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An Assessment Of Ivhs-opts Technology Impacts On Energy Consumption And Vehicle Emissions Of Transit Bus Fleets

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### Authors

Jolibois, Jr., Sylvan C.  
Kanafani, Adib

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CALIFORNIA PATH PROGRAM  
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# **An Assessment of IVHS-APTS Technology Impacts on Energy Consumption and Vehicle Emissions of Transit Bus Fleets**

**Sylvan C. Jolibois, Jr.**

**Adib Kanafani**

**California PATH Research Report  
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and Vehicle Emissions of Transit Bus Fleets

Sylvan C. Jolibois, Jr.

Adib Kanafani

Revised Version<sup>1</sup>

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<sup>1</sup>This report has been revised by Mark Hickman, a researcher within the PATH program, under the direction of Caltrans and PATH staff. The project scope and the overall content of this report are the responsibility of the original author.

# An Assessment of IVHS-APTS Technology Impacts on Energy Consumption and Vehicle Emissions of Transit Bus Fleets

## Abstract

This study seeks to examine the potential impacts of Advanced Public Transportation Systems (APTS) technologies in terms of vehicle emissions, air quality, and fuel consumption. To begin, the research is framed in terms of recent federal legislation showing increasing concern for air quality and fuel economy: the Clean Air Act Amendments (CAAA) of 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991. Air quality and fuel economy issues have played a prominent role in recent transportation policy. At the same time, the APTS program has been investigating technologies in a wide variety of areas. Ultimately, these APTS services may have considerable impact in attracting travelers from their cars to public transit. In this light, we examine the potential impact of these APTS technologies on pollutant emissions and fuel consumption. The results invite some skepticism about the potential benefits of APTS technologies in these areas. While transit buses produce less hydrocarbon (HC) and carbon monoxide (CO) emissions than autos on a passenger-mile basis, emissions of nitrous oxides (NO<sub>x</sub>) and especially particulate matter (PM) are higher for buses than for autos (again on a passenger-mile basis). Also, the fuel economy of buses is only slightly better than autos on a passenger-mile per gallon basis, and this advantage is virtually erased by the differential in costs of diesel fuel relative to gasoline. Technical improvements to diesel technology, as well as alternative fuels, can significantly reduce emissions, but result all in much worse fuel economy and are still very expensive relative to conventional engine systems. Therefore, we recommend that current program emphasis be given to those APTS technologies and services that can attract travelers from auto to transit without increasing bus miles. In addition, we suggest that state and federal APTS policy-makers and program managers give considerable weight to both the air quality and fuel economy goals in evaluating the long-term APTS research and policy agenda.

Keywords: Advanced Public Transportation Systems, public transit, emissions, energy consumption

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## Executive Summary

There has been increasing interest in the application of advanced technologies in public transit over the past several years. This has been encouraged by the development of a national program in Advanced Public Transportation Systems (APTS), and a comparable program here in California (California APTS, or CAPTS). This study seeks to examine the potential impacts of these proposed APTS technologies in terms of vehicle emissions, air quality, and fuel consumption.

The discussion is framed against the backdrop of recent federal legislation showing increasing concern for air quality and fuel economy. The Clean Air Act Amendments (CAAA) of 1990 and the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 both include strong statements about the importance of the transportation system in improving urban air quality. The CAAA presents air quality standards for a number of different types of vehicle emissions, while the ISTEA allocates some transportation funding based on planning and implementation of projects for regional air quality improvements. Air quality and fuel economy issues have thus played a prominent role in recent transportation policy.

At the same time, the APTS program has been investigating technologies in a wide variety of areas. Smart traveler technologies are designed to provide travelers with the information they need about transit services and payment options, so as to make transit travel more convenient and to reduce personal barriers to transit use. Smart vehicle technologies, on the other hand, are oriented toward improvements in vehicle operations, allowing more reliable, prompt, and direct transit services for travelers. Finally, the smart intermodal program has promoted the use of high-occupancy vehicle (HOV) facilities and preferential treatment of transit vehicles to improve overall transit speed and reliability. Ultimately, these APTS services may have considerable impact in attracting travelers from their cars to public transit.

Nonetheless, in light of the current emphasis on environmental issues in recent legislation, there is some skepticism about the potential benefits of APTS technologies in these areas. While transit buses produce less hydrocarbon (HC) and carbon monoxide (CO) emissions than autos on a passenger-mile basis, emissions of nitrous oxides (NO<sub>x</sub>) and especially particulate matter (PM) are higher for buses than for autos (again on a passenger-mile basis). Also, the fuel economy of buses is only slightly better than autos on a passenger-mile per gallon basis, and this advantage is virtually erased by the differential in costs of diesel fuel relative to gasoline. Technical improvements to diesel technology, as well as alternative fuels, can significantly reduce emissions, but all result in much worse fuel economy and are still very expensive relative to conventional engine systems.

