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# SEARCHING FOR SOLUTIONS

*A Policy Discussion Series*

# Transportation and Air Quality

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# Transportation and Air Quality

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The following is a list of other publications in the Federal Highway Administration's "Searching for Solutions: A Policy Discussion Series."

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| Number 1 | March 1992 | Exploring the Role of Pricing as a Congestion Management Tool |
| Number 2 | June 1992 | Exploring Key Issues in Public-Private Partnerships for Highway Development. |
| Number 3 | August 1992 | Public and Private Sector Roles in Intelligent Vehicle-Highway Systems (IVHS) Deployment |
| Number 4 | August 1992 | Assessing the Relationship Between Transportation Infrastructure and Productivity. |

Note: In addition, the Office of the Associate Administrator for Policy has published a supplement to the policy discussion series entitled "Searching for Solutions: Annual Policy Contract Research Program."

# FOREWORD

This report summarizes a Federal Highway Administration (FHWA) seminar on key issues in air quality and transportation planning held last year — supplemented by an individual perspective on findings which have emerged during the year since the 1991 seminar.

The passage of the Clean Air Act Amendments of 1990 confirmed attainment of air quality as a central objective of transportation policy, planning, and program development. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 further integrated conformity with the Clean Air Act into State and metropolitan transportation planning. These two pieces of legislation — the Clean Air Act Amendments of 1990 and the ISTEA — are two of the key elements of President George Bush's domestic agenda. This FHWA seminar provided an opportunity for a group of early participants in transportation/clean air planning to discuss a variety of emerging policy and technical issues. The individual presentations of seminar speakers have been summarized in Part B of this report. Part A of the report consists of an overview essay incorporating seminar discussions together with a perspective developed through the San Francisco Bay Area air quality conformity assessment by the authors who were key participants in associated technical activities over the last year. While recognizing that their conclusions and recommendations represent the authors' points of view, we believe the recent experience of California in meeting its own stringent air quality requirements has provided an instructive preview of several of the major challenges to be faced nationwide in the initial kinds of conformity assessment under the Clean Air Act Amendments of 1990.

While the discussion ranged widely, certain perspectives were substantially shared. First, conventional transportation control measures (TCMs) will not be sufficient to achieve attainment in many severe nonattainment areas and, therefore, unconventional approaches such as pricing and growth management may be considered. Second, political and institutional resistance to more effective TCMs may lead to a reexamination of vehicle technology-based solutions. Third, clean air mandates suggest the need for substantial investment in improved quantitative methods. These conclusions suggest that much remains to be learned about the fast-moving, rapidly changing field which is transportation/air quality planning.

This report is one of a series of *Searching for Solutions: A Policy Discussion Series*. The series will deal with key emerging highway transportation issues such as congestion pricing, privatization, transportation and air quality, and transportation and economic productivity. Issue papers will emanate from policy seminars sponsored by the FHWA to gather viewpoints on important topics or from FHWA policy research. We look forward to generating a wide-ranging dialogue on these and other important challenges facing transportation policy development.

Stephen C. Lockwood
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# Part A — Air Quality and Transportation Planning: An Assessment of Recent Developments

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## Introduction

Last year, the United States Federal Highway Administration (FHWA) sponsored a seminar on air quality as a transportation planning issue for the 1990s. Six professionals with recent relevant experience in clean air-related research or program development provided perspectives on the implications of current technical and regulatory developments, as well as lessons from past experiences in air quality-related planning. On-going conformity activities associated with California's State clean air transportation requirements provided another important perspective on challenges to be faced in nationwide implementation of the 1990 Clean Air Act Amendments.[3]

This transportation/air quality nexus continues to evolve rapidly. This paper, therefore, provides a summary and expansion of key points made by presenters. In particular, it adds the perspective introduced by the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA) which was in legislative proposal form at the time of the conference. It also integrates ideas and findings that have emerged in the period since the seminar,[4] discusses some major policy implications, and identifies topics on which additional work would be beneficial.[5]

The interest of transportation officials and professionals in the transportation/air quality nexus stems from a set of statutory and legal developments that appear to have given air quality a much larger role in urban transportation decision making than in the past. In particular, the 1990 Federal Clean Air Act Amendments (hereafter called the "1990 Amendments") contain explicit provisions about the responsibility of the transportation sector in improving air quality.[6] The 1991 ISTEA establishes the specific process by which transportation and air quality objectives are to be integrated in the planning and programming process. For example, the most polluted regions are specifically mandated to implement transportation control measures (TCMs) and a broad range of urban areas must reduce carbon monoxide (CO) and/or reactive organic (ROG) emissions significantly beyond the levels expected from currently mandated tailpipe controls.

Moreover, conformity is required among transportation plans, projects, and programs and the State Implementation Plan (SIP—the federally required air quality plan for each area); the conformity assessment must show that transportation investments will not exacerbate violations, cause new violations, or delay attainment, taking into account all elements likely to affect future ambient air quality (such as tailpipe emissions improvements and regional growth). Monitoring also is called for in the 1990 Amendments, with requirements for tracking vehicle-miles of travel (VMT) and other changes and incorporating the results into air quality plans. Together, these provisions seem likely to necessitate much more detailed examination of transportation-air quality relationships, and methodologies that adequately address key issues will be needed.

The laws of several States adds local impetus for transportation and air quality planning and analysis. A number have environmental impact

reviews that require detailed assessment of the emissions and air quality effects of transportation projects, and a few have "indirect source review" requirements which apply to the transportation emissions impacts of a wide variety of projects such as office complexes, shopping centers, and airports. In California, the 1988 State Clean Air Act requires local air quality management agencies to include trip and VMT reduction measures in their plans to attain the State ozone standard (which is set at .09, compared with the Federal standard of .12), and calls for progress in reducing emissions at a rate of some 5 percent a year.

Moreover, legal challenges over SIP status have drawn even greater attention to the impact of transportation on air quality. Notably, a lawsuit in the San Francisco Bay Area[7] has focused on the analyses that support transportation decision making. Of particular concern is the concept of "induced demand" for highway travel: whether and under what circumstances it may exist, what its effects on air quality might be, and whether current analytical tools can capture it. As the conformity provisions of the 1990 Amendments come into play, these analysis issues could be raised in other urban areas.

Air quality, thus, has become both a matter of some urgency and a long-range concern for transportation planners, particularly where highway programming is at issue. Past attention to the emissions and air quality impacts of transportation plans and programs might be described as episodic (i.e., linked to air quality plan submission deadlines in clean air legislation). But the 1990 Amendments have the potential to change that. Both the legislative history of the 1990 Amendments and the specificity of their transportation provisions suggest that Congress intended air quality to be a key criterion for transportation decision making in areas with persistent pollution problems. The 1990 Amendments define a transportation-air quality planning process that is ongoing and iterative, and require monitoring and revisions if adequate progress is not being made. They establish citizen suits as a means of enforcement. Hence, air quality seems likely to remain prominent on the transportation planning agenda as long as environmental groups and other concerned citizens show a determination to keep it there.

Against this backdrop, the seminar presenters identified a broad range of issues likely to emerge as the implications of recent clean air legislation become apparent. These can be grouped into two categories:

- **Alternate means of reducing mobile source emissions.** While the new legislation is more explicit about transportation controls, it retains great latitude for substitution among alternate approaches. Major options include additional changes in vehicle technology, vehicle inspection and maintenance, transportation control measures, land use modifications, and explicit pricing of transportation facilities.
- **Integration of transportation and air quality planning.** The new legislation carries a number of implications about the treatment of air quality issues in transportation planning and programming. Overall, it increases the responsibilities of transportation providers in air quality planning and standards attainment, mandates periodic review of transportation plans and programs and their air quality impacts, requires consistency among plans, programs, and projects, and underscores the role of quantitative analysis in transportation air quality planning.[8]

The remaining sections of the paper address these two broad areas. Key issues are raised, and matters deemed critical by the presenters are examined. Brief sections on policy directions and research are included at the end of the paper.

**While the intent of the paper is to communicate recent air quality developments to the transportation planning community, it is difficult to escape several obvious conclusions. First, significant reductions in mobile source emissions through reductions in travel (i.e., much over 5 percent from "baseline" levels) would be hard to achieve without a fundamental change in U.S. policy toward transportation pricing and land use. Second, although the auto, energy, and manufacturing sectors may feel they have shouldered a more-than-fair share of the emissions reduction burden, the tailpipe and stationary sources probably are the simplest places to achieve further improvements, whether from a technical, a behavioral, an**

**economic, or an institutional (political) point of view. Third, even if the majority of new emissions reductions are achieved through tailpipe and stationary source measures, clean air requirements (along with provisions of the ISTEA), have the potential to force a comprehensive reexamination of urban transportation planning. These conclusions were suggested by the FHWA seminar, and have become more apparent in the period since then.**

The seminar, sponsored by FHWA, was organized to encourage discussion of the major air quality and transportation issues. Six speakers made presentations: (1)Introduction to the Transportation and Air Quality Problem, by Martin Wachs of the University of California at Los Angeles; (2) Effectiveness of Transportation Control Measures in Reducing VMT, Trips and Emissions, by John Suhrbier of Cambridge Systematics; (3) Air Quality Strategies Not Controlled by Highway Decision Makers, by Richard Joy of Sierra Research; (4) Issues of Highway Capacity and VMT, Trips, and Emissions by Elizabeth Deakin of Deakin, Harvey, Skarbardonis, Inc. and the University of California at Berkeley; (5) Air Quality, the Transportation Planning Process, New Control Measures, and Improvements to Forecasting Models by George Scheuernstahl of the Denver Regional Council of Governments; and (6) Summary and Interpretations by Greig Harvey of Deakin, Harvey, Skarbardonis, Inc. Summaries of these presentations can be found in Part B of this report. The following material builds on the speakers' presentations, the seminar discussion, and added views of the authors based on the California experience.

# Methods for Reducing Mobile Source Emissions

The 1990 Federal Amendments and the 1988 California Clean Air Act are more specific than earlier legislation about how to control transportation emissions. Depending on the severity of the pollution problem, and on the specific pollutant in question,[9] measures to reduce vehicle trips or vehicle miles traveled (VMT) may be required. Nevertheless, the legislation retains much flexibility to customize travel restrictions and to tradeoff travel restrictions for additional technological controls on vehicles and stationary sources. Under the 1990 Amendments, these tradeoffs will have to be initiated and maintained through an ongoing, negotiation-intensive process.

The first round of discussions among transportation and air quality planners will occur during preparation of the initial SIP submission (due 15 November 1992). Some envision a negotiation among transportation planners, air quality planners, the business community, environmental interests, and implementing agencies. One goal of such a process would be an agreed-upon division of responsibility for emissions reductions among stationary sources, vehicle controls, and travel restrictions. In order to be full and effective participants in the negotiation, transportation planners will have to develop clear, well supported evidence about what can and cannot be done to alter travel behavior (and at what cost), and also will have to become conversant in the language of vehicular and stationary source controls.

The following subsections highlight key issues in the debate about mobile source emissions controls, including the feasibility and cost-effectiveness of transportation controls, additional vehicle emissions controls, land use initiatives, and economic incentives.[10] This sequence mirrors the order in which questions have arisen under the 1988 California Act:

1. How much emissions reduction can be achieved with the bundle of transportation policies commonly referred to as "reasonably available transportation controls"?

2. If reasonably available transportation controls are not adequate to meet emissions reduction targets, what can be done to further reduce emissions at the tailpipe?

3. If sufficient tailpipe controls prove infeasible (either technically or politically), are there additional options – possibly land use planning and/or transportation pricing – for reducing mobile source emissions?

