= · 12

United States
Environmental Protection
Agency

Office of Air and Radiation
Washington, DC 20460
Region 9
San Francisco, CA 94105

450/2-89-020
September 1990

Air

EPA

Transportation Control Measure: State Implementation Plan Guidance

Revised Final Report

TRANSPORTATION CONTROL MEASURES: STATE IMPLEMENTATION PLAN GUIDANCE

Work Assignment No. 39
Contract No. 68-02-4393

SYSAPP-90/084

September 1990

Prepared for

U.S. Environmental Protection Agency
Region IX, Air and Toxics Division
75 Hawthorne Street
San Francisco, California 94105

U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Air Quality Management Division
Research Triangle Park, North Carolina 27711

and

Pacific Environmental Services, Inc.
1905 Chapel Hill Road
Durham, North Carolina 27707

Prepared by

Douglas S. Eisinger[1]
Elizabeth A. Deakin[2]
Lenna A. Mahoney[1]
Ralph E. Morris[1]
Robert G. Ireson[1]

[1] Systems Applications, Inc.
101 Lucas Valley Road
San Rafael, California 94903

[2] Institute of Transportation Studies
109 McLaughlin Hall
University of California
Berkeley, California 94720

F9910 89058r2

NOTICE

Funding for this report has been provided by the U.S. Environmental Protection Agency. The report has been subjected to the agency's peer and administrative review, and it has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endorsement.

This guidance document was issued as Congress debated amendments to the Clean Air Act. The amendments set up tiered requirements for control strategies depending on the severity of the air quality problem in an area. Transportation control measures are likely to be required in areas with more serious air quality problems. EPA will be issuing new overall SIP guidance and other information documents on specific TCMs. While this document will remain a primary information source on TCMs, readers should contact their EPA Regional Office to obtain the latest EPA SIP guidance.

ACKNOWLEDGMENTS

This report was prepared by Douglas Eisinger, Lenna Mahoney, Ralph Morris, and Robert Ireson of Systems Applications, Inc., and Elizabeth Deakin with the Institute of Transportation Studies, the University of California at Berkeley. This work has been accomplished under contract 68-02-4393, Work Assignment Number 39, through Pacific Environmental Services (PES) for the United States Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards and EPA Region IX Air and Toxics Division. Frances Wicher of EPA Region IX was the project manager and provided valuable direction, support, and editorial assistance. Laurel Impett, formerly of EPA Region IX, served as project manager during the initial planning stage. A number of individuals reviewed earlier report drafts and offered constructive comments: Lyle Chinkin, Jay Haney, Henry Hogo, and David Souten of Systems Applications all contributed to the report. The Transportation/Air Quality Review Group (TARG) of California, Nevada, and Arizona served as an excellent resource throughout the project. Important comments and recommendations were offered by peer reviewers from regional EPA offices, and state and regional transportation and air quality agencies. Special thanks go to Judy Rodich of Systems Applications for her editorial support.

ABSTRACT

This guidance document has been developed for the United States Environmental Protection Agency to summarize current knowledge about transportation control measures (TCMs). The target audience includes transportation and air quality management staff at all government levels. The guidance development effort is motivated by the need to provide post-1987 guidance to attain National Ambient Air Quality Standards (NAAQS); however, it is also timely to summarize TCM experiences of the past 10 to 15 years. The guidance document provides descriptions and examples of the most frequently implemented TCMs; institutional guidance such as assessing feasibility, agency responsibilities, and funding; and techniques for monitoring and enforcing TCMs. In addition, the document describes the tools available for evaluating TCM impacts on hydrocarbons, nitrogen oxides, and carbon monoxide emissions. Appendices present approaches to estimate TCM effects on PM-10 emissions; important sources of additional information; implementation experiences in various cities; and rules of thumb to quantitatively evaluate TCM transportation system effects. This is the first significant effort by the U.S. Environmental Protection Agency in more than a decade to provide national guidance on transportation control measures. The information presented demonstrates that there have been significant advances in TCM development over the past decade, and that TCMs are appropriate control options for state implementation plans.