Based on these findings, we make two recommendations. First, we suggest that current program emphasis be given to those APTS technologies and services that can attract travelers from auto to transit without increasing bus miles. Increases in transit passenger-miles, without increases in bus-miles, will yield greater air quality and fuel consumption benefits at the margin. Second, we suggest that state and federal APTS policy-makers and program managers give considerable weight to both the air quality and fuel economy goals. There appears to be a need for greater sensitivity to these goals in developing long-term APTS research and a policy agenda to solve emissions and fuel economy problems within the transit industry.

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# 1 Introduction

There has been much attention over the past several years directed to Intelligent Vehicle-Highway Systems (IVHS). This IVHS effort is examining the role of communications, information, and other technologies to improve the nation's transportation system. At present, this concept is driving considerable research efforts at many major universities as well as transportation planning within federal, state, and local governments. One aspect of this research which is drawing greater attention is Advanced Public Transportation Systems (APTS), exploring the role of these new technologies in the specific arena of public transit.

This report examines the potential impacts that IVHS technologies may have on the vehicle emissions, air quality, and consumption of energy. This study is restricted to transit operations in general and to motorized bus fleets more specifically. The main objectives of this report are to perform a qualitative assessment of the impacts of Advanced Public Transportation Systems (APTS) technologies on air quality and energy consumption in both the short term (5-10 years) and in the long term (10-20 years).

The research is conducted in a framework that relies heavily on an understanding of the institutional and legal mechanisms linking air quality and energy consumption to broader IVHS goals. At present, there is little empirical data from current research in IVHS and a comparable lack of reliable and relevant modeling techniques. These issues pose considerable constraints for both the methodology and the scope of this research. As a result, a more qualitative methodology was emphasized, including a review of associated literature in these areas as well as a review of historical data on energy consumption and air quality impacts of transit and intercity buses.

The study is divided into three major sections. First, we review the main thrusts of the legislation governing air quality for surface transportation; i.e., the 1990 Clean Air Act Amendments (CAAA) and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). The second section consists of a review of APTS program areas and their associated services to the public. The third section presents the qualitative analysis where the identified services and technologies are evaluated in the context of current trends in the transit industry.

## 2 Institutional and Legal Framework

The interest of transportation officials and professionals in the transportation and air quality arena has been stirred by a set of legal developments which have given air quality a much larger role in urban transportation decision-making than in the past. Specifically, the 1990 Federal Clean Air Act Amendments (CAAA) contains explicit provisions regarding the responsibility of the transportation sector for improving air quality.

### *2.1 The Clean Air Act Amendments (CAAA)*

Title I and parts of Title II of the CAAA (FHWA, 1992a) pay particular attention to the transportation sector. Title I establishes criteria for attaining and maintaining the National Ambient Air Quality Standards (NAAQS) — the federal standard developed by the Environmental Protection Agency (EPA) — that set allowable concentrations and exposure limits for various pollutants. Under the NAAQS, certain pollutants should not exceed specified levels more than once a year. Areas with levels that violate the standard are designated as non-attainment areas for the associated pollutants, and must reduce the emissions from any sources causing this pollution.

The EPA has identified three types of emissions sources: mobile, stationary, and area. Mobile sources consist primarily of transportation modes: motor vehicles, aircraft, marine vessels, etc. These mobile sources produce pollutants, including carbon

monoxide (CO), hydrocarbons (HC), oxides of nitrogen (NO<sub>x</sub>), and particulate matter (PM), known to degrade the air quality. These pollutants may be emitted either in high local concentrations or in geographically dispersed areas.

Title II of the CAAA identifies actions to be taken for reducing emissions from mobile sources. By and large, these actions are directed at automobile and gasoline manufacturers, and consist of guidelines and regulations for reducing tailpipe emissions on new vehicles. The emissions standards specified in the CAAA for cars and light-duty trucks are to be incorporated in the 1994 models, and those of the heavy-duty trucks by 1998. For urban transit buses, Title II establishes a stringent particulate emissions standard, scheduled to take effect in 1994.

## ***2.2 The Intermodal Surface Transportation Efficiency Act (ISTEA)***

The congressional adoption of ISTEA reflects a growing recognition that transportation programs, however vital for national mobility and international competitiveness, must be compatible with environmental goals. One of ISTEA's main objectives is to strengthen the emphasis on environmental aspects of transportation decisions. To this end, federal aid for highway and transit programs has been redesigned to help state and local officials meet the requirements of the CAAA. The general environmental features of ISTEA are as follows:

