes on the characteristics of traffic flow.

As might be expected, all present research and projects are emphasizing the development of systems that meet the Information Stage requirements. A typical system at the end of the Information Stage will include the following features (5):

- Dead reckoning map-matching navigation,
- Digital traffic information receiver,
- Static route planning,
- Color video display,
- Synthesized voice to supplement video display,
- Business directory—The "Yellow Pages",
- Map database including freeway signs and restrictions, and
- Electronic vehicle detection capabilities.

The required infrastructure to achieve this initial stage is quite limited in comparison to subsequent stages. The largest component of the required infrastructure is the traffic information center that collects, formats, and transmits the traffic information to the vehicles. Equipping toll stations to read vehicle ID and the placing of traffic transmitters will also be a costly and involved endeavor.

The requirement of timely traffic information, even in the early stages of ADIS's development, makes it necessary for ATMS and ADIS to be developed as an integrated system. Although traffic information centers may be physically separated from traffic management centers, a direct line of communication must be developed from the start to ensure the most efficient system.

It is often close to impossible to make a clear distinction between ADIS projects and ATMS projects. In most instances, these projects work hand-in-hand, with ADIS features relying on the information gathered by ATMS. For this reason, it is hard to quantify the exclusive benefits of ADIS. Nevertheless, the following is looked upon as the benefits to be derived by the features of advanced driver information system.

Potential Benefits—Throughout Development Stages

Although the full benefits of ADIS will not be realized until later developmental stages, the Information Stage can will provide significant environmental benefits. The benefits of the Coordination Stage and the advantages of recommending alternate routes in congestion—the Advisory Stage—are hard to quantify. For this reason, the following analysis limits the influence of ADIS to static route planning and navigation optimization—the general intent of the Information Stage.

It has been estimated that a significant amount of the driving in the U.S. is due to incorrect choice of route. Consequently, estimates of percent excess travel have been made and are shown in Table 7.

Table 7. Estimates of Percentage Excess Travel for Varying Trip Purposes (13).

Trip Purpose:	Causality	Excess Distance (%)	Excess Time (%)
Work Trips	Planning	4	7
	Navigation	-	-
Non-work trips (unfamiliar destination)	Planning	10	10
	Navigation	10	30

Because different proportions of excess travel apply to different trip purposes, the following assumptions concerning the distribution of total travel by purpose were made (13):

1. 40% of all VMT and VHT are work related,
2. Automobile travel to unfamiliar destinations amount to 25% of all non-work travel, and
3. Non-work trips to familiar destinations have the same characteristics as work trips.

Given these assumptions, the automobile travel that can be saved through route optimization and navigation (e.g., an in-vehicle ADIS device) was calculated as 6.4% of all VMT and 12% of all VHT. Interestingly, these figures correspond to work by the RACS project in Japan and the Autoguide project in England, which have shown an additional travel time saving of 6% to 14% by drivers travelling an optimum route (5).

Since at least 10% of the vehicle fleet is expected to have ADIS features by the end of the Information Stage (1995-2000), there is a potential for the following reductions in VMT and VHT by the year 2000:

$$\Delta \text{VMT} = (6.4\%) \times (10\%) = 0.64\% \text{ and}$$

$$\Delta \text{VHT} = (12\%) \times (10\%) = 1.2\%.$$

Based upon the hypothetical, one million urban population model, this can equate to the following savings.

$$\text{Saved VMT} = 5000 \text{ million miles of travel} \times 0.64\% \text{ and}$$

$$\text{Saved VMT} = 32,000,000 \text{ miles of travel.}$$

$$\text{Saved VHT} = 200 \text{ million hours} \times 1.2\% \text{ and}$$

$$\text{Saved VHT} = 2,400,000 \text{ vehicle hours.}$$

$$\Delta F = 0.0425 (32,000,000) + 0.60 (2,400,000),$$

$$\Delta F = 2,800,000 \text{ gallons/year, and}$$

$$\text{Total Percentage Change in Fuel Consumption} = -0.8\%.$$

The savings in emissions due to a 0.8% reduction in fuel and a new average urban areawide speed of 25.14 miles per hour is the following.

Resulting HC = 329.7 million gallons x 54.9 grams/gallon

Resulting HC = 1.81005×10^{10} grams/year

Percentage Reduction = -1.0%

Resulting CO = 329.7 million gallons x 353.0 grams/gallon

Resulting CO = 1.16378×10^{11} grams/year

Percentage Reduction = -1.4%

Resulting NO_x = 329.7 million gallons x 31.9 grams/gallon

Resulting NO_x = 1.05011×10^{10} grams/year

Percentage Reduction = -0.7%

The above calculations make the following critical assumptions:

1. 10% of the vehicle fleet in the area has an in-vehicle device,
2. 6.4% of all VMT and 12% of all VHT in urban areas are "wasted", and
3. The vehicles with ADIS devices do not contribute to "wasted" VMT or VHT.