EXECUTIVE SUMMARY

This document is one of several recent U.S. Environmental Protection Agency (EPA) efforts to help states achieve ozone and carbon monoxide National Ambient Air Quality Standards (NAAQS) in the "post-1987 era." Examples of these efforts include guidance to prepare emission inventories and to address mobile-source-related problems, and workshops to explain and discuss the agency's proposed post-1987 policy. This document focuses on mobile sources and complements other EPA activities to provide guidance related to mobile source controls. It is part of an effort to provide guidance on identifying, screening, evaluating, adopting, implementing, monitoring, and enforcing transportation control measures (TCMs). This document brings together substantial TCM information from numerous sources discussing TCMs' past effectiveness at controlling traffic problems and their potential application to improve urban air quality. This guidance document identifies important information sources and summarizes key steps in the TCM identification, analysis, and selection process. The target audience for this document includes air quality agency staff and transportation planning agency staff at all government levels who may be responsible for choosing and implementing transportation controls. The focus is to help planners select TCMs that will relieve urban ozone and carbon monoxide problems. An appendix (Appendix A) provides insights into applying TCMs to PM-10 problems. The document is organized into six main sections: (1) an introduction, (2) identification, description, and packaging of TCMs, (3) institutional guidance, (4) technical guidance, (5) organizational/administrative guidance, and (6) appendices.

Identification, Description, and Packaging of TCMs

Descriptive information is presented in three categories: (1) reviews of about a dozen measures—giving brief descriptions of each measure, examples of the measure's implementation and factors leading to successful implementation, and reported past effectiveness of the measure; (2) TCM "packaging" information (i.e., considerations to implement several measures as a single control strategy); and (3) recommended documents to obtain for follow-up research. The last category is perhaps the most important. Seven key references are identified (see Table 2-4) that represent a substantial body of knowledge on a variety of measures. If planners and analysts have resources to obtain only these seven documents, they will still have most of the TCM-specific resources needed to conduct their analyses and effectively choose and implement TCMs. Finally, users will find TCM "profiles" in Appendix C. These brief descriptions of actual projects help illustrate the range of TCM experiences to date and provide a real-world backdrop to the more general information presented.

Institutional Guidance

Numerous institutional issues influence how TCMs are selected and implemented. The institutional guidance discussion examines the scope and "fit" of particular measures and implementation strategies to specific areas, suggests which agency or agencies should take lead responsibility for TCM implementation, identifies funding needs and resources, and addresses the political acceptability of control strategies. The section highlights these issues with four in-depth examples of TCM strategies and their institutional considerations. The discussion closes with a look toward the future and emerging issues in TCM implementation.

Technical Guidance

Technical guidance identifies the range of tools available to forecast the travel impacts of measures and to estimate resulting emissions and air quality changes. This section, by identifying data necessary to carry out each step in the travel/emissions/air quality analyses chain, should prove to be helpful to both transportation and air quality staff. The section makes an effort to identify (primarily for air quality analysts) sources of uncertainty and variability in transportation forecasting methods that could affect the results of TCM-air quality analyses. Less time is spent discussing emissions and air quality assessment tools, since EPA has produced separate guidance documents on these topics. Transportation planners may wish to focus on the references mentioned in the travel demand modeling discussion to determine whether they identify previously unknown sources of useful information.

Organizational/Administrative Guidance

Successful TCM program management requires attention to administrative detail. This discussion is focused to help government officials monitor and enforce TCMs. Included are methods for monitoring background conditions and growth trends, for tracking implementation, and for assessing in-place performance and making adjustments as needed. Various enforcement issues are also addressed, including alternative approaches such as in-lieu fees and assessments. The concluding discussion presents issues to consider when setting up the administration of TCM programs.

Appendices

The document includes four appendices: Appendix A offers guidance for estimating the effects of transportation measures on PM-10 emissions; Appendix B lists additional recommended references; Appendix C profiles TCM descriptions, analyses, and implementation efforts; and Appendix D outlines past experiences and potential rules of thumb associated with TCM effectiveness.

Contents

89058p2 1

Figures

Tables

1 INTRODUCTION

BACKGROUND AND MOTIVATION

This guidance document will help state and local government officials incorporate transportation control measures (TCMs) into their state implementation plans (SIPs) for air quality control. The guidance focuses on choosing TCMs to help meet and maintain ozone and carbon monoxide National Ambient Air Quality Standards (NAAQS). Information presented addresses identifying, evaluating, implementing, monitoring, and enforcing TCMs. An appendix (Appendix A) addresses guidance concerning PM-10.