- **Flexible Programs:** One of the key components of ISTEA is the flexibility afforded state and local officials in the choices among highway, transit, and other transportation alternatives. For example, up to 30% of the funds from the Surface Transportation Program (STP), a major component of ISTEA, may be used directly for specific transit capital projects. Additionally, the federal program to provide 80% of capital funds for transportation projects may be increased to 90% for high-occupancy vehicle (HOV) lanes or for auxiliary lanes on interstate freeway projects.
- **Congestion Mitigation and Air Quality Improvement Program:** The ISTEA created a major new program to deal with congestion and transportation-related air pollution. The legislation authorizes \$6 billion in spending over a 6-year period to help states reduce or eliminate air quality problems. The severity of air pollution, a special concern of the legislation, is factored into the formula for distributing funds, thus giving priority to heavily congested corridors. In addition, transportation projects and programs identified in the CAAA can also be included for funding consideration, provided that the projects contribute to the attainment of at least one of the NAAQS.
- **Funds for Air Quality Planning:** While the CAAA significantly expanded state and local air quality requirements, ISTEA provides additional federal funding for related activities in two ways:
  1. The funds set aside from certain programs for urban transportation planning have been increased from one-half percent to one percent of the total allocation. This contributed to a considerable increase in federal outlays from 1991 (\$47 million) to 1992 (\$117 million).
  2. Planning and research activities may be funded directly from the STP and the National Highway System (NHS) funds. Previous funding channels restricted the amount of funding that could be allocated for planning and research activities; there are no such restrictions on the STP and NHS funding.

## **3 The Surface Transportation System and APTS**

The current surface transportation system is at a crossroads. Vehicle miles of traffic totaled almost 1 trillion in 1970; by 1988, that figure had doubled to over 2 trillion vehicle miles. This rise in traffic has resulted in significantly higher levels of traffic congestion. In 1970, the percentage of peak hour traffic operating under congested conditions on urban interstates was less than 40%;



today, that figure is almost 70%.

One approach that has been suggested to improve the efficiency and effectiveness of the surface transportation system is the use of technologies associated with IVHS. The rationale behind the move toward these new technologies is that they may promote more efficient uses of existing transportation infrastructure, reduce congestion, improve air quality, and reduce fuel consumption. One facet of this IVHS program is applying these newer technologies in the field of public transit, under the umbrella of the federal APTS program. These technologies would be used to improve the operation of high-occupancy vehicles, including transit buses, carpools, and vanpools. In turn, improvements in these operations are expected to increase the demand for, and use of, these types of services.

Currently, assessment of APTS products and technologies is proceeding in three areas: smart traveler, smart vehicle, and smart intermodal systems. These areas emphasize, respectively, the role of new technologies for improving the transportation-related decisions of the traveler, the efficiency of vehicle operation, and the movement of people in the transportation system as a whole. These areas have already received considerable attention (Labell et al., 1992), especially as a number of field operational tests have begun. The following sections identify the services and products believed to have potential impacts on air quality and energy consumption in the transportation system.

### **3.1 Smart Traveler**

The objective of the smart traveler program is to improve public information about ride-sharing and mass transit alternatives. Improving the availability, accuracy, and distribution of information may induce travelers to travel using higher occupancy vehicle modes. This, in turn, will have the effect of reducing vehicle emissions and fuel consumption, by removing travelers from travel alternatives (e.g., the private automobile) that create more pollution and consume more fuel per person trip. The information systems envisioned under this area would include improved fare payment and billing options, to increase the ease of access to transit and ridesharing services. These services also may reduce a traveler's reluctance to travel on transit by making it easier and safer to pay the fare electronically instead of carrying cash.

#### **3.1.1 Traveler Information Systems**

Several types of traveler information systems are envisioned to distribute travel information to travelers in a variety of settings. Pre-trip information systems, using kiosks, telephone, computer systems, and other media have been proposed to bring multi-modal information to travelers in their home, office, or other locales. Traditional information that could be more widely distributed using electronic means includes routes, schedules, and fares. In some demonstration projects, this information is relayed to travelers over the phone by human operators. More recent projects are examining other media with a higher level of automation in responding to requests, using synthesized voice messages conveyed over telephone lines or visual displays at a user interface. Moreover, if vehicle condition and location information is available in real time, this information may also be relayed to travelers. San Antonio (TX) has already implemented a system that provides real-time bus arrival information to travelers using a telephone; additional demonstrations of this technology are planned.

In-terminal information systems consist of electronic and computer displays located at transit stations or route stops. Such systems are more prevalent in air travel and heavy rail transit, but are receiving increasing attention within light rail and bus systems. The displays may simply deliver route and schedule information to passengers, but are now increasingly being used to relay up-to-date information on expected vehicle arrival and departure times, vehicle delays and cancellations, the terminal layout, and local services. These newer systems are also interactive, allowing travelers to query for more specific route information. Several cities, including Anaheim (CA), Baltimore (MD), Denver (CO), and Houston (TX), are planning to implement such in-terminal information systems.

Finally, in-vehicle information systems consist of technical innovations supporting the transit user and the vehicle operator.