## Conventional Transportation Control Measures

The term "Transportation Control Measure" (TCM) is broad enough to encompass virtually any action intended to decrease automotive travel or otherwise reduce vehicle emissions. Table 1 presents the list of TCMs for which guidance documents are mandated in the Clean Air Act. In common parlance, however, TCMs are most closely associated with a

core set of actions designed to: (1) Improve transit levels of service; (2) Support ridesharing; and (3) Build upon the special relationship between employer and employee to implement measures that make driving alone less attractive relative to other modes. It is in this more restricted sense that the term "TCM" will be used here.

Many areas will need TCMs to accomplish required mobile source emissions reductions. This has created pressure for funding TCMs through the federal transportation programs,[11] and for TCM implementation through the Transportation Improvement Programming (TIP) process.[12] Before enforceable commitments are made, however, there should be a concerted effort to understand the costs and effectiveness of individual measures, and the nature and extent of synergistic (or countervailing) effects.

The basis for such an understanding exists in the wealth of data available from recent nationwide experience with travel demand management (TDM), trip reduction ordinances (TROs), employer-based ridesharing, and rail transit expansion, as well as TCM program development under the California Clean Air Act of 1988.[13] This experience has made a number of things clear:

- **Employer-based trip reduction can be effective by limiting travel**, especially if discontinuation of free parking is an integral element. Evidence on this point comes from all over the country, but nowhere is it more instructive than in Los Angeles, where an Air District rule requires specific reductions in vehicular travel to each work site.[14] According to Giuliano and Wachs, Shoup, and others who have studied data from Los Angeles, the specified reductions appear feasible providing that: (1) employers are willing to charge for on-site parking;[15] (2) alternate free parking (e.g., on-street) is not readily available; and (3) incentives are offered to transit and ridesharing users.[16] Furthermore, parking charges appear to be nearly as effective when equivalent funds are returned as regular income,[17] so that the potential equity impacts of such a program might be managed in a politically acceptable way.

The Los Angeles program has raised concerns over the employer administrative cost of trip reduction – said to be in the range of $35 to $150 a year per employee at an affected site. Since it is not clear why a program of parking charges and transit/ridesharing subsidies should cost so much to administer, perhaps the reported costs reflect the expense of developing an initial plan and learning through hard experience what does and does not work. Under this hypothesis, one would expect administrative costs to drop as employers settled on the most effective measures.[18] After taking into account the fraction of the work force to which Regulation 15 applies, and the fraction of total travel contributed by work and work-related trips, the net effect of a fully-implemented program would be in the range of 3 to 5 percent reduction of total weekday ROG mobile source emissions.

For projected levels of ROG reduction, it is difficult to establish whether the benefits of an employer-based program are greater than the costs. As the previous paragraph suggests, individual employer costs (and implementation experiences) are highly variable. But even if implementation success could be measured accurately and related to specific employer actions, and direct costs could be made more precise, there would be a problem in assessing the full range of costs and benefits. There are likely to be significant effects on employee costs and benefits (price of parking, income enhancement, extra time for transit or participation in a carpool), employer costs and benefits (administrative costs, lost productivity associated with longer commute times, direct incentive payments), public sector costs (mostly administrative), and benefits to the society at large (reduced exposure to air pollutants, reduced peak congestion). From work in the Bay Area, it appears that employer-based trip reduction rules can be made to seem very expensive (per ton of emissions removed) or net beneficial simply by varying the assumptions about peak congestion relief between plausible

extremes.[19] In addition, a full cost-benefit analysis is hampered by wide disagreement over the health effects attributable to various atmospheric pollutants.

**Thus, while it has proven possible to change employee travel behavior through employer-based programs, pervasive uncertainties over costs and benefits have made it difficult to achieve a level of implementation that would yield a significant overall reduction in emissions.**[20]

- **Readily available TCMs mostly address work travel.** Home-based work travel is better understood than other types of travel, if only because peak-period capacity requirements have been the primary focus of transportation planning. In addition, home-based work trips appear more amenable to influence by explicit policy because of their relative density,[21] behavioral consistency,[22] and institutional simplicity[23] in comparison with non-work and non-home based trip types. As a consequence, the majority of proposed TCMs focus on home-based work trips. Since home-based work travel constitutes about 25 percent of all urban weekday VMT and an even smaller proportion of total trips, each percent of reduction among work trips appears much less significant when measured against the full spectrum of travel. For example, the California Clean Air Act's ambitious goal of a 1.5 worker-to-vehicle ratio in seriously-polluted areas, which implies a 25-percent reduction in vehicular work trips, yields less than a 5-percent reduction in ROG weekday mobile source emissions when it is spread over the full spectrum of travel.[24] **Transportation and air quality planners now recognize that TCM emissions reduction potential cannot be much greater than 5 percent without some way of addressing non-work and/or commercial travel.**[25]

- **A comprehensive program of conventional TCMs would produce a 5- to 8-percent reduction in daily trips and VMT.** The California Clean Air Act, with its stringent emission reduction requirements, provides an instructive preview of what may be expected from the federally mandated process. The first round of TCM planning under the California Clean Air Act, recently completed, has confirmed the lessons of earlier planning and implementation experience: that potential travel and emissions reductions from readily available TCMs (i.e., without major new funding or creation of new implementation authority) are generally small, and further reductions require significant new authority. For example, the Bay Area's program of conventional TCMs would reduce mobile source emissions by 1 to 3 percent without major new funding, and by 5 to 8 percent with a program that adds significant new capital investment.[26] Such a capital program would include aggressive transit expansion and a host of ridesharing incentives, together costing perhaps $100 per capita per year.[27,28]

**These predicted reductions appear small, but actually imply a 20- to 30-percent drop in work vehicle travel. This would constitute a massive change in Bay Area journey to work patterns. The need for such a change in work travel stems directly from the difficulty of reducing non-work travel.**

- **TCM cost-effectiveness studies are difficult to carry out.** In air quality planning, cost-effectiveness typically is expressed as gross cost per unit of emissions removed. Such calculations, when carried out in a simple fashion for transportation measures, can be quite misleading, especially when comparisons to other emissions reductions measures are made. This is because, unlike tailpipe controls or stationary source controls, transportation measures often yield multiple benefits (by reducing more than one pollutant or improving travel times, for example) and entail both direct and indirect costs (including private costs). In addition, both costs and benefits vary over time, yet the absence of an unambiguous estimate of net benefit per unit of pollutant removed makes it difficult to

integrate the data over multiple periods.

Cost effectiveness estimates derived from the existing TCM knowledge base often fall short of being a reliable guide for policy-making. For example, in many of the reported cost-effectiveness studies, expenditures that would occur without an air quality motive have been accounted as costs of the emissions reduction program, but benefits other than those due to emissions reductions have been ignored in the calculus. Thus what is being reported is neither a true cost-effectiveness measure, nor a true marginal cost/marginal benefit measure. Other problems in calculating cost-effectiveness stem from interactions among transportation projects and programs. Measures which are mutually supportive (e.g., HOV lanes and ridesharing programs) and measures which compete with one another (e.g., ridesharing and transit) are often accounted for separately, even though their net impacts could be accurately considered only in relation to one another.[29]

**In such cases use of simple measure-by-measure cost-effectiveness calculations could be quite misleading. Improving the situation may not be a simple matter of acquiring more information or doing more complex calculations: basic conceptual work is required in order to develop an appropriate framework for multi-cost, multi-benefit evaluation accounting for interactions among measures. If available, such a framework and associated facts could play an important role in discussions of the tradeoffs among TCMs, vehicle controls, and stationary source controls. Unfortunately, it is unlikely that the basic conceptual issues can be resolved in time for the next round of SIP revisions.**

- **Trips, and not just VMT, will need to be considered in TCM planning.** Current emissions factors account for both running emissions (related to VMT) and trip start emissions (related to the number of trips). Technology improvements to date have influenced running emissions more than start emissions, so that starts now account for half or more of mobile source carbon monoxide (CO) and reactive organic (ROG) emissions.[30] In particular, measures such as freeway incident management and park-and-ride, which affect speed and VMT but not trips, are in general less effective in reducing emissions than an assessment based on VMT only would indicate. **Hence, improvement strategies must increasingly focus on TCMs which affect trip generation and assessments of TCM effectiveness must increasingly account for both trip and VMT effects in order to be accurate.**

- **New emissions factors may alter the assessment of emissions reductions from TCMs.** Emissions specialists at the California Air Resources Board (CARB) and the U.S. Environmental Protection Agency (EPA) have collected data which indicate that existing methods may underestimate mobile source emissions by a factor of two or more. The reasons for this are not yet fully understood, but at least some of the discrepancy seems due to the absence of full accelerations from the Federal Test Procedure (FTP) used to certify autos for the American market.[31] The test procedure was developed for an early dynamometer with a restricted acceleration range. As a consequence, it is possible for an engine design to satisfy the test procedure and still act essentially like an uncontrolled vehicle during periods of very rapid acceleration. For example, CARB staff have reported that under some conditions, one full-bore acceleration up a metered freeway ramp may produce more ROG emissions than the remainder of a ten-mile trip.

Underprediction is also caused by underrepresentation of older vehicle use in urban areas and deterioration rates in the Mobile and EMFAC computer emission model formulations.

Another discrepancy arises from the way emissions factors are applied. Mileage-based emissions factors rise sharply for speeds above 55 miles per hour, yet few of the regional network models used in estimating the emissions

burden acknowledge speeds above 55. This is perhaps an understandable legacy of past efforts to enforce a 55-mph speed limit, but it also has the effect of underestimating emissions wherever faster speeds occur.

**Whether or not "off-cycle" (high acceleration, high speed) emissions turn out to be a critical problem, it is clear that mobile source emissions specialists are moving toward a comprehensive reevaluation of certification procedures and emissions factors. This review is likely to produce a refined and perhaps much altered picture of how mobile sources contribute to the emissions burden, with substantial (but currently unpredictable) implications for TCM planning.**

- **Emissions rates differ widely among operating vehicles.** The emissions performance of a randomly-chosen vehicle at a given instant is influenced by a number of factors, including the age of the vehicle (determining the basic level of emissions control), variations in the manufacturing process (affecting how well the vehicle matches its mandated performance), the extent of wear and tear and the vehicle's maintenance/modification history, the temperature of engine and catalyst (cold start, versus hot soak, versus fully warmed), roadway conditions (speed, volume, gradient, surface roughness), and the driver's style of operation (e.g., the intensity of acceleration and deceleration for a given average speed). Not one of these factors is trivial. Taken as a set of independent random variables, they would be expected to produce wide variation among the operating fleet—perhaps as much as several orders of magnitude difference between the best and the worst in a large sample.

  Using a roadside infra-red detection device, Stedman of the University of Denver has found that a few vehicles in the operating fleet account for a majority of mobile source emissions. He cites repeated instances of measurement in which the poorest one percent of a sampled fleet accounted for 30 percent or more of the total CO and ROG emissions. He argues that if his findings were to prove indicative of overall fleet condition, TCM programs would be a crude means of reducing emissions in comparison with a strategy that identified and directly removed "super-emitters" from the fleet. **He also argues that the least well-adjusted vehicles are probably owned by unemployed or marginally-employed individuals who are less likely to be reached through employer-based programs. Notwithstanding these issues, if the super-emitters identified in Stedman's work are used disproportionately for non-work travel, then conventional TCMs will not be able to attain even the modest emissions reductions suggested above.**[32]

  While there has been some controversy over the policy recommendations offered by Stedman, there is little dispute over the basic conclusion that super-emitters are present in the fleet. The problem lies in how one might go about finding and removing a significant portion of the super-emitting vehicles. Assuming that high emissions are due primarily to correctable physical causes, there are questions about the enforceability of spot readings from a Stedman-type device, about how many enforcement teams would have to be deployed to monitor a significant portion of the vehicle fleet, about the costs of the overall program (including court costs and follow-up), and about how to handle the equity concerns that will arise if low income households indeed do account for a majority of the super-emitting vehicles. There is also the possibility that much emissions variation is due to uncorrectable physical causes (cold starts) or driver behavior, in which case the ability to identify super-emitters in motion may not yield much improvement over an enhanced inspection and maintenance program.[33] Much research remains to be done.