These numbers indicate that by the year 2000 urban areas can anticipate a 1.0% reduction in HC emissions, a 1.4% reduction in CO emissions, and a 0.7% reduction in nitrogen oxide emission through route optimization and navigation.

If assumption number 1 (shown above) was to be changed to 100% of the vehicle fleet in the area having an in-vehicle device, the total benefit to be gained through route optimization and navigation is as follows.

Saved VMT = 5000 million miles of travel x 6.4%

Saved VMT = 320 million miles of travel

Saved VHT = 200 million hours x 12%

Saved VHT = 24 million hours

ΔF = 0.0425 (320,000,000) + 0.60 (24,000,000)

ΔF = 28,000,000 gallons/year

Total Percentage Change in Fuel Consumption = -8.4%

The savings in emissions due to a 8.4% reduction in fuel and a new average urban areawide speed of 26.6 miles per hour is the following.

Resulting HC = 304.5 million gallons x 53.5 grams/gallon

Resulting HC = 1.63018×10^{10} grams/year

Percentage Reduction = -10.9%

Resulting CO = 304.5 million gallons x 334.1 grams/gallon

Resulting CO = 1.01748×10^{11} grams/year

Percentage Reduction = -13.8%

Resulting NO_x = 304.5 million gallons x 32.4 grams/gallon

Resulting NO_x = 9.85751×10^9 grams/year

Percentage Reduction = -6.8%

These numbers indicate that the total benefits that can be derived by route optimization and navigation are a 10.9% reduction in HC emissions, a 13.8% reduction in CO emissions, and a 6.8% reduction in nitrogen oxide emissions. In other words, these numbers represent the "ceiling" for the emission reductions possible through route optimization and navigation.

Although this analysis did not quantify the benefits to be derived through the Advisory and Coordination Stages, the benefits that can be gained through the Information Stage suggests that ADIS can be an outstanding tool for reducing vehicle emissions.

Representative Projects and Demonstration Projects

Present advanced driver information systems are working to achieve the "Information Stage" guidelines. Projects in the United States and abroad are to be implemented, or have been implemented on a small demonstration scale. All of these projects have the same objective—navigation support and the timely dissemination of traffic information. For this reason, it would serve no end to make an exhaustive description of all the present ADIS projects. Instead, the following is a listing of representative projects and their location of development. A short description is also given on each project's capabilities.

ADIS Projects	Location of Development/Sponsors
Pathfinder	U.S.A.--FHWA, Caltrans, General Motors Corporation
TravTek	U.S.A.--General Motors Corporation, American Automobile Association, FHWA, Florida Department of Transportation
AMTICS	Japan--National Police Agency, the Ministry of Posts and Telecommunications, the Japan Traffic Management and Technology Association, and 59 private companies
RACS	Japan--Public Works Institute of the Ministry of Construction, and the Highway Industry Development Organization

Each Projects Capability/Purpose:

- Pathfinder: Navigation, Real-Time Traffic Congestion.
- TravTek: Navigation, Route Guidance, Real-Time Traffic Congestion, General Traffic Information, Trip Services, Pretrip Planning, Emergency Communications.
- AMTICS: Navigation, Real-Time Traffic Congestion, Trip Services, Personal Communication, Emergency Communication.
- RACS: Navigation, Real-Time Traffic Congestion, Trip Services, Personal Communication.

The following European programs are established organizations that give guidance to the advanced technologies in transportation. Included in each program are individuals from both the private and public sectors.

European IVHS Programs:

1. PROMETHEUS European IVHS partnership on vehicle-oriented projects.
2. DRIVE European IVHS partnership on infrastructure-oriented projects.

These organizations, which oversee the research on advanced technologies in transportation, allow for full coordination of major programs that transcend the borders of individual countries. Whereas most of the North American projects have been pursued on a stand-alone basis, most of the European IVHS projects work together to arrive at the development of an optimum transportation system (14). If not for Mobility 2000, which was a self-appointed, informal assembly of individuals from the public and private sectors, the United States would have no mean of coordination. It is going to take substantially more organization if this nation truly wishes to pursue the optimum in advanced transportation facilities. It is this particular area where a significant amount can be learned from our counterparts abroad.