Travelers are aided by onboard displays and communications devices providing information on routes, schedules, and connecting services. For vehicle operators, displays and communications systems may indicate schedule deviations, control measures to improve service reliability (e.g., waiting for a connecting bus), or even local area maps including routes and stops. The Americans with Disabilities Act (ADA) requires all fixed-route transit vehicles to provide both visual and audio information to passengers, identifying major intersections and key transfer sites. In this light, increased interest in these systems is expected, not only to meet legal requirements but also to enhance customer satisfaction.

### 3.1.2 Integrated Fare Media

Integrated fare media may be used for all or most surface travel modes, increasing the convenience of transit and other travel alternatives. A magnetic stripe card is the most common and popular device that can now be used on bus, subway, and paratransit fare collection systems. Currently, magnetic stripe cards are used for multi-agency travel in both the San Francisco Bay area (CA) and in the Greater Los Angeles (CA) area. In the future, smart cards may be used in much the same way. However, the smart card has considerably greater flexibility in that it will contain a “memory” and may be used for many other purposes, in the same way one might now use an ID card, a credit card, or a bank ATM card. The versatility of such a smart card would make it easier for travelers to use transit and other high-occupancy travel modes.

### 3.1.3 Multi-modal Trip Reservation and Billing Systems

In addition to integrated fare media, new technologies would permit travelers to make reservations and obtain tickets for an entire trip (origin-to-destination) from the initial carrier. Broad inter-agency agreements allow services to be coordinated, and a central source handles billing for fares across all travel modes. The airline and rail passenger travel sectors have the only currently existing multi-modal trip reservation systems. Nonetheless, several transit-based systems are being developed through the “Mobility Manager” concept, providing a central clearinghouse for information on travel choices and service providers as well as a central processor of financial transactions. There are a number of “Mobility Manager” demonstration projects already underway, including those in Norfolk (VA) and Medford (OR).

## 3.2 *Smart Vehicle*

The main objective of the smart vehicle element of the APTS program is to improve fleet operations by increasing the reliability and efficiency of vehicle operations. This objective may be met by new technologies which assist transit agencies with fleet management, as well as technologies which improve operations for the vehicle directly. By improving fleet operations, it may be possible to reduce vehicle miles of travel and improve the efficiency and reliability of vehicle operations. This in turn may reduce the amount of fuel consumed and the amount of pollutants emitted by transit vehicle fleets. Vehicle-based systems may also improve the performance of vehicles by monitoring fuel consumption and emissions levels, allowing earlier detection and correction of problems on board.

### 3.2.1 Automatic Vehicle Location (AVL)

AVL has been identified as the primary mechanism through which the operations and communications objectives are to be met. Already, a significant number of North American transit agencies have installed or are planning to install these systems. Essentially, AVL technology collects data on a vehicle’s position at various time intervals and transmits this information to an operations control center. At the control center, this information may in turn be used to generate control actions, such as speeding up or slowing

down a vehicle to maintain a schedule. In addition, AVL technologies can provide an emergency notification function to alert the control center of problems on board a vehicle. In the longer term, the data collected by an AVL system may help transit agencies to collect vehicle route and schedule information electronically, yielding a rich data source to improve operations and service planning. The AVL system may thus provide more long-term benefits through service plans that are sensitive to air quality and fuel consumption measures.

### 3.2.2 Automated Demand-Responsive Dispatching and Scheduling Systems

Automated demand-responsive dispatching systems can be used to schedule trips, dispatch shared-ride vehicles, and perform accounting and billing functions through the use of computers and advanced communications technologies. Increasingly, traditional transit agencies are looking to cater their services to the market, allowing flexible vehicle routing or directly demand-responsive paratransit services to carry patrons from origin to destination. Such services may be more viable than traditional “dial-a-ride” services in the past because of the efficiency of automated functions to facilitate vehicle routing, scheduling, and dispatching. Most directly, automating these functions may increase the overall efficiency of transit or paratransit operations, allowing reductions in fuel consumption and vehicle emissions. More indirectly, however, these more flexible and demand-responsive services may induce travelers to use transit or shared-ride vehicles rather than single-occupant autos, yielding additional energy and air quality benefits.

### 3.2.3 Other Vehicle-Based Systems

New technologies directly on board the vehicle also offer the promise of more efficient vehicle operations. A number of technologies have already been proposed to improve driving conditions. Lateral and longitudinal collision warning equipment is now being installed on Greyhound inter-city bus fleets, notifying the driver of objects that are in dangerous proximity to the bus. Similar technologies could also be applied to transit bus fleets in the near future. In the longer term, some IVHS technologies may allow automation of certain driving functions, including speed and steering control. While these technologies are still very much in the initial phases of development, they offer some hope for improving the reliability and efficiency of vehicle travel, including transit vehicle fleets.