- **The most polluted areas may require larger emissions reductions than conventional TCMs are likely to produce.** A number of areas appear to require overall emissions reductions on the order of 20 to 30 percent over what can

be achieved through currently adopted vehicle emissions controls. This level of emissions reduction may in fact be more than new vehicle controls and TCMs together will produce in this decade. In California, the requirements are even more stringent. For example, the San Francisco Bay Area, rated "serious" under the California Act,[34] is estimated by the regional Air Quality Management District to need an additional 35-percent mobile source ROG emissions reduction over-and-above what currently adopted California vehicle controls can achieve. The same will be true in other States if a recently filed lawsuit over Federal ozone standards is successful.[35] Conventional TCMs cannot produce reductions of this magnitude.

Thus, there is much uncertainty about TCMs just at the time when statutory support for TCM implementation has grown. There will be institutional pressure for rapid implementation of measures that are "reasonably available"—that is, measures which do not require additional statutory or regulatory authority. Some of these reasonably available measures benefit the transportation system in other ways (such as by helping in congestion relief), with few side effects and at relatively low cost. Implementation in such cases is rarely questioned. However, the majority of reasonably available measures do not offer such a clear imperative for implementation. Either costs are unknown (and difficult to know), or air quality benefits are made uncertain by developments such as CARB's findings on the effects of off-cycle emissions. The EPA, the U.S. Department of Transportation (DOT), and others have gathered information about experience with TCMs, but uncertainty over assumptions and local conditions limits the generalizability of findings.

In order to simplify and speed the process of screening potential TCMs, there is a need for reliable comparative documentation of experience with TCMs, particularly of the costs and of the actual emissions consequences based on up-to-date emissions models. Until this kind of information is made available to policy-makers, it will be difficult to respond quickly and with confidence to the new mandates for TCM implementation.

**In summary, existing knowledge about TCMs probably is sufficient to support policy-making at the most basic level; i.e., for taking a first cut at the balance among stationary source, tailpipe, and TCM-based emissions reductions. Experience indicates that "available" TCMs (without additional funds or authority) will rarely yield more than a 5-percent reduction, and in most cases would not yield more than a 2-percent reduction, in overall mobile source CO and ROG emissions.[36] Analyses conducted for the Bay Area, Los Angeles, Denver, Phoenix, and several other metropolitan areas also indicated that further measures considered politically acceptable, but requiring extensive new funding, are unlikely to yield more than an additional 5-percent emissions reduction. In several cases, these additional measures would entail public expenditures on transportation infrastructure equal, on a per capita basis, to the full Federal, State, and local funding stream provided to the areas under ISTEA. Thus, conventional TCMs cannot reasonably be assigned responsibility for more than perhaps 2 percent of the required mobile source reductions (or 7 percent, if expanded funding authority is considered feasible).**

# Vehicle Technology

The limited potential of conventional TCMs, and uncertainties about implementability and air quality impacts, have led to a renewed push for vehicle technology as a primary means of achieving Clean Air Act goals. A number of improvements appear possible, including:

- **Enhanced inspection and maintenance.** "Inspection and maintenance" is a generic term for a range of programs that periodically test and renew the effectiveness of emissions control equipment. It is well established that emissions performance varies among otherwise identical vehicles, and that on average such performance tends to deteriorate as vehicles age. Emissions variability occurs for many reasons related to the physical condition of the vehicle,[37] including: (1) vehicles may come off the assembly line with flawed emissions equipment;[38] (2) the canister controlling evaporative emissions may behave unpredictably if a vehicle sits unused for too long a period; (3) catalytic con-

verter performance can be severely degraded by even a single exposure to leaded or otherwise impure fuel; (4) performance deteriorates as engine parts age and wear; (5) errors occur during maintenance and repair; and (6) illegal modifications are made in order to alter engine characteristics (especially to improve acceleration). While more of these defects are likely to accumulate in older vehicles, it is quite possible for debilitating emissions control defects to be present in a vehicle of any age.

The purpose of an inspection and maintenance program is to identify and correct as many of these defects as possible. There are numerous issues involved in the design of such a program, including: (1) institutional setting (e.g., publicly versus privately operated); (2) measurement technology (e.g., idling tests, versus dynamometer-based tests, versus in-use tests);[39] (3) required performance levels for vehicles of different ages; (4) testing frequency; (5) allowable public and private costs; and (6) enforcement method. By varying the design of an I&M program along these six dimensions, it is possible to achieve widely different levels of effectiveness. For example, California has an I&M program to conduct idling tests annually in private garages, with certification required for vehicle re-registration but with a modest cap on repair costs (to protect low income households). One goal of this program is a 25-percent reduction in fleet hydrocarbon emissions, below the level expected from a fleet without I&M. However, a recent review indicated actual reductions of only 10 to 15 percent, which led the State to broaden the scope of the program and to raise the cap on repair costs. Additional changes will be considered if the next review shows a continued shortfall from the 25-percent goal.

While there is little doubt that significant improvement in fleet performance is possible, there also is much disagreement over the appropriate design of an I&M program (on both technical and political grounds). Through a combination of test center corruption, exemptions for very old vehicles, repair cost caps, and unregistered vehicles,[40] a substantial (possibly the dirtiest) portion of the fleet is not reached by conventional I&M. It may require a markedly different approach to reach this segment of the fleet and achieve the full potential of I&M. In particular, random in-use testing (as demonstrated by Stedman) with repair subsidies for low income households is seen by many as an attractive alternative to the conventional approach.

- **Oxygenated fuels.** The addition of oxygenated compounds directly to gasoline can improve the efficiency of combustion and lower the output of CO and ROG. The EPA and CARB studies indicate that a 2- to 2.5-percent increase in oxygen content would produce at least a 10 percent reduction in CO,[41] at an added cost of 10 to 15 cents per gallon.[42] Recognizing this, the 1990 Amendments require oil companies to sell oxygenated fuels in moderate and severe CO nonattainment areas starting in the fall of 1992.[43]

  Oxygenated fuels might offer several improvements over current emissions factors. For example: (1) since the fuel changes mandated by the 1990 Amendments do not yet appear in the Mobile or EMFAC series of emissions models,[44] it is legitimate to take additional CO running emissions credits of perhaps 10 percent; (2) if a State is willing to require oxygenated fuel sales year-round, similar running emissions credits could be extended to ROG calculations;[45] and (3) further CO and ROG reductions may be possible through additional fuel reformulation.

- **Pre-heated catalytic converters.** Cold starts have become a much larger segment of the mobile source emissions burden because the catalytic converter cannot function effectively until it has been heated by exhaust gases. This has led to proposals for equipping the catalytic converter with a heating element and an auxiliary power supply (presumably a second battery) that would bring the converter up to operating temperature in a brief period after the ignition is turned on.[46] Several designs have been suggested, and it appears technically feasible to require pre-heated catalysts on all new vehicles by the end of the decade. A clear

estimate of the emissions improvement and the added capital and operating cost per vehicle must await further R&D, however.[47]

- **Electric vehicles.** California has a requirement for the availability of a modest number of "zero-emission vehicles" (ZEVs) by the end of the decade, with substantial market penetration by 2010.[48] General Motors and others, while showing caution about the technology timetable, have indicated that they expect to be players in this market. Battery technology remains a serious constraint on the production of an electric vehicle that would replace existing vehicles in function, but there is reason to think that households could supplement their vehicle holdings with electric models based only on current battery technology and used largely for local trips.[49]

Together with a host of lesser improvements, the first three of these measures appear able to produce large additional reductions in tailpipe emissions of CO and ROG – perhaps as much as 35 percent. Electric vehicles are less certain, but may be able to contribute some reductions in California and possibly elsewhere by the turn of the century.

As simple as they appear, the technology options are not without potential impediments to implementation. At least three concerns have been raised:

- **Controlling oxides of nitrogen ($NO_x$).** Unlike CO and ROG, $NO_x$ is a product of efficient combustion and so can increase as CO and ROG decrease. $NO_x$ also is a key ingredient of smog. A recent National Academy of Sciences report argued that the balance of ROG and $NO_x$ in the emissions stream may be nearly as important as overall levels, and that failure to attain Federal ambient air quality standards in some regions may result from inadequate controls on $NO_x$. Put plainly, some regions may need a $NO_x$ strategy along with a ROG strategy to solve their ozone problems, yet most of the available tailpipe options either do not affect $NO_x$ or actually increase $NO_x$ emissions. Under a $NO_x$ strategy, outright reductions in travel (in conventional vehicles) would become more important, relative to tailpipe solutions than they have been in the past.
- **Cost.** Auto manufacturers and legislators have expressed much concern over the effect of emission controls on the prices of new cars. Because auto price elasticity is substantial, even a modest increase in price (say, $300) can reduce sales by a couple of percent. Since the combined average cost of scheduled improvement plus pre-heated catalytic converters likely would be at least this high, it is difficult to deny that proposed tailpipe controls would be felt by the auto industry. In addition, application of new technologies to all vehicles would over control those sold in unpolluted areas, an issue for many States with little or no pollution problem.
- **Political acceptability.** In debates over the 1991 Amendments, there were a number of references to "sharing the burden" among tailpipe controls, stationary source controls, and travel reductions. Some argued that because travel reductions had not followed from earlier Amendments, it was now time to be more explicit about the role expected from transportation controls and the transportation planning sector. If anything, the impulse to protect American industry has grown since the 1991 Amendments were passed, and the political pressure to deflect the burden from the auto and petroleum industries may have grown as well.

**It appears that further emission reductions resulting from fleet turnover, cleaner fuels, "high tech" inspection and maintenance, and new emission control technologies (etc.), will be far greater than those achievable from TCMs,[50] however, it is an open question whether there is either technical justification or sufficient political consensus to impose another round of technology changes on the auto and fuels industries and the traveling public. Whether this reluctance will continue as the costs and effectiveness of alternatives assume clearer form remains to be seen. As with TCMs, there is a need for better information about the costs and benefits of technology improvements. Through explicit language about TCMs, the 1990 Amendments created an expectation that**

**vehicle technology would not have to carry the entire load. If that apparent intent of the legislation cannot be fulfilled, current political conditions dictate that a persuasive case be made on all sides.**

## Land Use

Two other approaches to mobile source emissions reduction are often suggested in air quality debates: fostering land use patterns that minimize emissions, and pricing transportation to achieve more efficient use of the infrastructure.[51]

Land use approaches have been part of the dialogue about emissions control since the 1970 Federal Amendments. They often are dismissed as impractical because of the fragmented institutional setting of most land use decisions in the U.S., and because of the long implementation horizon. Yet recent debates about air quality and other aspects of the urban environment have made much of the linkage between low density land uses and high rates of per capita travel. Data from large cities worldwide show a consistent, strongly negative correlation between residential density and measures of metropolitan average per capita vehicular travel consumption (VMT, trips, fuel consumption, emissions). Using readily-available survey and demographic data, the same relationships can be replicated for any metropolitan area. Some have suggested that income may be the driving force behind these relationships, but evidence indicates that income accounts for only a portion of travel variability with land use.

With wider dissemination of data about land use and travel consumption, interest in land use controls for emissions reduction has grown. Environmental groups, in particular, infer from the data that infrastructure investments will worsen per capita emissions when they support development at the urban fringe (where the lowest density, highest travel consumption districts are found) and will improve per capita emissions when they create arrangements of land uses that require less vehicular travel (either by placing compatible uses in close proximity or by linking activity centers and residential areas through mass transit).