FINDINGS

The following is a synthesis of each advanced technologies' ability to reduce urban areawide vehicle emissions. These results are constrained by the assumptions and conditions as stated in their calculation. See the "Summary" of this report for a synopsis of the relevant assumptions and conditions used in the calculations of this research.

Technologies	% Reduction in HC	% Reduction in CO	% Reduction in NO
Arterial Traffic Management and Control ¹	8%	13%	0%
Freeway Traffic Management and Control ²	0% - 2%	0% - 4%	0%
Integration of Freeway and Arterial Traffic Management ³	Up to 15%	Up to 12%	0%
Advanced Driver Information Systems (10% of fleet with in-vehicle devices) ^{4,5}	> 1%	> 2%	> 1%
Advanced Driver Information Systems (100% of fleet with in-vehicle devices) ^{4,5}	> 11%	> 14%	> 7%

¹ Highly dependent upon the "before-after" conditions.

² Dependent upon the actual urban travel characteristics.

³ Based upon the Smart Corridor projections.

⁴ Does not include the benefits of advising alternate routes while in congestion.

⁵ Highly dependent upon the assumed "wasted" VMT and VHT in urban areas.

RECOMMENDATIONS

Through the analyses of this research the following recommendations for reducing vehicle emissions were developed:

The first recommendation is to focus on signalized arterial improvements. Signalized arterial improvements are effective because typical arterials account for the majority of urban VMT and VHT, and because this form of traffic flow improvement obtains benefits throughout the entire day, rather than just a few peak period hours.

The second recommendation—which is actually a statement—is that in some cases freeway traffic management and control can be effective in improving air quality. Its appropriateness is dependent upon the actual travel characteristics of the urban area.

The third recommendation is to integrate freeway and arterial traffic control systems. The Smart Corridor system, for instance, expects reductions of vehicle emissions on the order of 10% to 15% through traffic management integration. Based upon these numbers, a substantial benefit can be gained through this endeavor.

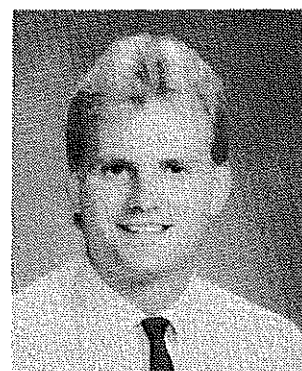
The last recommendation is to put an emphasis on getting timely traffic information to the "traveler." Although this research only analyzed the benefits of in-vehicle devices, the benefits to derive from pre-trip planning could be just as significant as navigation and route optimization. For this reason, the term "traveler" is used, rather than simply the "motorist."

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APPENDIX

Extreme Areas (1)
Los Angeles, CA

Severe (8)
Baltimore, MD
Chicago, IL-IN-WI
Houston, TX
Milwaukee, WI
Muskegon, MI
New York, NY-NJ-CT
Philadelphia, PA-NJ-DE-MD
San Diego, CA

Serious (16)
Atlanta, GA
Bakersfield, CA
Baton Rouge, LA
Beaumont, TX
Boston, MA-NH
El Paso, TX
Fresno, CA
Hartford, CT
Huntington, WV-KY-OH
Parkersburg, WV-OH
Portsmouth, NH-ME
Providence, RI
Sacramento, CA
Sheboygan, WI
Springfield, MA
Washington, DC-MD-VA

Moderate (32)
Atlantic City, NJ
Bowling Green, KY
Charleston, WV
Charlotte, NC-SC
Cincinnati, OH-KY-IN
Cleveland, OH
Dallas, TX
Dayton-Springfield, OH
Detroit, MI
Grand Rapids, MI
Greensboro, NC
Jefferson Co, NY
Kewaunee Co, WI
Knox Co, ME
Louisville, KY-IN
Memphis, TN-AR-MS
Miami, FL
Modesto, CA
Nashville, TN
Pittsburgh, PA
Portland, ME

Moderate (cont.)
Raleigh-Durham, NC
Reading, PA
Richmond, VA
Salt Lake City, UT
San Francisco-Oakland-San Jose
Santa Barbara, CA
Smyth Co, VA
St Louis, MO-IL
Toledo, OH
Visalia, CA
Worcester, MA

Marginal (39)
Albany, NY
Allentown, PA-NJ
Altoona, PA
Birmingham, AL
Buffalo, NY
Canton, OH
Columbus, OH
Erie, PA
Essex Co, NY
Evansville, IN-KY
Fayetteville, NC
Greenbrier Co, WV
Greenville-Spartanburg, SC
Hancock Co, ME
Harrisburg, PA
Indianapolis, IN
Johnson C-Kingsport-Bristol
Johnstown, PA
Kansas City, MO-KS
Knoxville, TN
Lake Charles, LA
Lancaster, PA
Lewiston, ME
Lexington, KY
Lincoln Co, ME
Manchester, NH
Montgomery, AL
Norfolk, VA
Owensboro, KY
Paducah, KY
Poughkeepsie, NY
Scranton, PA
South Bend, IN
Stockton, CA
Sussex Co, DE
Tampa, FL
Waldo Co, ME
York, PA
Youngstown, OH Sharon, PA

Figure A Cities Classified as being in Violation of Ozone Standards.