There are also other on-board sensor technologies that may improve fuel use and air quality. Sensors have already been developed that can monitor fuel consumption on a transit bus, and there is considerable research underway on sensors that can detect pollutants in vehicle exhaust. With these technologies, drivers may discover problems with the fuel delivery or exhaust system on a bus much earlier. The benefits of such sensor systems include shorter delays in diagnosing problems and more accurate and prompt maintenance action.

## 3.3 *Smart Intermodal Systems*

This component of the APTS program would improve transit and ridesharing activities by providing these vehicles with preferential treatment within a regional transportation system. Advanced technologies allow monitoring and control of high-occupancy vehicle (HOV) and bus-only lanes. In addition, regional traffic control systems can accommodate preferential treatment of HOV's and transit vehicles at traffic signals, allowing these vehicles to bypass congested intersections in the road network. These improvements in transit and HOV traffic flow may provide benefits in two ways. Most directly, reducing congestion for HOV's and transit buses translates into more efficient engine operation, reducing pollutant levels and fuel consumption. More indirectly, however, improvements in transit and HOV service can also attract private auto drivers to these modes, allowing additional air quality and energy benefits.

### 3.3.1 HOV Facility Operation

High-occupancy vehicle facilities may be monitored by new surveillance and vehicle tag technologies, allowing law enforcement officials to identify HOV lane violations or respond to accidents or other incidents on the HOV facilities. This in turn would improve vehicle flow over the facility. In addition, a number of areas, such as San Jose (CA) and Los Angeles (CA), have a separate signal (or no signal at all) for HOV's at ramps to freeways. HOV's may thus bypass congested ramps onto the freeway, or onto an HOV facility.

### 3.3.2 Traffic Signal Preferential Treatment

A number of cities have experimented with the preferential treatment of transit vehicles at traffic signals. Typically, this involves a signal transmitted from the vehicle to a local controller, allowing a shorter red signal or an extended green signal for the approaching vehicle. Such preferential treatment results in shorter signal delays for transit vehicles, with a resulting reduction in idling time and associated fuel usage and emissions. The city of San Jose (CA), among others has implemented a scheme for preferential treatment of light rail vehicles; plans are in the works for other demonstrations for bus fleets, including those of the San Francisco (CA) Muni and the Chicago (IL) CTA.

## 4 Evaluating APTS Services - Trends in the Industry

Transit operations in the U.S. have been losing shares of the surface travel market consistently over the last twenty years. The proportion of transit trips has decreased to around 3 to 5% of the total trips by all surface modes (Volpe Center, 1992). Given this current condition, it seems appropriate to examine the role APTS services may have in reversing this trend. Summarizing the discussion from section 3, there are two main areas in which there seems to be hope for attracting people to public transit. First, APTS technologies can mitigate some of the barriers travelers may perceive to using transit by providing information, offering easier payment options, etc. At the same time, APTS may allow transit operators to increase the efficiency and effectiveness of transit and other HOV operations, thereby making transit options more attractive to the traveler. Given these goals of APTS development, we are particularly interested in knowing how these technologies may affect the air quality and fuel consumption impacts of the transportation system.

### 4.1 Air Quality Impacts

As mentioned before, the CAAA of 1990 has added momentum to the goal of reducing tailpipe emissions from mobile sources in urban areas. This has been reflected most obviously in the tighter standards for tailpipe emissions for transit buses, enacted as part of the CAAA legislation. Concern has also been reflected in the development of bus engines and alternative fuel sources with reduced emissions levels. In this section, we examine the air quality and emissions impacts of bus fleets, particularly with an eye to how the potential shift of travel from the automobile to transit services under APTS may affect overall emissions rates.

Statistics from the Environmental Protection Agency (EPA) offer some insight into the emissions rates of automobiles versus those of diesel buses under current operating conditions. Table 1 shows the ratio of emissions rates of a diesel bus versus those of a typical passenger car (Santini and Schiavone, 1991). These statistics are based on an assumed auto occupancy of two people and a bus occupancy of thirty passengers. The most obvious dimension to note from this

**Table 1: Ratio of Transit Bus Emissions to Auto Emissions**

Emissions Measure	Bus to Car Ratio, per Vehicle	Bus to Car Ratio, per Passenger
Hydrocarbons (HC)	2:1	0.15:1
Carbon Monoxide (CO)	4:1	0.27:1
Nitrous Oxides (NO <sub>x</sub> )	9.5:1	0.63:1
Particulate Matter (PM)	500:1	33.3:1

Source: Santini and Schiavone, 1991, p. 6.

table is that while transit diesel buses do have higher emissions rates in all four emissions categories when compared on a per-vehicle basis, they have lower emissions rates on a per-passenger basis in all categories except particulate matter (PM). This suggests that shifting travelers out of their automobiles and into transit buses provides direct benefits in several emissions categories. Inasmuch as APTS technologies can achieve this mode shift, emissions levels of HC, CO, and NO<sub>x</sub> can be reduced directly, on a per-passenger basis.