Because statutory authority differs in each metropolitan area, available land use control mechanisms also vary. In California, the State Act allows air districts to establish indirect source review (ISR) programs for oversight of land use and facility location decisions.[52] It has been suggested that ISR could be used to elicit design features beneficial to air quality, such as mixed uses at employment centers, high-quality pedestrian treatments, bicycle facilities, and direct links to transit lines. Minnesota's ISR program is used in much this fashion.

Alternatively, locally-originating policies and programs could have the same effect. Such cities as San Diego, Portland, OR, Seattle, and Boston have many of these policies already in place. In a few cases state planning acts or regional planning laws may provide yet another way for land use and transportation to be more closely coordinated, though to date few areas have taken strong stances in response to air quality concerns.

Because of the heightened interest in transportation – land use connections, the current cycle of air quality planning has a chance of producing some kind of land use review among the proposed emissions control measures. But at the present state of knowledge, given the requirements for demonstrating feasibility, effectiveness, and implementability under the State Implementation Planning (SIP) process, EPA may find it difficult to assign emissions reduction credit to land use measures. Uncertainty exists in many aspects, including:

- **Which land use patterns correlate with reduced per capita vehicular travel consumption?** The process of averaging masks much of the informative variation present in land use data, especially the joint effects of household and neighborhood characteristics on travel consumption. By the same token, case study data (e.g., from new pedestrian-oriented developments) have been neither extensive enough nor well enough controlled to show whether the associated travel patterns are more efficient. Overall, the evidence is suggestive rather than definitive, and there is a need for objective analyses and evaluations in sufficient quantity and range to understand key relationships.
- **Which relationships are causal and what is the direction of causality?** Statistical correlations do not imply causal relationships. For example, we do not know whether less dense residential development (and associated decreases in retail/service

density) "causes" people to travel more by vehicle, or whether people with a proclivity toward extensive auto mobility select themselves into low density areas. In the second case, a gradual increase in density would be likely to yield much less of a drop in per capita travel than in the first case (assuming all those preferring easy auto mobility did not move instantly). Time-series data are needed for studying the relationship between land use and travel. A better form of time series data would be longitudinal panel studies that show changes in personal and household behavior as land use characteristics change.

- **What is the magnitude of improvement to be expected from various measures or combinations of measures, and over what time frame will the improvements materialize?** We are just beginning to understand the extent of variation in travel behavior with different patterns of development. It will take a number of years of careful research to gather enough reliable data to yield a systematic predictive capability (including an understanding of market size for preferred land use patterns). Until this occurs, it will be relatively easy to estimate the emissions effects of specific site designs with which we have prior experience, but difficult to draw conclusions about the feasibility or effectiveness of large-scale implementation.

In light of the above comments, it seems unlikely that a deep enough understanding of land use/travel interactions will be developed in time for the next round of SIP revisions, at least not at the level of generalizable regional impacts. On the other hand, the option of denying any credit for land use measures is unappealing if only because it would remove the incentive to initiate programs with a large potential long-term payoff. It might be possible for EPA and DOT or the NAS to convene a group of experts to review available case study data and form an early recommendation on a reasonable range of claimed emissions reductions. Subsequent studies would be likely to supersede such judgment-based recommendations, but such an approach would encourage regions to pursue land use options that otherwise might be lost for lack of timely initiation.

**To summarize, it is difficult to assess the potential of land use measures in mobile source emissions reduction. Intuition—and data that appear to validate intuition—have led planners and environmentalists to argue that sparse, poorly integrated development is one root of the congestion and air quality problems that afflict urban areas. Whether or not this assertion is valid, and to what degree, many—perhaps most—participants in the pending transportation/air quality policy-making process are inclined to accept its basic premise and may expect to include land-use measures in TCM plans. Some Federal guidance to help clarify the options would smooth and speed the policy making process.**

# Pricing

Perhaps the most surprising aspect of the recent round of transportation-air quality planning in California has been the role played by congestion pricing and other transportation user fees. Economists have long argued that many functional problems in the transportation system stem from inaccurate price signals. But a presumption of political infeasibility has kept pricing from serious policy consideration. Faced with mounting congestion and the stringent goals of the California Act, planners in Los Angeles and the Bay Area have found it necessary to invoke fees, tolls, and the like simply to satisfy mandated planning goals in a technically feasible way. While most of these proposals have yet to run the political gauntlet—local and State—(and may not soon be raised in a legislative forum), they already have received a more serious public airing and garnered more media support than at any time in the past.

As proposed in the Bay Area, the pricing approach rests on four user fee concepts: congestion charges, smog charges, parking fees, and gasoline taxes. These fall into two conceptual categories: charges that are firmly rooted in the economics of transportation (i.e., "market-based") and fees that exploit a convenient institutional framework for revenue collection (i.e., "fee-based").

Market-based policies are ones that can be can be justified by the internal or external costs of transportation. The Bay Area Economic Forum, a business coalition based in San Francisco, introduced "market-based" to the terminology of the Bay Area clean air debate with a 1989 proposal for pricing as a substitute for

"command and control" emissions reduction measures proposed in Los Angeles. Two of their suggestions were adopted by Bay Area air quality planners:

- **Emissions charges** – This would be an annual charge based on an estimate of each vehicle's emissions in the previous year, set to recover the "true" marginal cost of auto emissions. It might be levied at the time of registration, based on a reading of the vehicle odometer and a measurement of the tailpipe emissions. Coupled with information about the characteristic performance of each make and model, these data would be used to develop an estimate of annual emissions. Health and damage costs per unit of emissions then would be used to set the annual fee. Vehicle fleet and emissions cost data suggest that fees for the existing fleet might vary between $5 and $1,000, with the average at $125 (about $.01 per mile).

- **Congestion charges** – These would involve a large number of localized tolls in congested corridors throughout the region, employing Automatic Vehicle Identification (AVI) technology. Under the Economic Forum proposal, revenues would be reinvested in new infrastructure (transit or highway) until the marginal cost of a capacity increment matched the congestion charge. Bay Area planners did not adopt such a rigorous approach, assuming that some portion of the revenues might have to be bartered for political support. They substituted an arbitrary highway level-of-service criterion (LOS D/E) in place of the Forum's marginal cost criterion.

Fee-based policies are ones arising from a convenient administrative framework for revenue collection. In the Bay Area, analyses made it clear that market-based measures alone could not achieve the state emissions reduction mandate. Planners fell back on two other pricing strategies with known administrative requirements:

- **Employee parking fees** – The intent of this proposal was to achieve a minimum employee parking charge of $3 per day, payable monthly, with the bulk of the revenues recycled as added transit and ridesharing incentives. The $3 level was loosely selected to represent the "opportunity cost" of land dedicated to parking in a typical suburban location.

- **Gasoline taxes** – A simple increase in the pump price of gasoline by $2 per gallon was proposed. The $2 level was selected to roughly match the average cost of a State-administered automobile insurance program.[53]

Many other pricing approaches would be possible, but a preliminary screening suggested these two would offer the strongest basis for analysis and public discussion.

The Bay Area pricing proposal is in the long-run phase of the Region's adopted State TCM Plan. Together with a program of conventional TCMs, these market-based measures would enable the Bay Area to achieve the emissions reduction goals of the State Clean Air Act.[54]

Given the politics of urban transportation policy, the fact that a pricing proposal of this type could survive so long on the public agenda is remarkable. A number of factors appear to have played a role in the altered status of pricing:

- **California's stringent ozone standards** – The California one hour ozone standard currently is .09 ppm with zero exceedences (versus the Federal standard of .12 ppm with not more than three exceedences in three years). It is virtually impossible to meet the .09 standard by the legislated deadlines without some degree of VMT and trip reduction; even remote areas record ozone levels in the .08 ppm range. Moving standards to lower levels would require significant lifestyle changes, and potentially have severe economic impacts nationwide. The California standard is based on a reading of the epidemiological literature, and there does not appear to be sentiment at this time for relaxing it. Thus, all of California's large cities (and a number of the smaller ones as well) must pursue TCMs.

- **Specific requirements for transportation/air quality planning under the California Clean Air Act** – The Bay Area was required to plan for attainment of the state standard without additional automotive emission controls.[56] Based on Air District estimates, this implied a five-percent per year reduction in mobile source reactive organic (ROG) emissions beyond what would be achieved through adopted California tailpipe controls. It was quickly apparent that stringent TCMs would be needed to achieve this level of reduction.

- **Experience with "command and control" transportation measures** – Trip reduction programs based on voluntary, advertising-induced mode shifts by commuters have had modest effect. Regulation 15 (the South Coast Air Quality District in Los Angeles mandatory employer trip reduction measure) has been most effective when employers instituted parking fees.

- **Plan and program conformity under the Federal Clean Air Act Amendments** – Conformity under the final EPA guidelines will be based on adherence to a mobile source emissions budget that includes specific reductions to be accomplished according to a specified schedule. Without a showing of attainment on schedule, and without a showing of progress at required intervals, it could be difficult to obtain the necessary plan and program approvals. A set of contingent pricing measures would make it possible to adjust the emissions reduction strategy year by year to keep it on the expected progression of reductions.

- **The ubiquity of congestion** – Many policy makers and civic leaders appear to have concluded that neither funding nor public support is present in sufficient quantity to "build our way out of congestion." This has led the business community (among others) to search for other means of reducing congestion, including land use changes and pricing.

- **Toll roads, public/private partnerships** – The interest in toll road development and privately funded and operated highway improvement offers a convenient opportunity to introduce pricing, somewhat outside the conventional institutional framework.

- **Advances in technology** – Automatic vehicle identification (AVI) has become sufficiently reliable to support large-scale monitoring of the vehicle fleet. Given an identifier on each vehicle, all congested points on the freeway and arterial system could be monitored and priced to reduce trips and/or VMT.

- **Fairness of the existing funding stream** – The gasoline tax and other fees proportional to use provide less than half of all transportation revenues in California, while local sales taxes now account for over 25 percent.[57] The view is increasing heard that explicit pricing might be fairer than the current system, especially if funds were directed at the transportation and/or housing needs of the low income community.

- **Evolution of the anti-tax movement** – Tax increases with vague targets remain a political anathema. However, the willingness of voters to impose new taxes for specific, desired projects has become apparent. It is possible that a large restructuring and expansion of the transportation funding stream would be feasible if accompanied by clear, geographically specific, iron-clad expenditure commitments.

- **The Congestion Pricing Pilot Program** – The 1991 ISTEA supports a continuing interest in "testing" pricing solutions and provides Federal support and "legitimatization" to the concept of time, place, and occupancy-specific user fees.

While these factors have kept pricing on California's planning agenda, there is no explicit commitment to implementation other than a statement that implementation will occur beginning in 1994 if the State Legislature provides appropriate statutory authority. In essence, the market-based plan challenges the Legislature to support its Air Act either by forcing fundamental change in vehicle technology or by helping the Region to implement a far reaching transportation pricing proposal (or some combination of the two).

One question for national policy is whether California's unique circumstances alone account for its serious consideration of market-based measures. Looking at the factors cited above, only the statutory framework is truly unique to California (i.e., the more stringent ozone standard and the California Clean Air Act specifics). Most of the other factors are present throughout the country. Furthermore, while the Federal standard is less stringent than California's, other provisions of the Federal Act require rates of improvement that sometimes may not be attainable with only existing technologies and conventional TCMs. Thus, there is reason to think that at least some places outside California will look to pricing as an option.

If market-based measures do receive consideration in Federal TCM planning, a number of supportive actions may be necessary. In particular, suitable analysis tools will be needed; currently a surprising number of MPOs lack data on such basic factors in travel choices as household incomes and travel costs, and hence cannot adequately model any pricing policies. Even when good analyses can be done, however, there may be a big gap between the promise of pricing measures and their feasibility from a legal and political standpoint. Restrictions on tolls on Federal-aid highways have been substantially reduced by ISTEA (except for the Interstate System). Nonetheless, concerns about taking away a public benefit ("free" roads), equity issues, and the like may block implementation.