Three major factors motivate the U.S. Environmental Protection Agency's (EPA's) desire to release TCM guidance: (1) the Clean Air Act §108 instructs EPA to publish "from time to time" information concerning transportation planning and guidelines; (2) the EPA's proposed post-1987 policy for ozone and carbon monoxide state implementation plan (SIP) revisions (the "post-1987 policy") identifies transportation controls as an essential part of control strategies for many nonattainment areas (as of 31 December 1989, 96 areas were still nonattainment for ozone NAAQS, and 41 areas were nonattainment for carbon monoxide NAAQS); and (3) following the release of the proposed post-1987 policy, numerous state and local officials asked EPA to help them identify, evaluate, and adopt TCMs.

It is also timely to summarize TCM experiences of the past 10 to 15 years. TCM guidance was first prepared for air quality planning purposes in the late 1970s; additional studies supported the last major round of transportation/air quality planning in the early and mid-1980s; and, recently, local governments have turned to TCMs to control growth and relieve traffic congestion (air quality benefits accrue as a bonus). These more recent actions, commonly referred to as either transportation demand management (TDM) or transportation system management (TSM), include familiar TCM air quality improvement measures such as ridesharing and traffic flow and transit improvements. In updating its guidance, EPA wants to distill current and past experience with TCMs to provide guidance and examples to local and state transportation and air quality agencies that will evaluate TCMs in their attainment plans.

As documented in this report, although the TCM information base is still incomplete, a wealth of information exists concerning many facets of TCMs: discussions profiling individual measures, the efficacy of packaging measures to address various problems; and methods available to analyze TCMs' effects on traffic, emissions, and air quality. A substantial portion of this information was first developed during the late 1970s in response to Clean Air Act §108 requirements. The U.S. Environmental Protection Agency (EPA) and other agencies, primarily the U.S. Department of Transportation (DOT), produced substantial TCM guidance during the late 1970s and early 1980s. Appendix B includes a listing of these documents, which fall into three categories: overview guidance published by EPA, EPA-published guidance specific to individual measures, and related guidance materials published by other agencies. TCM research has continued over the past few years. Some of this more recent work was completed to promote improved air quality; most has been undertaken to help alleviate the traffic congestion problems plaguing the nation's urban and suburban areas. This document synthesizes this substantial information base and directs the reader to important supplementary documents.

In addition to giving the reader essential information, this guidance document provides a roadmap for the use of this information. Where possible, the guidance identifies valuable information sources, briefly reviews how they might be utilized, and indicates how they can be obtained. The guidance provides advice regarding (1) information gathering and analytical tasks that must be taken to adopt and implement specific TCMs; (2) methods available to complete these tasks; and (3) references available to help the reader understand and use these methods.

EPA SIP-APPROVAL CRITERIA SPECIFIC TO TCMs

Prior to beginning the effort to inventory existing TCMs and implement new measures, it is important to bear in mind the criteria against which EPA will evaluate TCMs included in future SIP submittals. EPA's proposed post-1987 policy (EPA, 1987a) defined six criteria TCMs must meet before the agency can consider them for approval in a SIP. States must provide EPA with

1. A complete description of the measure and its estimated emissions reduction benefits;

2. Evidence that the measure was properly adopted by a jurisdiction(s) with legal authority to commit to and execute the measure;

3. Evidence that funding has been (or will be) obligated to implement the measure;

4. Evidence that all necessary approvals have been obtained from all appropriate government entities (including state highway departments if applicable);

5. Evidence that a complete schedule to plan, implement, and enforce the measure has been adopted by the implementing agency or agencies;

6. A description of the monitoring program to assess the measure's effectiveness and to allow for necessary in-place corrections or alterations.

These six criteria are unlikely to change under the proposed amendments to the Clean Air Act. It is thus important that SIP submittals be designed such that their TCM strategies meet EPA approval criteria. Some previous SIP submittals to EPA have included TCMs failing to meet all adoption criteria; in these cases, the agency has been forced to disallow the state from taking credit for projected emissions reductions attributed to these measures (e.g., see EPA, 1988b). Problems that have arisen include (1) failure to substantiate emission reduction estimates for a measure, (2) local agencies committing to implement measures over which they lacked legal authority (e.g., committing to fleet-wide use of alternative fuels and I/M program improvements that required state legislative action); (3) partial funding commitments that do not secure long-term funding for continued implementation; and (4) lack of written evidence that a legally enforceable commitment has been obtained from the lead agency to carry out TCM implementation, monitoring, and enforcement.