These ratios are a little suspect, in that the assumed bus occupancies of approximately 30 passengers per bus may be overly optimistic, although the same is true of the automobile occupancy figure of two persons per auto. However, reducing the average automobile occupancy to 1.6 and reducing the bus occupancy to 10 persons per transit bus (statistics suggested by Davis and Strang, 1993) still results in ratios that are less than 1:1 for HC and CO emissions (new statistics would be 0.36:1 for HC and 0.65:1 for CO). The ratio for NO<sub>x</sub> emissions would increase to 1.51:1, while that of particulate matter increases to about 80:1.

Similar benefits of APTS technologies in reducing vehicle emissions have been noted by other studies. In particular, the study done by Jack Faucett Associates for the Volpe Center (Jack Faucett Associates, 1993) offered similar observations about HC and CO emissions, and suggested that there was still some question about the potential impacts for NO<sub>x</sub> emissions. Their observations, listed in table 2, strengthen these likely emissions benefits of APTS technologies.

The emissions figures suggested here still point to significant problems in current transit bus fleets with respect to NO<sub>x</sub> and PM emissions. It is known that NO<sub>x</sub> emissions are “pre-cursors” for the creation of ozone in urban areas, due to the reaction of these nitrous oxides with oxygen and other chemicals in the vicinity of buses and other mobile sources. Moreover, it is typically the

**Table 2: Impacts of APTS Technologies**

Variable	Short-Term Impacts		Long-Term Impacts	
	Corridor	Regional	Corridor	Regional
Traffic Flow	Positive	Positive	Positive	Positive
Vehicle Trips	Positive	Positive	Positive	Positive
Trip Distance	Insignificant	Insignificant	Insignificant	Insignificant
Mode Shifts	Positive	Positive	Positive	Positive
HC Emissions	Positive	Positive	Positive	Positive
CO Emissions	Positive	Positive	Positive	Positive
NO <sub>x</sub> Emissions	Uncertain	Uncertain	Uncertain	Uncertain

Source: Jack Faucett Associates, 1993, page 3-24.

ambient ozone levels that are most often responsible for violation of the NAAQS in larger urban areas. In this respect, increasing transit mode share may have the unintended effect of increasing NO<sub>x</sub> emissions per person trip and thereby resulting in a worse, rather

than better, performance with respect to the NAAQS. While the data seem to support this hypothesis, the magnitude of this impact is less certain. Overall, some statistics suggest that the nitrous oxide emissions of transit bus fleets would increase the national ozone concentration levels by about 0.2%; however, ozone concentrations in certain “hot spots” in central business districts may be increased by upwards of 8% (Santini and Schiavone, 1991).

The emissions of particulate matter from bus fleets may also lead us to be suspect of mode shifts to transit brought about by APTS technologies. The statistics in table 1 clearly indicate that buses produce significantly higher concentrations of particulate matter than autos, even when corrected on a per-passenger basis. Some researchers have argued that the impact of bus fleets on particulates only contributes on the order of 0.5% of the concentration of PM in urban areas like Los Angeles, largely because mobile source emissions are a small fraction (19%) of total regional PM emissions (Santini and Schiavone, 1991). Again, however, the overall magnitude of this contribution masks the problem of “hot spots” such as central city areas, where buses contribute a much higher proportion of PM than this broad average. These statistics on PM emissions cast additional doubts on the air quality benefits of APTS technologies.

In the midst of this discussion, research over the past ten to fifteen years has suggested that engines running on alternative fuels may be used to lower the emissions rates of transit buses. For this study, we may consider the net benefit brought about by the introduction of APTS as well as the substitution of buses running under alternative fuels. In particular, there are a number of technical improvements in bus fuels and engines that may yield lower emissions of NO<sub>x</sub> and PM. The literature to date suggests that it is difficult to reduce both NO<sub>x</sub> and PM emissions simultaneously. To be more precise, under current engine and fuel systems, there is some synergy between the two emissions levels such that technical “improvements” which reduce one set of emissions also increase emissions of the other. This makes it difficult to evaluate the effectiveness of alternative engine and fuel systems, as there is an inherent trade-off between the two measures.

A recent study examined alternative fuel and engine technologies in bus fleets (Small, 1991). Four different technical options were considered for reducing PM emissions in transit bus fleets:

1. *Low-aromatic fuel*: This fuel is developed by an additional process that removes substantial sulfur from traditional diesel fuel. As a result, SO<sub>x</sub> emissions (part of PM emissions) are reduced.
2. *Particulate traps*: A particulate trap is attached to the exhaust system of the bus.
3. *Low-aromatic fuel and particulate traps*: A combination of the above.
4. *Methanol*: An alternative fuel requiring a different fuel-burning system in the buses’ engine.