**Market-based measures diverge so completely from existing transportation policy that both planning and implementation are bound to be problematic. But the potential benefits also are large, for air quality as well as for other transportation problems such as congestion. Momentum must develop at the grass roots, but Federal and State governments can help by making sure that localities are as free as possible to experiment with pricing measures, and by considering implementing legislation when they are asked to do so.**

# Summary

Mobile source emission reductions pose serious challenges for both transportation and air quality planners. Measures which are readily available and enjoy public acceptance are likely to have only modest impacts; measures whose impacts could be substantial, such as land use changes and revised transportation pricing policies, are more likely to face legal and institutional barriers as well as public opposition. Automotive technology probably remains the most publicly acceptable way to achieve large emissions reductions, but the costs could be substantial. A lack of data on the benefits of emission reductions and the full benefits and costs of alternative transportation policies hampers progress.

# Integration of Transportation and Air Quality Planning

Another important aspect of the 1990 Clean Air Act is a provision requiring DOT plans and programs to "conform" with applicable SIPs. Without doubt, Metropolitan Planning Organizations (MPOs) and State Transportation Departments are as concerned about the conformity provisions as about any other element of the 1990 Amendments. The basis for this concern lies both in the process outlined by the Amendments and in the outcome of a recent court case brought by environmental groups against the Metropolitan Transportation Commission (MTC), the San Francisco Bay Area's MPO.

The role of transportation in the SIP is the same as it was under earlier Amendments. Each SIP is required to show attainment on a schedule dictated by the Act. Transportation influences the attainment demonstration in two ways: 1) based on projected emissions factors, demographic and travel forecasts, and assumed future highway and transit networks, a mobile source emissions inventory is estimated for the attainment year and at intervals prior to the attainment year; 2) transportation controls are included as necessary to show reasonable progress and attainment.

The conformity provisions were intended as a way of guaranteeing commitments assumed in the SIP attainment demonstration. Each Regional Transportation Plan (RTP),

Transportation Improvement Program (TIP), and other federally-required plan or program must be certified as: 1) implementing all TCMs within its purview; and 2) not adding to mobile source emissions in a way that would alter progress toward attainment or nullify the attainment demonstration. As a practical matter, satisfying the second certification criterion will require an analysis of each plan or program sufficient to show that emissions with the plan or program in place will be at or below the levels assumed in the attainment demonstration.

The San Francisco Bay Area conformity lawsuit illustrates the challenge presented by this requirement. The MTC initially undertook a conventional "state of the practice" analysis to determine the emissions impacts of previous plans. The environmental groups argued that conventional regional transportation models overstate the emissions benefits of highway investments by fully reflecting speed improvements but showing little or none of the "induced" travel resulting from faster times since MTC rarely equilibrates its models beyond mode split. This is important because trip distribution (and other models in the MTC system) also depend on travel times. The environmental groups argued that MTC's conformity assessments would not be valid unless feedback and equilibration addressed all of the potential effects of travel time.

There followed a debate about theory versus practice in travel demand analysis. In reference to the literature of travel demand, all sides agreed that a wide array of travel time effects (on demand) could not be categorically ruled out. These range from the route choice, mode choice, and destination choice effects implied above, to trip generation, auto ownership, and various location choices by households and employers.

MTC suggested that good conventional practice would require some kind of feedback mechanism through trip distribution but no farther. The environmental groups replied that such a procedure would ignore the most basic sources of "induced" travel - namely, the possibility of location shifts and added growth stimulated by new infrastructure (either highway or transit). They suggested that a failure to account for such effects would constitute an unacceptable level of uncertainty in air quality assessments. In a situation of non-attainment, the appropriate response to such uncertainty (it was argued) would be to defer highway projects until the region was firmly in attainment.

MTC proposed an analysis procedure with travel time feedback to trip generation, auto ownership, residential location, and employment location. As it happened, MTC's travel models did incorporate the feedback to trip generation and auto ownership in a credible way (though the full set of linkages had been exercised only in selected model runs). Furthermore, land use models routinely employed by the Association of Bay Area Governments (ABAG) relied upon travel time inputs to determine basic land allocations.

MTC thus could propose a plausible analysis procedure addressing most of the travel responses highlighted in the lawsuit. Three potentially significant phenomena were still omitted: time-of-travel, trip chaining, and regional population and economic growth. MTC proposed to treat time-of-travel in an ad hoc way, making adjustments based on empirically-observed variations in peaking factors (i.e., corridor-by-corridor as a function of congestion). They argued that models of trip chaining in the literature were not yet sufficiently advanced for inclusion in a traditional travel model format, and that existing non-home-based models would account for at least some of the travel time effect on trip chaining. Finally, they argued that practical models of regional growth as a function of infrastructure investment were not available for inclusion in the conformity analysis procedure, and in any event the growth stimulus would not be important enough to matter.

The environmental groups countered that regional economic stimulation was a central issue in conformity, so important that its omission would compromise the integrity of the entire process. They pointed out that a small acceleration in population and job growth (and attendant vehicle trips) could swamp any expected emissions improvement from faster, smoother traffic flow (as determined for a specific horizon, such as the attainment year). And they noted that many of the highway and transit planning documents in the region stressed support of continued economic growth as a principal justification for projects. Economic stimulus has been an evident rationale for infrastructure investment, and studies often attribute specific areawide economic benefits to major projects. This seeming con-

tradiction in the position of the transportation planning community was stressed in declarations prepared for the case.

The judge considered these arguments with substantial assistance from his Special Master. He accepted MTC's proposed conformity analysis procedure, including the argument that MTC at this time could not be reasonably expected to model the effect of infrastructure on regional growth. However, he explicitly qualified his finding and noted that nothing in his reading of the 1990 Amendments would preclude EPA from requiring such an analysis in future guidance.

In discussions and seminars since the judge's ruling, some observers have been struck by the very small differences found in emission and travel effects between the Build and the No Build scenarios - even though MTC's TIP is probably more ambitious than most (16% population increase, 2% increase in lane miles, 40% increase in HOV, and significant increases in transit.) This may mean that recent major capital investment decisions (major highway expansions, major rail transit expansions) will have relatively small importance from an air quality perspective.

Others inside the transportation planning community also have been concerned about the issue of regional growth. For MTC's execution of the approved analysis procedure has shown that the emissions benefits of the TIP may not be large (on the order of 1 percent ROG improvement regionwide, with larger improvements - and some ROG increases - corridor-by-corridor). It would not take much population growth – especially on the urban fringe – to outweigh this level of emissions reduction. Hence, it seems likely that growth stimulus will continue to be an issue in conformity assessment.

The effect of the Bay Area case on implementation of the 1990 Amendments is not clear. Nominally, the case turns on an MPO commitment to review highways, already included in an approved SIP, a requirement not found elsewhere in the country. However, the case explicitly addressed the issue of what kind of analyses would be needed to assess the regional impacts of highway capacity investments, and it entered into the public record extensive expert testimony and judicial rulings to the effect that analyses far more extensive and complex than those usually done by MPOs are needed to adequately comport with accepted theory.

EPA and FHWA have found that current analysis capabilities in all but a dozen or so of the largest regions are unable to support MTC's type of recursive methodology. There is a reluctance to require analysis procedures so far ahead of the state of practice and which have not been thoroughly tested. But there is a lingering suspicion that more extensive linkage and feedback loops may be needed. Several MPO Administrators have posed the question as follows: "If my organization is sued over a TIP approval or favorable environmental review, is there a chance that some other judge would be willing to invoke the analysis principles established via the MTC case?" Since the answer to this question is obviously affirmative, the natural extension is: "Wouldn't it be prudent to develop MTC-style analysis procedures now in order to avoid a potentially more expensive and more time-consuming legal entanglement later?" The answer to this question is not quite so obvious; the cost of data collection and model development now may or may not be less than the "expected" present cost of possible future delays and legal battles. Given the political and institutional costs of the kind of litigation MTC has experienced, there will be pressure from the MPOs (and probably from their local constituencies) to put more resources into model development. It also would not be surprising to see sentiment for standardized models, at least in terms of key variables and structural properties. Such standardization would lend credibility to each MPO's analyses.

Nor are these issues confined to the larger metropolitan areas. While more detailed and demanding requirements apply to the larger urban areas, the size of the metropolitan area is not necessarily a good indicator of the severity of the pollution problem(s) or of the complexity of the issues faced in air quality planning. Thus, small and medium-sized metropolitan areas might need to develop better planning and analysis capabilities than otherwise would be expected, in order to respond to air quality planning needs.

Some transportation professionals may be troubled by the extent of reliance on models implied by this discussion. Experienced urban

transportation modelers have said that accurate, convincing analyses of all the phenomena noted here are well beyond the state-of-the-art (without denying their theoretical importance, however).

In one view, existing models were conceived to support relatively narrow sizing and location decisions, given assumptions about basic facility needs. This is certainly the dominant use to which urban travel demand models have been put. However, this view misses a larger issue: The world outside the transportation planning community shows increasing interest in decision making about infrastructure. In forums such as the Sierra Club/CBE lawsuit, as well as in less confrontational circumstances, interests concerned about environmental impacts are asking how transportation planners know what infrastructure should be built.

Rules of administrative procedure, requirements for environmental impact assessment, and the norms of rational decision making all imply a strong analytical foundation for transportation policy. In effect, the current institutional structure rests upon claims of solid analytical support for projects receiving Federal funds.

In truth, the aggregate of projects in a TIP is not likely to be a uniquely "best" way to spend available funds (in the rational, comprehensive decision-making sense). Viewing transportation decision-making in the larger context of urban governance, one must recognize the pressure on jurisdictions to compete for scarce public works resources, the momentum of plans laid out decades ago (because so many land use decisions anticipate infrastructure), and the natural tendency of elected officials to direct resources at problems that are immediate and apparent (rather than necessarily attacking the root causes). From this perspective the TIP may not be justified on technical grounds alone, but it does constitute an elaborately crafted set of agreements that the MPO endangers at its own peril.

This line of thought suggests a fundamental mismatch between the assumptions behind the Clean Air Act conformity assessment and the reality of urban transportation decision-making, more so in light of the 1990 Amendments' increased reliance on a rational, analytical paradigm. Political and legal conflict may well result from this mismatch, and could be quite intense as expectations clash during the next decade. Nevertheless, there is a learning process taking place. For example, the Bay Area conformity analysis did yield a positive conformity finding on the TIP, albeit with seemingly small benefits for so large an investment (and revealing several problematic corridors). There is some evidence that these results are filtering to sub-regional decision makers and ultimately will influence the kinds of projects brought into the TIP.

It appears likely that MPOs are going to have to conduct more far-reaching analyses of major projects, and that analytical procedures will be scrutinized in unprecedented detail. It would not be at all surprising to find groups with environmental concerns developing their own fully functional network models in some areas, as occurred in some controversies over electric utilities power plant development proposals. The transportation institution monopoly on technical analysis may not continue and the public will not be immune to competing views.

As this landscape becomes increasingly clear to MPOs, they will want to improve analytical capabilities and will need the resources to do so. The MPOs will seek a more theoretically sound, universally accepted knowledge base for urban travel demand analysis. In the absence of DOT investment in the development of new procedures, MPOs would be required to go out and get this on their own, through NARC or less formal cooperation, with funds solicited from a variety of sources. Yet, with so much Federal investment at issue, the DOT stake in good analysis would seem obvious. The reassertion of technical leadership on the part of DOT implied by ISTEA, together with the new "partnership" style promised through ISTEA implementation, suggests the following quartet of initiatives: a DOT in-house research program; an initiative carried out via committee established by the NAS or the Transportation Research Board (TRB); a model guidance and model development project sponsored by NARC; a set of assessments of model predictions versus performance carried out by MPOs, States, or perhaps university researchers.