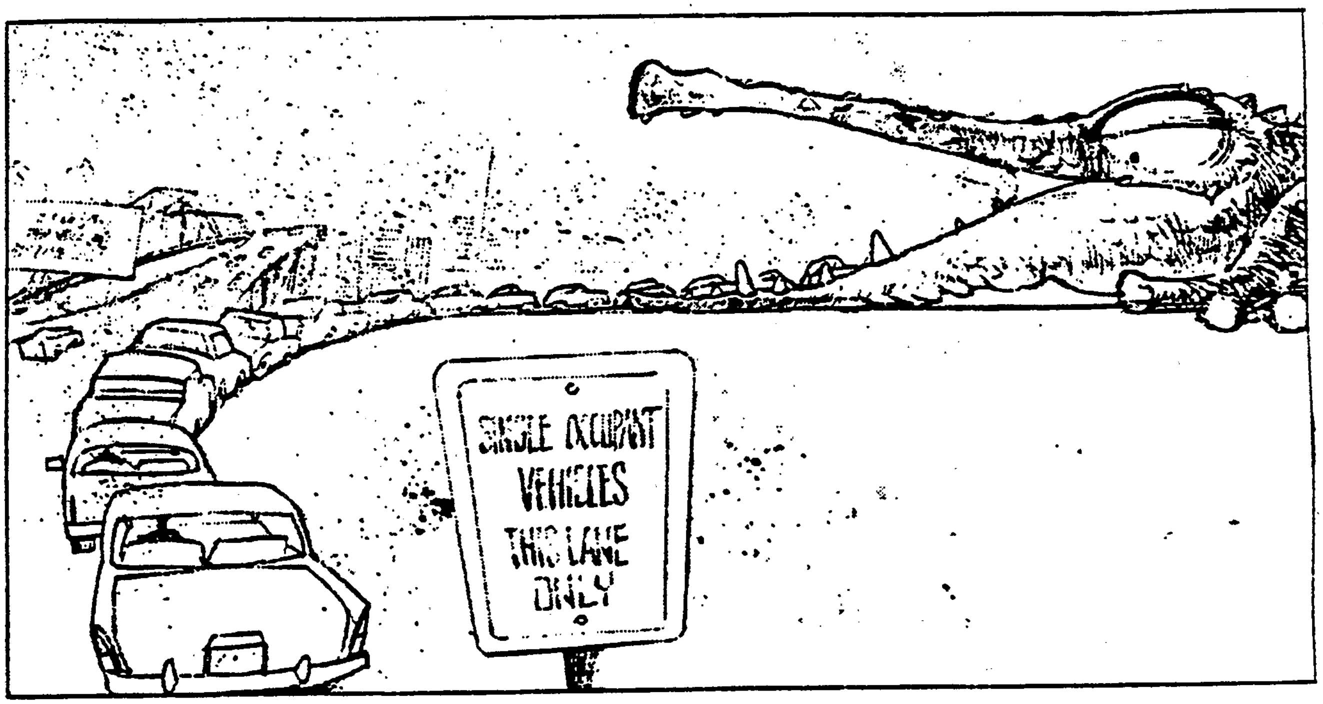
Pending changes to the Clean Air Act will establish new SIP planning requirements and schedules; local and state agencies should contact their EPA regional office to obtain the latest guidance and policy on SIP development.

PREPARATION OF THIS DOCUMENT

The guidance development effort proceeded in two stages; the first outlined guidance needs (Eisinger et al., 1988); the second prepared the guidance document. To outline guidance needs Systems Applications conducted a series of interviews during June and July of 1988. The interview process solicited comments from federal, state, and local government officials throughout the country regarding what a guidance document should contain. Interviewees were chosen to represent both the transportation and air quality analysis communities, and to highlight different geographic interests and planning experience. The 15 individuals interviewed reflected experience specific to 6 geographic areas: New York/New Jersey, Washington, D.C., Chicago, Denver, Arizona, and southern California. In addition to the interviews, the outline effort drew from recent and past EPA experience with transportation control measure planning, as documented in several studies.

Guidance preparation focused on three broad stages: (1) literature reviews, (2) supplemental interviews, and (3) peer review of draft products. These efforts sought to summarize current understanding of TCMs and the methodologies available for their evaluation. The literature review identified key references for TCM analysts to obtain, and summarized important findings from other studies that were too detailed to be of general usefulness to the air quality analyst. Should analysts wish to develop a library for their agency concerning specific measures or methodologies, the guidance cites numerous studies that offer more detailed information. Supplemental interviews and peer review helped to further develop and critique the guidance. The peer-review process involved review by more than 40 individuals from across the country. Officials from EPA regional offices, and state and local transportation and air quality agencies offered comments and suggested changes to an earlier draft version of this report.