This research discovered higher reductions in PM emissions as one moves across these four technologies. Low-aromatic fuel yielded about a 26% reduction in PM emissions from the typical transit bus, while reductions of PM emissions of 77% were observed for particulate traps. Both options in synergy produced benefits of about 81% reduction, while the methanol bus cut PM emissions by almost 96% (Small, 1991, p. 20).

These statistics suggest that PM emissions can be reduced by a factor of 4 or 5 with selected modifications to existing diesel technology, while an alternative fuel like methanol can reduce emissions by a factor of 20 to 25. Given the ratios of bus to auto PM emissions of 33:1 to perhaps up to 80:1 (from table 1), alternative fuels like methanol could reduce this ratio to 3:1 at the least, and perhaps down to almost 1:1. Thus, it seems that shifts in mode from auto to transit buses can yield more minor air quality impacts in terms of PM and perhaps NO<sub>x</sub> if alternative fuels can be adopted simultaneously.

These improvements in bus technology, however, have an associated price. Small’s study also examined the cost-effectiveness of these four technical alternatives, using the ratio of the total cost of the measure to the net reduction in kilograms of PM emissions. The direct measures were \$1.58/kg for fuel modification, \$3.63/kg for particulate traps, \$3.95 for the combination, and

\$19.98/kg for methanol. The results suggest that while alternative fuels like methanol can achieve reductions in PM emissions five times larger than fuel modification and particulate traps, the average cost per kilogram reduction is more than five times greater. Thus, there is an inherent trade-off in the potential reduction of these emissions and the cost of the technology to realize them.

#### **4.2 Fuel Consumption Impacts**

Shifts in mode split from private automobiles to public transit that occur due to APTS technologies also may have impacts on overall fuel consumption. Intuition might expect that the higher vehicle occupancies of public transit may indeed provide better fuel economy than individual drivers in their own cars. From this perspective, it would seem that improvements in transit market share have great appeal for fuel economy.

One may also look more generally at trends in both automobile and transit bus fuel economy. Over the past twenty to twenty-five years, there has been considerable improvement in automobile fuel economy. The regulatory power of the Clean Air Act of 1970, and subsequent regulations from the EPA for new automobile fleets, has had considerable effect on fuel consumption by the U.S. automobile fleet. These standards have required automobile manufacturers in the U.S. to increase the average miles per gallon in manufactured vehicle fleets several times since the original CAA rulings.

In 1970, automobiles in the U.S. averaged about 13.4 miles traveled per gallon of gasoline, or about 22.8 passenger-miles per gallon of gasoline when average automobile occupancy measures were included. The latest statistics from the FHWA (Davis and Strang, 1993), based on data from 1990, suggest that the fuel economy of automobiles has improved by about 50% over the 1970 data: about 20.9 vehicle-miles traveled per gallon, or about 33.4 passenger-miles per gallon of gasoline. At the same time, vehicle miles of travel by automobile have increased dramatically since 1970; however, the net gasoline consumed by automobiles between 1970 and 1990 only increased by about 6.3%.

While automobile fuel economy has risen substantially over the past twenty-five years, the statistics for transit buses are much less salutary. Average bus fuel economy has decreased from about 4.4 miles per gallon of diesel fuel in 1970 to about 3.8 miles per gallon in 1990. Even though passenger-miles of travel have increased from 18.1 billion in 1970 to over 21.1 billion in 1990, the net fuel economy of transit bus fleets has decreased from 56.1 passenger-miles to 37.1 passenger-miles per gallon of diesel fuel (Davis and Strang, 1993). This latter statistic is compounded by the expansion of bus mileage over the same period. Between 1970 and 1990, transit bus miles have increased from 1.41 billion to 2.15 billion. This amounts to a 52.8% increase in bus miles, compared with a much smaller 16.6% increase in passenger miles over the same time period.

Clearly, APTS technologies can contribute to the bus fuel economy measures if they are able to improve the ratio of passenger-miles to vehicle-miles. Such benefits may be possible by increasing the number of passengers on buses, or simply by improving the efficiency of service so that vehicle miles may be reduced. In addition, APTS measures that reduce idling, such as signal pre-emption, can improve transit fuel economy.

However, the statistics presented above indicate that the impacts on fuel consumption of diverting a traveler from the private auto to transit are small. Simply based on the average fuel consumed per passenger mile, private auto yields 33.4 passenger-miles per gallon of gasoline, while transit buses attain only 37.1 passenger-miles per gallon of diesel fuel (Davis and Strang, 1993). This implies that fuel savings amount to only about 0.003 gallons per passenger-mile, or about 0.03 gallons over a typical 10-mile trip. When one factors in the (usual) higher cost of diesel fuel relative to gasoline, the economic value of fuel savings from diverting travelers from auto to transit virtually disappears. This suggests that, at least at the margin, there is little or no benefit in fuel consumption from a mode shift to transit.