The role of modeling is not the only significant issue brought out by the conformity provisions of the Clean Air Act. Questions have been raised about a host of technical and procedural matters, such as:

- Whether non-federal projects are subject to conformity review
- Whether conformity requirements apply in attainment areas
- What to do if there is a change in background conditions and assumptions
- How detailed the assessment of Regional Transportation Plans must be
- How TIP amendments should be handled
- Whether transit projects should be subjected to a similar level of analysis as highway projects
- How to handle localized CO hot spot analyses.

The language of the 1990 Amendments is much more specific about conformity than ever before, but remains amorphous enough to allow great latitude for interpretation. Resolution of the above issues will determine how effective (and how onerous) the conformity provisions can be. Many observers, particularly in the environmental community, hold great hope for conformity assessment as a means of laying bare and ultimately rationalizing the way transportation decisions are made. For this reason alone, it is certain that DOT and EPA decisions about conformity will be scrutinized closely and disputed hotly if they fail to alter the status quo.

# Conclusions

**Several basic conclusions are supported by the findings of the FHWA seminar and subsequent events in California and elsewhere:**

- Recent developments have made air quality a more important factor in transportation policy, and transportation planning and programming will have to adjust accordingly.
- Emissions controls on new vehicles and vehicle inspection and maintenance could yield additional emissions reductions, but necessary regulations might be strongly resisted by rural States and the automotive and petroleum industries.
- There is a likelihood that transportation controls will be necessary in perhaps two dozen of the most severely polluted metropolitan areas.
- In some areas, conventional transportation controls (transit improvements, ridesharing, employer-based incentives, traffic flow improvements) will not be sufficient to show attainment. For areas requiring more extensive emissions reductions, and for areas preferring not to implement the full spectrum of conventional TCMs, DOT and EPA will need to provide appropriate guidance on land use and pricing measures.
- MPOs will be under pressure to upgrade their data resources and modeling capabilities, both to provide more credible analyses of TCMs and to support conformity assessment.
- The requirement for conformity of transportation plans, programs and projects to state air quality plans is viewed by many outside the traditional transportation planning community as a critical feature of the 1990 Amendments. The guidelines implementing the conformity provisions will be hotly contested if they do not produce significant change in transportation decision-making.

# Research Needs

Based on these findings and conclusions, several research needs can be identified. They include:

- A robust cost-effectiveness framework for TCM analysis.
- A clear exposition of vehicle technology options and the extent to which they could be implemented effectively, as an option for fleet vehicles, or perhaps more broadly in the most polluted cities.
- Better understanding of land-use - transportation - emissions relationships, ranging from site design impacts to longer term, larger-scale impacts on location of jobs and housing, distribution of shopping and other non-work trips, and number of trips made by vehicle.

- Realistic short-term and long-term land use options and their benefits and costs.
- Potential emissions effects of pricing measures.
- Methods for mitigating adverse distributional consequences of pricing.
- Improvements to the state-of-the-art in urban transportation modeling:
  - network representation
  - time of travel (peaking)
  - trip chaining
  - auto ownership/trip generation (effects of infrastructure characteristics)
  - residential and employment location
  - regional growth.

A central issue is whether current institutions are capable of supporting activities which may challenge established beliefs and ways of doing things. Research sponsorship is one matter; put in broader terms, the issue may well be whether current institutions permit a search for improved mobility along many dimensions. Provisions of the new Intermodal Surface Transportation Efficiency Act challenge urban areas to begin such a search. Some institutional arrangements and assignments of responsibility may be better suited to the task than others, and this too would be a valuable topic for investigation.

A decision-making paradigm that is more informed than simple "fair-share" distribution of public capital, yet is less dependent on deterministic "knowledge of the future" than current rational planning approaches, would be another area for attention. Modeling assumes an ability to forecast the future that may not be realistic or necessary. Scenario testing approaches suggest an alternate use of modeling as a means of exploring policy implications; it gives explicit recognition to the "if-then" character of the models, clarifies the assumptions on which they rest, and provides opportunities for the introduction of qualitative information into forecasts. Control theory suggests another direction: data from monitoring could be used to make adjustments in operation and to identify needed improvements, perhaps selecting from a set of responses previously agreed upon in contingency plans. A broader look at such options might uncover new directions for transportation planning, policy, and institutions.

# Resources

Citizens for a Better Environment et al. v. Peter B. Wilson et al., Civil No. C-89-2044-TEH, and Sierra Club vs. Metropolitan Transportation Commission, et al., Civil No. C-89-2064-TEH (consolidated).

Harvey, G. [1989] "Residential Location and the Journey to Work in Suburban Households". Department of Civil Engineering, University of California, Berkeley.

Harvey, G., and E. Deakin [1991] "Toward Improved Regional Transportation Modeling Practice", prepared for the National Association of Regional Councils, Washington, DC. December.

Hawthorn, G., and E. Deakin. [1991] "Conference Summary: Best Practices for Transportation Modeling for Air Quality Planning", prepared for the National Association of Regional Councils, Washington, DC. December.

Newman, P.W.G., and J.R. Kenworthy. [1989] **Cities and Automobile Dependence: A Sourcebook**. Gower, Brookfield, VT.

Stedman, D. [1991] Presentation at "The Transportation-Land Use-Air Quality Connection: A Policy and Research Symposium". Public Policy Program, UCLA Extension, Lake Arrowhead, CA. November 6-8. (Reported in Taylor, B. and E. Shirazi, "Symposium Summary", UCLA, January 1992.)

# Part B — Summary of Presentations

## Introduction to the Transportation and Air Quality Problem: Martin Wachs, University of California at Los Angeles

Prof. Wachs pointed out that the relationships between transportation and air quality are extremely complex, and our understanding of the relationships is inadequate. Nevertheless, he argued, we need to act despite each uncertainty. Mistakes will undoubtedly be made, and we need to establish mechanisms for learning from experience.

Prof. Wachs pointed out that air pollution health problems are real, and that over 100 million Americans live in areas that don't meet health standards; nevertheless, most people live in areas that do meet standards (60%-40%). Flexibility to address differences in areas' problems and opportunities would make sense: some of these differences are the pollutants at issue, the severity of the pollution problem, the options available, the contribution from transportation versus stationary sources, and whether the area is growing. But the practice has been to apply national uniform standards, and this raises issues about imposing costs on all because of the problems of some.

Because cars are a major source of pollution, strategies to clean up cars must be considered. With cars, technological improvements have produced major emissions reductions, but further reductions will come at increasing costs per unit of benefit. Cold starts will be an increasingly important issue (but work on pre-warmed catalysts will help reduce this problem.) Old cars and poorly tuned cars are being recognized as a major pollution source and addressing this problem may help reduce emissions problems. Alternative fuels are a possibility, but costs are high and their transitional character raises doubts about their practicality. Electric vehicles may be a long-term solution, but they currently pose performance shortcomings and market risks. Fleet vehicle strategies are a potential high-payoff area, but there is a lack of institutional framework for dealing with fleets.

Turning to TCMs, Professor Wachs pointed out that most measures can provide congestion relief as well as air quality improvements; but results are modest. He noted the difficulties in competing with subsidies for the auto via equally large subsidies for transit, and pointed out that auto taxes related to emissions are an option (but one that faces severe difficulties garnering support.) Similarly, elimination of parking subsidies and parking-related tax reforms would be highly effective but lack popular support. Congestion pricing, which has become more technically feasible thanks to advances in vehicle identification systems, is hampered by equity concerns and lack of political support.

Professor Wachs concluded by noting that while land use and urban form are long-term options, they are ultimately central to our ability to manage urban transportation and related concerns. We are pushing up against our state of knowledge, as well as raising fundamental issues concerning "command and control" intervention versus belief in letting the "market" work.

## Effectiveness of Transportation Control Measures in Reducing VMT, Trips and Emissions: John Suhrbier, Cambridge Systematics, Inc.

Mr. Suhrbier pointed out that, while the new CAA introduces some changes in TCM emphasis (such as trip reduction ordinances), transportation-air quality planning is now in its

third round. As a result, there is a strong body of knowledge on TCMs and their effectiveness. There also are numerous case studies of specific TCMs as well as studies of implementation experiences in a number of nonattainment areas. This work is a valuable resource base for the next round of TCM planning.

Mr. Suhrbier noted that many TCMs are voluntary, while others are mandatory. EPA must have enforceable SIPs and so tends to favor mandatory (enforceable) TCMs. Difficulties in implementation often stem from financing problems, from a lack of clear institutional responsibility for a measure, and/or from a lack of political support. TCM implementation nevertheless must be assured in order for EPA to approve a SIP. Consequently the implementation feasibility of various measures is a central concern.

Turning to TCM effectiveness, Mr. Suhrbier noted that their impacts vary widely. A distinction needs to be made between trip reduction and VMT reduction because of the cold start issue. Emissions reduction is also affected by speeds, stops and starts. Thus, TCM effectiveness depends on the what the measure itself does (reduce trips, reduce VMT, reduce stops and starts, increase speeds, etc.) and on the size of the market segment affected. Some TCMs are not very effective by either measure. Other TCMs are effective for the trips to which they apply, but they apply only to work trips, or are further confined to peak period trips to the central business district (CBD). Because this is a small fraction of overall travel, no matter how effective the measure, its overall impact will be modest.

Mr. Suhrbier noted an increasing interest in land use and growth management options, such as locating high density housing and mixed use development near transit and requiring growth to be compact. He pointed out that such policy options face serious implementation issues in many areas, and their effectiveness is not fully understood. Several studies now underway should help clarify these interrelationships.

Mr. Suhrbier concluded by noting that the analysis of transportation-air quality measures, and more generally of the impacts of transportation investments on overall growth patterns, is difficult and often strains existing models' capabilities. While quick response methods can help fill the analysis gap, model improvements are needed.

## Air Quality Strategies Not Controlled by Highway Decision Makers: Richard Joy, Sierra Research

Mr. Joy noted that congestion relief and emissions reduction are not necessarily consistent. He showed data indicating that ramp metering, which is widely used to reduce congestion on freeways, may result in uncontrolled emissions due to accelerations at the ramps, which in turn may lead to higher overall emissions. He further argued that most TCMs that have been implemented provide for voluntary changes in travel rather than imposing restrictive regulations on travelers. On the other hand, he noted that one of the reasons people in Los Angeles may be willing to consider extensive TCMs is that congestion has become so severe that drastic actions seem necessary. An alternative to such measures may ultimately be sought in additional technological advances.

Mr. Joy pointed out that major improvements have resulted from technological changes to the automobile, and that more improvements are now mandated. He argued that, while additional controls on new vehicles will be costly, controls on the many older vehicles now in use could achieve a great deal. Enhanced inspection and maintenance programs also will produce substantial benefits, especially by identifying and removing gross emitters.

New fuels could produce important emissions reductions, depending on their formulation and application, but not all fuels work in current vehicles, and some are costly and would require substantial new infrastructure if they were to be put into widespread use. Others introduce questions about emissions benefits as well. Reformulated gasoline may be an attractive option because it works with existing vehicles and distribution systems. CAFE standards encourage alternate fuels, however.

California's low emission vehicle program and associated standards are based on research that shows the feasibility of further reductions in emissions, according to Mr. Joy, but questions of cost and durability remain to

be worked out. Zero emission vehicles will require electric technology. Similarly, federal requirements for cold temperature CO emissions can be met with available technology for the first round (though probably at relatively high cost), but will take technology development for later stages of required improvements (second tier standards.)