As the example on the following page indicates, there are numerous opportunities to creatively approach transportation control; the sections that follow provide users with the technical support they need to carry out these creative efforts.



Drawing by William Cone, © 1989, the San Francisco Chronicle. Reprinted with permission.

89058

2 IDENTIFICATION, DESCRIPTION, AND PACKAGING OF TCMS

OVERVIEW

This section (1) lists important transportation control measures identified in both the Clean Air Act and in EPA's proposed post-1987 policy and broadly categorizes their effects; (2) describes 13 measures in greater detail; (3) suggests sample packaging arrangements for TCM implementation (i.e., arrangements that exploit synergistic or complementary characteristics of measures); and (4) identifies information sources for a more detailed review of individual controls.

IDENTIFICATION OF TCMs

The Clean Air Act of 1977, §108(f) identifies several transportation control measures as potential air quality control options. Many of these are included in proposed amendments to the Clean Air Act (CAA).

Table 2-1 lists measures included in pending CAA amendments. The list includes broad TCM categories (e.g., transit and traffic flow improvements), specific measures (e.g., voluntary no-drive days), and sample implementation strategies (trip-reduction ordinances, employer-based transportation management). The list should not be viewed as exhaustive, but rather indicative of the types of TCMs states should consider in developing their TCM control strategy. In the past, EPA policy has required and probably will continue to require states to consider all §108(f) measures for inclusion in their SIPs. If a state fails to include a §108(f) measure, it must provide substantial justification.

Over the years, many transportation control measures have been included in various state and regional air quality implementation plans. Table 2-2 identifies several broad TCM categories that comprise more than 70 individual measures.

Table 2-3 lists measures identified in both the 1977 Clean Air Act and in pending revisions to the CAA that are covered in this guidance. The list does not include tailpipe controls or some of the more controversial measures such as mandatory no-drive days; gas rationing; or gas, parking or vehicle taxes. Table 2-3 also categorizes these measures by whether they affect transportation supply or demand, and whether their primary effect is to (1) reduce vehicle trips, (2) induce mode shifts, (3) shift travel time, and/or (4) improve traffic flow. Categorizing measures can help select

TABLE 2-1. TCM categories identified in pending congressional amendments to the 1977 Clean Air Act.

Measures Implemented in Various Locations Throughout the Country
1. Rideshare incentives (e.g., carpools)
2. Work schedule changes (compressed work week; staggered work hours)
3. Employer-based transportation management
4. Improved public transit
5. "Park and ride" and fringe parking
6. Parking management programs
7. Road pricing (tolls)
8. Traffic flow improvements
9. Trip-reduction ordinances
10. Voluntary no-drive days
11. Control of extended vehicle idling
12. Reduction of cold start emissions
13. Gasoline fuel additives
14. Conversion of fleet vehicles to cleaner fuels or engines
More Controversial Measures
1. Mandatory no-drive days
2. Gas rationing
3. Gas, parking, or vehicle taxes

TABLE 2-2. Sample transportation control measure categories and implementation approaches.

Category	Example Implementation Approaches
Bicycle use	Bikeways/lanes Bike storage Education programs Shower/locker facilities
Carpooling/Ridesharing	Carpool matching programs Vanpool programs Public information programs Transportation management associations "No-drive" days HOV lanes/freeway ramps Trip-reduction ordinances Park and ride and fringe parking facilities
Commercial vehicle control	On-street loading zone restrictions Off-street loading areas Peak hour on-street loading prohibition Truck route system Peak-hour truck restrictions
Employer-based transportation management	Trip reduction ordinances Transportation management associations Rideshare program incentives Preferential parking programs for HOVs In-house transportation coordinator On-site transit pass sales Shuttle services to transit Vanpool subsidies
HOV lanes/Roadway assignment	Exclusive bus lane arterial (take or add a lane) Bus-only street Reversible/contra flow bus and car lanes Freeway HOV bypass Exclusive HOV lane-freeway (take or add a lane) "No-drive" days