Serious Areas (3)

Los Angeles-Anaheim-Riverside, CA
Steubenville-Weirton, OH-WV Non-Mobile
Winnebago Co, WI (Oshkosh) Non-Mobile

Moderate Areas (48)

Albuquerque, NM
Anchorage, AK
Baltimore, MD
Boston-Lawrence-Salem, MA-NH
Chico, CA
Cleveland-Akron-Lorain, OH
Colorado Springs, CO
Denver-Boulder, CO
Duluth, MN-WI
El Paso, TX
Fairbanks Ed, AK (Non-MSA)
Fort Collins-Loveland, CO
Fresno, CA
Greensboro-Winston Salem-H. Point, NC
Hartford-New Britain-Middletown, CT
Josephine Co, OR (Grant Pass, Non-MSA)
Klamath Co, OR (Non-MSA)
Las Vegas, NV
Medford, OR
Memphis, TN-AR-MS
Minneapolis-St. Paul, MN-WI
Missoula Co, MT (Non-MSA)
Modesto, CA
New York-N. New Jer-Long Is, NY-NJ-CT
Philadelphia-Wilm-Trent, PA-NJ-DE-MD
Phoenix, AZ
Portland-Vancouver, OR-WA
Provo-Orem, UT
Raleigh-Durham, NC
Reno, NV
Sacramento, CA
San Diego, CA
San Francisco-Oakland-San Jose, CA
Seattle-Tacoma, WA
Spokane, WA
Stockton, CA
Syracuse, NY
Washington, DC-MD-VA

Figure B Cities Classified as being in Violation of CO Standards.

Table A. Emission Rates for the 1980 Automobile Population (Grams/Gallon given speed).

Speed	Emission Rate HC	Emission Rate CO	Emission Rate NO _x
5	142.3	1601.3	24.6
10	87.7	807.9	25.4
15	69.6	557.2	27.3
20	60.9	437.1	29.6
25	55.0	354.8	31.8
30	50.4	289.9	33.6
35	46.7	241.5	35.0
40	44.2	210.6	36.1
45	42.8	195.1	37.2
50	42.2	187.2	38.8
55	41.1	169.9	41.2
60	37.2	123.1	45.7
65	34.7	91.0	50.2
70	32.2	58.9	54.7

Notes: The above table was constructed by taking the average emission rate per mile (grams/mile given speed) and multiplying by the average fuel economy (miles/gallon) of the 1980 automobile fleet.

Linear interpolation between 5 mph speed increments was utilized for the approximation of emission rates in this research.

Sources: *Demand Estimation, Benefit Assessment, and Evaluation of On-Freeway High Occupancy Vehicle Lanes* (15).

Transportation Energy Data Book: Edition 11 (16).

Model for Estimating Motor Vehicle Emissions

Components of Model

- Demand Function,
- Link Performance Function, and
- Emission Function.

Demand Function

Assumed that traffic flow conditions on a link can be described by the average speed on the link.

$$\text{Demand} = V_i = D_i (s)$$

Where:

- V_i = Demanded Volume,
- s = Vector of Traffic Speeds, and
- D_i = Demand Function.

Link Performance Function

Assumed that the physical design and operation of a link can be described by the links capacity. Assumed that traffic flow improvement measures can be represented by changes in capacity.

$$S_i = P_i (V_i, c_i)$$

Where:

- S_i = Speed of link i,
- V_i = Volume on link i, and
- c_i = Capacity on link i.

Emission Function

$$e_{pi} = R_p (s_i)$$

Where:

- e_{pi} = Pollutant p Emissions Rate on link i,
- s_i = Speed on link i, and
- R_p = Emission function for pollutant p.

Exhibit A. Model for Estimating Motor Vehicle Emissions (1).

$$E_{pi} = V_i R_p (s_i)$$

Where:

E_{pi} = Emission Rate in grams/roadway mile/hour.

Empirically derived linear relationships for the 1982 average motor vehicle emission rates.

- Emission rate for Carbon Monoxide (CO)

$$e_{co}(s) = 6.4 + 464/s$$

Where:

e_{co} = grams/veh-mile of Carbon Monoxide (CO) and

s = miles/hour.