Overall, Mr. Joy argued, technology improvements can deliver emissions reductions at relatively low cost to consumers, and they will be needed, since TCMs are not likely to achieve the kind of emissions reductions mandated.

## Issues of Highway Capacity and VMT, Trips, and Emissions: Elizabeth Deakin, Deakin, Harvey, Skabardonis, Inc. and the University of California at Berkeley

Professor Deakin noted that traffic flow improvements traditionally have been used to reduce emissions by reducing the number of stops and starts and increasing speeds. However, the benefits of traffic flow improvements are now being questioned by environmentalists, who argue that benefits may be offset because of route shifts, destination shifts, changes in travel mode, and eventually, locational shifts in response to the improved travel conditions.

Professor Deakin pointed out that many state and regional transportation agencies have carried out their analyses making the assumption that traffic levels and traffic patterns would be the same with or without the transportation investments they are proposing. However, such an assumption lacks theoretical backing. Theory says that short-term responses would include route shifts, mode shifts, time of day shifts, destination shifts, and higher trip rates; over the longer run shifts in housing location choice and employment location choice also could be expected.

One question is the magnitude of such responses, that is, the size of the long-term offset to short-term benefits resulting from improved traffic flows and speeds. Elasticities with respect to travel time provide some evidence; in the Bay Area the elasticities indicate that the offset is in the 10 to 30 percent range.

A second question concerns localized impacts of shifts in trip making, especially for CO. Bay Area corridor studies indicate such "hot spots" can be a significant issue, if new facilities concentrate traffic in areas vulnerable to CO violations.

Available modeling approaches tend not to consider these linkages, or to do so sketchily, according to Professor Deakin. Trip distribution is particularly poorly modeled; time of day of travel is not modeled much at all. The impacts of transportation improvements on trip rates, auto ownership, etc., are mostly ignored. Location shifts often are not modeled at all, and when they are modeled the approaches tend to be highly simplified (e.g., land price adjustment is not considered, though it is well understood that capitalization of benefits would partially offset shift effects.)

Professor Deakin reported a growing concern regarding the impacts of transportation investments on overall regional growth rates. This effect is not well understood, but it is hard to argue that no growth inducement occurs and still claim economic development benefits for transportation investments, she noted.

Overall, Professor Deakin said, demands for rigorous analysis of transportation – growth linkages raise questions about the state of practice versus research, about model reliability (uncertainty, error propagation, etc.); and about the degree to which forecasting is an art versus a science. she advocated research to address the transportation – growth issue and to build up modeling capabilities.

## Air Quality, the Transportation Planning Process, New Control Measures, and Improvements to Forecasting Models: George Scheuernstuhl, Denver Regional Council of Governments

Mr. Scheuernstuhl argued that relationships between transportation agencies and air

quality agencies need to be improved, and air quality agency concerns must be accommodated in transportation planning. At the same time, MPOs must deal with multiple concerns and objectives of which air quality is but one. Responding to both mobility needs and air quality needs suggests that we should focus on projects which are mutually beneficial. Some of the likely candidates are TDM; arterial improvements; congestion management; and multimodal projects such as HOV lanes.

Mr. Scheuernstuhl also noted that, given modest resources for transportation investments of all types, it was particularly important to be objective about various measures' impacts: most TCMs have modest impacts, but some projects which have been favored in the past are fairly well understood not to be particularly effective. On the other hand, he noted, even major transformations of land use and transportation have relatively modest effects, largely because most development and most transportation infrastructure is already in place and changes work at the margin. Mr. Scheuernstuhl also echoed the view that demand management and pricing would be the most effective way to go but would likely face substantial institutional, political, social, and economic barriers.

Turning to modeling issues, Mr. Scheuernstuhl noted that the conformity procedure set forth in the Clean Air Act depends on regional modelling and is likely to be costly and time-consuming. He argued that the limitations of models are substantial but since we are going to continue to rely on them, investments in better modeling are necessary.

Mr. Scheuernstuhl's list of needed improvements began with better inputs on population, land use, and transportation networks. He noted that UTPS needs to be made more efficient to run (less costly and time-consuming); at the same time it needs to be more sophisticated. For example, MPOs increasingly must deal at a fine scale of urban impact, address non-home based trips, represent bus lanes and HOV lanes, etc. The regional models should support such analyses. Mr. Scheuernstuhl argued that much effort over the last decade has been devoted to cost-cutting mechanisms rather than model improvements. In his view, however, modeling shortcuts are inadequate, error from aggregation often outweighs cost savings, and certain microcomputer approaches represent false economies because the assumptions and simplifications they embody are not defensible. While sketch planning methods developed in the '70s are helpful, there is a need to update modeling capability for TCMs. Other needs, he indicated, include better data bases for tracking VMT, better procedures for project level analysis for conformity, and more research on pricing, tolls, and suburban transit options.

## Summary and Interpretations: Greig Harvey, Deakin, Harvey, Skabardonis, Inc.

Mr. Harvey summarized the presentations and added his own views, as follows.

- TDM will need to be a major focus of transportation – air quality planning because it has both air quality and congestion benefits. However, the benefits are mostly modest and should not be exaggerated.
- Many TCMs are narrowly focused on peak period downtown work trips, and as a result they are aimed at only about five percent of total trips. Strategies which address other trip types are needed.
- Vehicle technology will continue to produce very important gains, but it comes at a cost.
- The cold start issue is critical and implies a need to reduce trips and not just VMT, though the problems may be reduced as technology improves.
- Unconventional measures such as identifying and retiring gross emitters and using tax and price incentives to induce consumers to buy and use clean cars may have great promise, but they face serious implementation difficulties.
- Parking pricing and road pricing strategies are economically rational and increasingly are advocated, but federal and state policy is not fully supportive and political opposition is likely.

- Clean fuels could produce benefits, but are problematic because of high costs and the transitional nature of their applicability.
- Land use and growth management approaches have increasing credibility in may areas; localities need the flexibility to pursue these strategies.
- Capacity improvements' regional benefits appear to be partially offset by traffic growth and travel shifts, but not completely (70%+ of the benefits remain.)
- Localized impacts such as a project's attracting or shifting traffic into violation prone areas can be problematic for CO analyses. These potential impacts need to be considered, if possible, before the project reaches the EIS stage. This suggests a change in design practice to identify where CO violations might occur, and select the location and design of facilities and mitigation measures accordingly.
- The assumption that a region's growth pattern is not affected by transportation facilities or that trip rates and O-D patterns are exogenously determined and fixed is not supportable, although in many cases the effects will be minor.
- Models need improvement so that they are able to address the many issues raised about transportation, land use, growth, and air quality. This will be costly but necessary since shortcuts do not suffice. Models need to be consistent with theory (reflect the full range of travel responses, represent income effects, etc.).
- Good data are needed for good models, and this has been ignored in many areas.
- Modeling "chicanery" and advocacy via modeling are issues. Environmentalists are increasingly sophisticated about models, and will catch insupportable assumptions or inadequate approaches.
- Better analysis capabilities must be accompanied with greater attention to monitoring and feedback; analysis should be part of a broader learning process.
- Institution-building and institutional linkages will be needed to successfully implement many TCMs. Transportation agencies will need to consider air quality improvement one of their own responsibilities and not just the responsibility of air quality agencies.
- Federal and State law should make it possible to utilize the full battery of measures, conventional or otherwise, if regional agreements to do so can be forged. Federal and State agencies should provide incentives and remove barriers in this regard.
- Planning and implementation require adequate funding.
- Research is needed on the interrelationships among transportation, land development, urban form, economic development, and the environment.

# Endnotes

1. Deakin, Harvey, Skabardonis, P.O. Box 9156, Berkeley, CA 94709 (510/841-0438).

2. Deakin, Harvey, Skabardonis, Inc. and the University of California at Berkeley.

3. The presenters were (in order of appearance): Martin Wachs, the University of California at Los Angeles; John Suhrbier, Cambridge Systematics; Richard Joy, Sierra Research; George Scheuernstuhl, Denver Regional Council of Governments; Elizabeth Deakin, DHS Inc. and the University of California at Berkeley; and Greig Harvey, DHS Inc. A full transcript of the seminar is available upon request, and a summary of major points from each presentation may be found in the Appendix.

4. The past twelve months have been a period of intense debate over transportation/air quality issues, and the dimensions of some problems have become clearer since the April FHWA meeting.

5. Preparation of this paper was supported in part with funding from the Federal Highway Administration. However, the views expressed are those of the authors, who also remain solely responsible for any errors or omissions.

6. Debates as the 1990 Amendments and ISTEA were crafted stressed the historic role of stationary source and automotive technology improvements in achieving air quality goals, and suggested that a more explicit focus should be placed on measures to reduce travel along with (or even in place of) additional technology improvements. Both Acts were heavily influenced by these debates.

7. The Region's 1982 SIP submittal included a non-attainment plan for the post- 1987 period. When the Bay Area failed to attain the ozone standard in 1987, no action was taken to implement the region's contingency plan, except for those provisions underway as part of ongoing transportation programs. In one unimplemented provision, the Metropolitan Transportation Commission (MTC) committed to review the air quality effects of highway projects and to consider delaying any with negative consequences until the region was in attainment. The Sierra Club and Citizens for a Better Environment (CBE) brought suit in the Federal District Court of Northern California to force MTC to perform a substantive analysis of each project. Citizens for a Better Environment v. Wilson and Sierra Club v. Metropolitan Transportation Commission (consolidated cases), C89-2064TEH, U.S. Dist. Ct. for No. Dist. of CA, 1991. This case is discussed in greater detail in Greig Harvey and Elizabeth Deakin, "Toward Improved Regional Transportation Modeling Practice," December, 1991.

8. The extent to which these requirements also affect non-federal as well as federal projects is not entirely clear at the time of this writing, nor is there agreement on the transportation/air quality planning responsibilities of areas which attain the ambient air quality standards. Regardless, the legislation will have wide ranging effects. Moreover, even if non-federal projects are exempted from conformity reviews, they will have to be considered in the overall transportation emissions inventories required in nonattainment areas.

9. The transportation sector is more responsible for some pollutants than for others. According to current emissions factors, 90 percent or more of atmospheric carbon monoxide (CO) comes from mobile sources. Reactive organic (ROG) and oxides of nitrogen ($NO_x$) - the precursors of smog - arise from a broader range of sources in a mix that varies among metropolitan areas. In the San Francisco Bay Area, for example, about one-third of the anthropogenic (human-made) ROG emissions and one-half of the $NO_x$ emissions arise from transportation sources. ROG emissions from natural sources (principally vegetation) are slightly greater than from anthropogenic sources.

Note, however, that pending revisions to emissions factors, based on the latest scientific evidence, are likely to raise estimates of both the absolute levels of CO and ROG emissions and the portion attributable to mobile sources. For example, in public presentations, staff of the California Air Resources Board (CARB) have reported that, based on preliminary findings, CO and ROG mobile source emissions may be underestimated by a factor of two or more.

10. Stationary sources were not directly addressed in the FHWA seminar. At least two points did emerge, however. First, while technology "fixes" for large stationary sources may be less painful politically than travel restrictions, it is not clear that the bulk of remaining control options for area sources (e.g., control of consumer items such as solvents, small gasoline engines, barbecues, and hair spray) are any less difficult to present to the public. Second, air quality planners generally can provide precise measures of cost-effectiveness for large stationary source controls, and comparable data will be expected from the transportation community even though transportation costs and benefits are much more difficult to specify and measure (because there are numerous benefits and costs, some of them externalities).

11. ISTEA allocates a portion of discretionary funds for clean air-related transportation projects in the most severely-polluted metropolitan areas.

12. There may be attempts in some regions to link Federal transportation grants to local implementation of TCMs that do not qualify for direct Federal funding. In the San Francisco Bay Area, for example, environmental groups have argued that implementation of TCMs requiring local government action could be a condition of Metropolitan Planning Commission (MPO) inclusion of localities' projects in the Federal transportation program.