continued

TABLE 2-2 continued

Category	Example Implementation Approaches
Improved paratransit	Taxi/group riding programs Dial a ride Jitney service Taxi deregulation
Improved transit management	Marketing program Maintenance improvements Vehicle fleet improvement Operations monitoring program Transfer improvements Tax incentives for transit Trip-reduction ordinances Fare reductions Elderly and youth fares Commuter discounts
Improved transit operations	Bus route and scheduling modifications Express bus service/freeway stops Bus traffic signal preemption Bus terminal/stop improvements Simplified fare collection and transfers Long-range transit improvements HOV lanes Security improvements Shuttle bus service
Information distribution	Traffic condition announcements/signs Public education programs Ridesharing/park and ride signage Rideshare matching programs Transit/paratransit promotion
Parking management	On-street parking restrictions Residential parking control Off-street parking restrictions HOV preferential parking Parking rate changes Bus stop relocations Loading zone restrictions

continued

89058pl 3

TABLE 2-3. Categorization of selected TCMs listed in the 1977 Clean Air Act and in pending legislation (does not include "tailpipe" controls).

TCM Category (by primary effect)	Measure	Measure Cited in CAA §108(f)	Mode Shift Effects	Implementation Location
A,B	Bicycle storage facilities	x	To bikes	1,3,6
A,B	Carpool programs/incentives	x	To pools	2,3,4,7
A,C	Compressed work week			3
A,B,C,D	Employer-based transportation management	x	To all options	3
A,B,D	HOV lanes	x	To transit and pools	2,4
A,B	Improved public transit	x	To transit and pools	1,2,3,4,5,6,7
A,B	Park and ride/fringe parking	x	To transit and pools	2,3,4
A,B,D	Parking management	x	To transit and pools	1,2,3,5,6
A,B	Road pricing (tolls)	x	To transit and pools	4
C	Staggered work hours/flex time	x	To transit and pools	3
D	Traffic flow improvements	x		1,2,3,4,5,6,7
A,B,C,D	Trip-reduction ordinances		To all options	1,2,3,4,5,6,7
A,B	Voluntary no-drive days		To all options	3,5,7

Category Key:

A. Reduces vehicle trips
B. Induces mode shifts
C. Shifts time of travel
D. Improves traffic flow

Implementation Location Key:

1. Locally/at intersection or street segments
2. Along arterial street corridors
3. In employment centers
4. Along freeway (or other major facility corridors)
5. In residential neighborhoods
6. In commercial centers
7. Applied region-wide

89058r2 1

specific alternatives for further analysis. Most categorization schemes are limited, however; many measures overlap and/or reinforce one another and could justifiably be placed in more than one category (or in different categories).

TCM DESCRIPTIONS

This part of the guidance provides descriptions for measures analogous to those listed in Table 2-3. The discussion defines each measure and identifies innovative or recent implementation efforts, factors necessary to the measure's successful implementation, complementary measures, and observed effectiveness for each measure (usually in terms of traffic mitigation capability). The measures covered include:

- Area-wide ridesharing
- Bicycling alternatives to motor vehicle travel
- Employer-based transportation management programs
- High occupancy vehicle (HOV) lanes
- Park and ride and fringe parking
- Parking management programs
- Road pricing
- Telecommuting and teleconferencing
- Traffic flow improvements
- Transit improvements
- Trip-reduction ordinances
- Voluntary no-drive days
- Work schedule changes

Readers are strongly encouraged to read Appendix C, which presents 14 examples of "real world" TCM analyses and implementation programs, and describes applications of some of the strategies and methodologies outlined in this guidance document.

Area-wide Ridesharing

This strategy focuses on increasing vehicle occupancy during peak traffic periods. Carpools, vanpools, and subscription bus services are common ridesharing approaches. Implementation can be accompanied by tax incentives for employers sponsoring pooling programs, public information programs to promote ridesharing, government subsidies to ride in pools (and other public/private partnerships).

Innovative/Recent Implementation Efforts. HOV lanes complement Seattle's publicly operated vanpool program (the largest in the nation). Seattle's State Route 520 has the only freeway concurrent flow project that operates an HOV lane on the outside shoulder (ITE, 1988a).