Initial investigation of alternative fuels suggests that these fuels are not nearly as fuel-efficient or cost-effective as existing petroleum-based fuels. For example, the energy content of methanol typically requires that vehicles consume almost twice as much of

it as conventional gasoline per mile of travel. Also, methanol currently costs at least as much as gasoline per gallon, indicating that it is at least twice as expensive on a vehicle-mile basis as conventional gasoline. One must thus trade off the additional expense of methanol-based systems with our dependence on petroleum products. Even if we could convert all of our current transit fleets to methanol, the savings in petroleum would amount to only about 37,300 barrels of crude oil per day, or less than 0.3% of the total transportation energy use in the United States (Davis and Strang, 1993).

## 5 Conclusions

The development and deployment of IVHS technology has been presented as a means to alleviate congestion, reduce energy consumption, increase transportation safety, improve air quality, and increase worker productivity. APTS technologies have also been promoted as one of the most effective ways of simultaneously achieving all of the listed objectives. Certainly, the smart traveler, smart vehicle, and smart intermodal services being promoted as part of APTS may serve to attract travelers from their automobiles to public transit. These services may increase the attractiveness and the performance of public transit in terms of several key characteristics: speed, reliability, flexibility, convenience, and safety.

However, the current legislative climate places notable emphasis on environmental and intermodal issues. The potential for developing and implementing some innovative transit technology programs may be dependent on public funds allocated under the stipulations of the 1990 CAAA and the 1991 ISTEA. The flexibility in regional transportation spending found under ISTEA could lead to greater involvement by transportation agencies in developing and deploying APTS services. Yet, because of the air quality stipulations of the CAAA, there will continue to be considerable concern about the ability of transit investments to improve regional air quality.

With the likelihood that APTS technologies will lead travelers to switch from their automobiles to public transit for their trips, it is still uncertain whether there can be significant benefit for regional air quality and fuel consumption. The data we have assembled for this study suggest that, even under current diesel fuel and engine systems, emissions per passenger-mile for bus transit are considerably lower than automobiles in both categories of hydrocarbons (HC) and carbon monoxide (CO). However, the data also suggest that emissions of nitrous oxides (NO<sub>x</sub>) and, more noticeably, particulate matter (PM) may be higher for buses than autos on a passenger-mile basis. Alternative fuels or other clean-air technologies can assist in reducing NO<sub>x</sub> and PM emissions from transit bus fleets, but only at a significant expense.

Similarly, at the margin, the fuel economy (measured in passenger-miles per gallon of fuel) of an urban transit bus is only very slightly better than for an automobile. When the cost of fuel is included, there is likely no difference between the fuel economies of the two modes. Alternative fuels such as methanol have significantly worse fuel economy (almost double the fuel consumed per passenger-mile) and are at least as expensive per gallon as gasoline and diesel fuel. This leaves considerable doubt of less fuel consumption, or fuel expenditures, as people switch from auto to transit.

These observations suggest particular directions for research and development for the APTS effort, both in California and in the U.S. First, in terms of APTS investment, there should be substantial effort placed on the technologies that draw travelers to transit without significant commitments to alter existing transit service. The environmental and energy concerns regarding the value of bus transit relative to the automobile can be alleviated in part by efforts that bring about increases in transit passenger-miles without increases in vehicle miles. APTS services which seem oriented toward this goal include:

1. Smart Traveler systems, with emphasis on traveler information systems, integrated fare media, and multi-modal trip planning and billing services;
2. Smart Vehicle systems that improve existing system reliability, such as AVL systems in conjunction with real-time monitoring and



control; and,

3. Smart Intermodal systems, which increase the speed and reliability of transit services through HOV facilities and preferential treatment of transit vehicles at traffic signals and toll booths.

Such services may result in increasing transit passenger-miles and allowing (albeit modest) improvements in transit emissions levels and fuel economy on a passenger-mile basis.

The air quality and fuel economy impacts of services that may increase bus miles with uncertain effects on mode choices are uncertain, and may result in further degradation of air quality and fuel economy measures. APTS services in this area include smart vehicle technologies such as personalized public transit or flexible routes and schedules based on real-time vehicle dispatch and routing. Further investigation of the air quality and fuel economy impacts of these services is necessary.

The recent emphasis on and enthusiasm for APTS technologies seem to have lost sight of the broader air quality and fuel consumption goals of U.S. transportation policy, as articulated in the CAAA and the ISTEA. In developing a research and development program, the transit industry in both California and the U.S. would do well to reconsider the options for achieving these two goals. From this research, it appears that APTS technologies alone will not be sufficient to address these objectives. Technical research is needed on engine and fuel systems that can allow bus fleets to improve fuel economy and reduce emissions, supplemented by policy actions that give greater emphasis to air quality and fuel consumption problems.

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