13. The California Clean Air Act specifically calls for TCM implementation. See the reports on TCMs such as: U.S. Environmental Protection Agency, Office of Moblie Sources, Transportation Contol Measure Information Documents, 1992, prepared by Cambridge Systematics, Comsis Corporation, K.T. Analytics, and Deakin Harvey Skarbardonis. See also: U.S. Environmental Protection Agency, Transportation Control Measures: State Implementation Guidance, 1990, prepared by Douglas Eisinger et al, SAI.

14. South Coast Air Quality Management District (SCAQMD) Regulation 15 requires all employment sites above a certain size to submit and implement a plan for achieving peak-period worker-to-vehicle ratios of 1.3, 1.5, or 1.75, depending on location. Employers are given broad discretion in choosing trip reduction methods.

15. Fees of $40 to $100 a month are reported in "successful" programs.

16. For example, free close-in parking for carpools and vanpools, and subsidized transit passes.

17. There is considerable uncertainty about how to compensate low- and middle-income workers for the personal costs of TCMs without negating the trip-reducing effects. One viewpoint is that no net change in behavior will occur if a transportation fee is exactly offset by the addition of equivalent income. An opposing viewpoint is that behavior will change even with an exact offset because the average worker is not likely to spend an entire increment of general income on a single item (i.e., there are many other elements of the household utility function). The Los Angeles data seem to support that the second viewpoint, but this is far from a definitive conclusion.

18. Costs incorporated in the above figures include fees charged to cover the Air District's administrative expenses, consultant costs, and annual costs for Employee Transportation Coordinators (salary, benefits, and fees for training and annual refresher courses), as well as some direct costs of program elements. Parking fees and related income subsidies are not included.

19. Value-of-time benefits depend on peak period volume reductions, which are determined not only by mode and time-of-travel changes among directly-affected workers, but also by (potentially) compensating shifts by other travelers who perceive improved travel times. Since congestion and delay are highly sensitive to peak flows, relatively small changes in volume can yield large travel time benefits.

20. Other implementation problems with employer-based trip reduction include concerns over equity implications (lower income workers tend to be most affected) and conflicts

with pre-existing labor contracts (free parking often is guaranteed explicitly).

21. By density is meant the number of individuals moving together in space and in time. Higher densities provide greater latitude for collective travel arrangements.

22. By behavioral consistency is meant the comparatively well-understood and consistent responses of work travelers to level-of-service indicators such as in-vehicle time, walk time, waiting time, price, and reliability. Workers have less choice about whether and when to travel, and so travel for work appears less complex and more predictable than travel for other trip purposes.

23. By institutional simplicity is meant the ease with which responsibility for work travel reduction can be assigned to the employer. Comparable institutions do not exist for most other types of travel. (Corporate fleets are one exception, though the same organizations are involved; schools, airports, and large office and retail developments also might provide convenient institutional "handles" for travel reduction.)

24. Home-based work trips constitute about 25 percent of all VMT and 20 percent of all vehicle trips that occur in an urban network. Speeds are somewhat lower on average for work trips because of peak period congestion (hence emissions per mile are somewhat higher), but less so than one would expect because most non-work trips occur on the local street system. A higher fraction of the work trips are cold starts (also resulting in higher emissions), but again the difference is smaller than expected because current catalyst-equipped vehicles become "cold" after only one hour. On the other hand, somewhat more of the work travel occurs in newer vehicles that are cleaner on average. The net result is that percentage emissions reductions calculated for work trips only are reduced by a factor of 4 or 5 when applied to the total mobile source emissions inventory. This may be an obvious point, but it results in much confusion and some consternation when TCM planning results are presented to decision-makers.

25. The need to address non-work travel may be even greater than suggested here. Ozone episodes often occur on weekends. Weekend emissions from mobile sources may be important contributors to these episodes. A 1981 Bay Area survey indicates that residents make about as many trips on a weekend day as on a typical weekday, and produce about 95 percent as many in-region vehicle miles. But aside from a cursory tabulation, no analysis has been performed on the weekend portion of the survey, and little is known about the nature of Bay Area weekend travel. As a result of clean air requirements, pressure for a deeper understanding of weekend travel is likely to arise.

26. Over a 7 to 10 year horizon. Reductions could be greater beyond this horizon, especially with supportive zoning changes (e.g., to increase density and assure mixed use development around transit stations).

27. Employer-based trip reduction programs were included in the initial Bay Area proposal, but in a mild form without a rigorous performance criterion (or the parking charges and monetary incentives likely to result from such a performance criterion). A Regulation 15-type program has been proposed in the Air District. The estimated effectiveness with this program added would be in the range of 7 to 10 percent.

28. The program envisions an annual expenditure of $600 to $700 million **per year** after 1993, for accelerated rail transit investment, expanded bus operations, and cost-effective shared access services to rail transit stations.

29. There also is the issue of packaging measures to increase implementation feasibility. In particular, apparently ineffective measures may be part of a political compromise that facilitates other politically difficult but more effective measures. Mass transit improvements often fall into this category. Viewed in isolation, a rail transit extension may "cost" $300-$500 thousand and a bus system operating subsidy may "cost" $50-$150 thousand per ton of ROG removed, whereas such highly effective measures as tolls or parking charges may be self-financing and may yield net benefits after accounting for travel time changes and other costs. Yet the provision of improved transit may be an absolute prerequisite to acceptance of tolls or parking charges. Taken together, the transit, tolls and parking charges in total might well achieve very large benefits through reductions in congestion.

30. A requirement for pre-heated catalytic converters, now under consideration by the California Air Resources Board, would decrease the relative importance of start emissions by half or more, but would not eliminate the problem.

31. The FTP is a precise sequence of accelerations and decelerations based on actual trip sampling conducted in Los Angeles in the 1960s. Recent studies by the California Air Resources Board indicate that a typical trip now entails more acceleration and deceleration than a similar trip would have entailed 30 years ago. EPA is repeating these tests in other cities chosen to be representative of the national urban setting.

32. Estimates of effectiveness are based on average fleet characteristics, but most TCMs would be more likely to affect trips by lower-than-average emitting vehicles, if newer, better-adjusted vehicles are used for commuting.

33. An in-motion monitoring program also would help to identify deficiencies in the inspection and maintenance program. Stedman has argued that variation due to correctable physical causes alone is large enough to justify an in-motion monitoring program, especially because it is difficult to gauge the "true" emissions performance of a vehicle in the artificial context of inspection and maintenance.

34. Although considered to be a "serious" ozone non-attainment area under California law, it is considered as "moderate" under the Federal law.

35. In September 1991, the American Lung Association filed suit against EPA to force a reduction (tightening) of the one-hour ambient ozone standard from .12 parts per million (ppm). The original federal standard was .08 (through 1978), but in the face of inconclusive scientific evidence supporting that standard and strenuous objections to over-control, the standard was relaxed to the current .12 level. The Lung Association argues that the epidemiological record now is clear enough to support a return to the original standard or to an even more stringent standard.

36. Note that these are reductions from future year emissions that would occur absent the TCMs. In a growing region, a package of TCMs estimated to reduce VMT by five percent on a continuing basis would have increasing effectiveness as measured in tons of pollutant reduced as the base grows.

37. These are in addition to vehicle operation-based sources of variability such as speed, acceleration, cold starts, and hot soaks.

38. There is no requirement for manufacturers to test the emissions performance of every vehicle (but manufacturers can pre-test each vehicle subjected to the Federal Test Procedure). Manufacturing defects and variability in component tolerances cause some super-emitting vehicles among the new car fleet.

39. In-use tests might be based on random application of the Stedman infra-red measurement device described earlier.

40. Unregistered vehicles have been presumed to be owned mostly by low income households, but this has not been verified through a focused study.

41. Oxygenated fuels generally have been put forward as a CO strategy. ROG reductions are less certain and depend on fuel formulation, but reductions of a similar magnitude appear to be feasible.

42. This would amount to $20 to $30 per vehicle per year if oxygenated fuel were sold for the four months during which CO exceedences most often occur.

43. There is a procedure to divert supplies to the most severe areas in the event of a shortage.

44. "Mobile" is the emissions factor model maintained by EPA and "EMFAC" is the model maintained by CARB. Mobile 4.1 and EMFAC 7SPD are the current versions.

45. This would involve an additional cost of $40 to $60 per vehicle per year, or about $10000 per ton of ROG removed (for typical vehicle usage and 1992 average emissions factors). This compares favorably with the average cost per ton of stationary source ROG reductions.

46. Operation (and the degree of inconvenience) would resemble the use of a glow plug on a diesel-powered vehicle.

47. If the device were effective enough to turn each cold start into a hot start, then trip start emissions of CO and ROG would be reduced by 25 to 35 percent, and overall emissions for an "average" urban trip would be reduced by 10 to 15 percent (based on CARB's EMFAC 7E factors and Bay Area trip data, and assuming full penetration of the fleet). It would take about 5 years of sales for the pre-heated catalyst equipped vehicles to account for half of the trips and VMT. Cost data are not available, but modifications are unlikely to cost as much as the catalyst itself (about $300), even with a second battery. There would be a modest increase in operating expense to cover the cost of periodic battery replacement.

48. As a practical matter, "zero emission vehicle" is synonymous with electric vehicle. An electric vehicle is not truly zero emission (unless the local generating capacity is completely non-fossil), but the viewpoint in Los Angeles is that the associated emissions can be "exported" by purchasing power (fossil-based or other) from elsewhere. This same assumption may not hold for other parts of the country, where ozone problems often extend over a wider area. Each state contemplating an electric vehicle requirement will have to carry out a net emissions analysis to determine the actual benefit.

49. Studies of long-term vehicle use indicate that virtually all vehicles in the fleet are used at some point in a way that would violate the range of existing battery technology (assuming a conventionally-sized vehicle). Studies of single-day vehicle use, on the other hand, indicate that few vehicle trip patterns, on a given day, exceed the range of current battery technology (say, 100 miles). In addition, households have shown an increasing tendency to own more than one vehicle per licensed driver, partly to allow for special-purpose or limited-use vehicles. It would seem possible, then, for households to rearrange (or expand) their fleets to accommodate limited-range electric vehicles for use in everyday travel patterns. The key considerations for such a market would be price, ease of use, and reliability rather than range.

50. Presentation by Philip Lorang, EPA, in "Conference Summary: Best Practices for Transportation Modeling for Air Quality Planning", by Gary Hawthorne and Elizabeth Deakin, December 1991.

51. In the interest of brevity, this discussion does not address every possible emissions control measure. One group of measures that could prove significant in the long-run includes telecommuting and other technology-based changes designed to substitute computers and communication for travel. That emerging telecommunications technology can have a profound effect on work, shopping, and leisure is not in doubt, though the net effect on consumption of travel remains to be seen. As more is learned from current experiments, it may become possible to build telecommuting and similar measures into air quality plans.

52. This authority is being challenged, however, and the Legislature has been asked to remove it from the California Act.

53. No explicit recommendation for a state-administered insurance program was made at the time this proposal was put forward. However, since that time such a proposal has been introduced in the Legislature.

54. MTC analyzed the pricing measures using its data resources and system of regional models. A key feature of the MTC models is the presence of price throughout the model hierarchy.

55. Recent press reports of lung lesions among Los Angeles children, and of increased asthmatic sensitivity from chronic exposure to low levels of ozone, give some sense of the direction of this literature. However, the legislature may revise the permitted number of violations upward (perhaps making California Law inconsistent with the Federal Rule,) or may lengthen the time frame for attainment.

56. The legislature has adopted special requirements for several urban areas of the State, including the Bay Area.

57. California Office of the Governor. Governor's Budget Summary 1990-91.