In the range of 10-25 miles/hour this is a good approximation to the composite CO speed-emission relation of warmed-up vehicles in the 1982 automobile fleet.

- Emission rate for Hydrocarbons (HC):

$$e_{hc}(s) = 0.16 + 38.8/s$$

Where:

e_{hc} = grams/veh-mile of Hydrocarbons (HC) and

s = miles/hour.

In the range of 10-30 miles/hour this is a good approximation to the composite HC speed-emission relation of warmed-up vehicles in the 1982 automobile fleet.

- Emission rate for Nitrogen Oxides (NO_x)

$$e_{no}(s) = 1.1 + 0.04 \times s$$

Where:

e_{no} = grams/veh-mile of Nitrogen Oxides (NO_x) and

s = miles/hour.

Benefits of Freeway Management, Cont.

The air quality benefits of freeway management are dependent upon the percent of total areawide travel on the freeways and by the percent of freeway travel that is subjected to congestion. In deriving an aggregate benefit of freeway management, some generalizations were made on these two variables. Upon the estimation of these percentages, it was concluded that freeway management is not a viable solution to reducing vehicle emissions. This "rule-of-thumb," like most inferences made on averaged data, has its exceptions.

In some of this nation's largest metropolitan areas, a higher than average percentage of travel is done on urban freeways. In addition, a higher than average percentage of the freeway VMT experiences congestion in the peak periods. Because of this, these cities can realize a substantial air quality benefit through freeway management.

In Table B, the actual representative figures for eleven metropolitan area are shown. These cities currently have established freeway management centers, and represent the highest potential for benefits from freeway management. The table indicates averaged values and actual values for each individual city. Clearly, the average values are not indicative of these metropolitan areas. Using the 19.4% figure for San Francisco, the following potential benefits are possible:

Assuming a reduction of 16.5% in total travel time due to freeway management, the decrease in VHT is:

$$(16.5\%) \times (19.4\%) = 3.2\%.$$

By the same token, the increase in areawide speed is:

$$(20\%) \times (19.4\%) = 3.9\%.$$

Exhibit B The Benefits of Freeway Management, Cont.
Using the hypothetical urban area, the fuel savings are:

$$\begin{aligned} \Delta \text{VHT} &= 0.032 \times 200 \text{ million vehicle hours and} \\ \Delta \text{VHT} &= 3,841,200 \text{ vehicle hours.} \end{aligned}$$

$$\begin{aligned} \Delta \text{F} &= 0.6 \text{ (6,402,000 vehicle hours) and} \\ \Delta \text{F} &= 3,841,200 \text{ gallons of gasoline.} \end{aligned}$$

Therefore, the percentage change in fuel consumed is -1.2%. The emissions after a 1.2% reduction in fuel consumption and a 3.9% increase in speed are:

Resulting HC = 328.7 million gallons x 54.1 grams/gallon,
Resulting HC = 1.77829×10^{10} grams, and
Percentage Change = -2.8%.

Resulting CO = 328.7 million gallons x 342.2 grams/gallon,
Resulting CO = 1.12470×10^{11} grams, and
Percentage Change = -4.7%.

Resulting NO_x = 328.7 million gallons x 32.1 grams/gallon,
Resulting NO_x = 1.05661×10^{10} grams, and
Percentage Change = -0.1%.

These figures indicate that for unusual cases, freeway management can have a substantial impact on urban emission levels. The appropriateness of any action depends on the actual travel characteristics of the urban area.

Exhibit B. The Benefits of Freeway Management, Cont.

Table B Percentage of Daily Congested Freeway VMT versus Total Daily Areawide VMT (17).

All VMT in 1000s

City	Total VMT	Fwy VMT	Fwy % of Total	Percent of Peak Fwy VMT Congested	Fwy Peak Congested VMT	Congested Fwy as a % of Total Areawide VMT
New York, NY	225510	80920	36	60	21850	9.7
Washington D.C.	62980	25020	40	65	7320	11.6
Chicago, IL	119640	34440	29	55	8520	7.1
Detroit, MI	79050	22550	29	40	4060	5.1
Minn-St. Paul, MN	41270	16860	41	30	2280	5.5
Dallas, TX	50310	22650	45	55	5600	11.1
Houston, TX	72630	28290	39	70	8910	12.3
Los Angeles, CA	244960	106680	44	75	36000	14.7
San Bernardino, CA	23660	12620	53	80	4540	19.2
San Diego, CA	50290	26760	53	45	5420	10.8
San Fran-Oak, CA	77800	41970	54	80	15110	19.4
Averaged Values			33	20		2.0