Factors for Success. Trip ends (origin and destination) should be in smaller areas with a long trip in between; commutes less than 5 miles and 20 minutes are not likely to promote pooling (Batchelder et al., 1983); work roundtrips averaging about 25 miles for carpoolers and 30 miles for vanpoolers appear to work well; buspools with a 10- to 60-mile route length have low failure rates (Pratt and Copple, 1981); arrival and departure times should fall within a short period; disincentives should exist to limit single-occupancy vehicle use (e.g., congestion, no available car, long commute, parking restrictions); large employment concentration at destination site (i.e., more than 500 employees) and limited public transit access (Deakin, 1988; Batchelder et al., 1983); employer size should be sufficient to allow matching of 10 to 12 people for vanpools from the same community (Pratt and Copple, 1981); van/car pools should have pull-up points (e.g., at location of employment) or other convenient formation points.

Complementary Measures. Park and ride lots, preferential vanpool/carpool parking (e.g., parking fees for single occupant vehicles), transportation management associations, high occupancy vehicle lanes (for buses and pools), parking management programs discouraging single-occupant vehicle use during peak periods, employer-based transportation programs, trip-reduction ordinances, pricing strategies (e.g., differential tolls, fuel surcharges), public awareness programs.

Examples. CARAVAN in Boston; Commuter Computer in Los Angeles; RIDES for Bay Area Commuters, Inc., in San Francisco; Minnesota RIDESHARE in Minneapolis/St. Paul; municipality of metropolitan Seattle (Metro) has nation's largest publicly operated vanpool program (with more than 260 vanpools).

Effectiveness. Quantitative measures of effectiveness are difficult to establish. A survey of 38 urban areas found annual work-related VMT reductions of .03 to 3.6 percent (Deakin, 1988). Some 15 to 20 percent of new vanpoolers may delay the purchase of a new auto or sell one they already own (Pratt and Copple, 1981).

Recommended Information Sources. Booth and Waksman, 1985; MTC, 1985; Wiersig, 1982; Pratt and Copple, 1981; DiRenzo and Rubin, 1978.

Bicycling Alternatives to Motor Vehicle Travel

Some limited travel situations might allow bicycle alternatives as substitutes for motor vehicle use. Bicycling is generally a viable option if employees live within 4-6 miles from work, though this can vary substantially depending upon the individual (walking is mostly feasible for those within one mile of the work site). Implementation can encourage bicycle use directly to the work site (e.g., by providing on-site shower, locker, and storage facilities), or can encourage bicycle use to a transit facility (e.g., by installing bike storage facilities at commuter rail stations).

Innovative/Recent Implementation Efforts. Xerox Corporation's Palo Alto, California, facilities provide bike racks in covered sheds; flexible work schedules; and showers, lockers and free towels; 18 percent of the company's employees bicycle to work. The bike program is further encouraged by city bike lanes, a high number of employees who live close to work, and legal bike access on an expressway close to the office (MTC, 1985).

Factors for Success. Reasonably level terrain; shower facilities; secure bicycle storage facilities; bike routes; very short commute distances; mild, noninclement climate; and supportive route signalizations, lane striping, repaving, and signing.

Complementary Measures. Flexible work schedules; employer-based transportation management programs; trip-reduction ordinances; transit improvements; parking management; voluntary no-drive days; bike parking; bike lanes.

Examples. Numerous bicycle facilities have been constructed throughout the country. Areas known to have active bicycling communities include Davis, California; Tucson, Arizona; Denver, Colorado (CSI, 1986); and Missoula, Montana.

Effectiveness. Few studies are available to help quantify potential mode shifts related to improved bicycle facilities. On the basis of a review of experience in Detroit (CSI, 1986), Phoenix planners projected 1 percent of all trips less than 6 miles as being replaced by bicyclists; the same study also noted that Los Angeles planners project 1 percent of all trips less than 3 miles being replaced by bicyclists (MAG, 1987a).

Recommended Information Sources. CSI, 1986; MTC, 1985; Caltrans, 1983; EPA, 1979.

Employer-Based Transportation Management

Employer-based programs can include a wide variety of specific transportation control measures. All are geared to reducing single-occupant vehicle use during peak-hour commutes. Typical programs include some combination of preferential parking for vanpools/carpools, in-house coordinator with computerized matching capability, on-site transit pass sales, shuttle services to transit, purchase or subsidy of vanpool, and other incentives. Implementation can be motivated by mandatory trip reduction ordinances or voluntary employer action. Programs usually involve 100 percent funding by employers, though some municipalities might create tax incentives for employer programs (Deakin, 1988).

Innovative/Recent Implementation Efforts. Groups of employers in the same geographic area have formed transportation management associations (TMAs) to encourage alternative commute modes (sometimes referred to as transportation management organizations). The California Department of Transportation (CALTRANS) has a program to provide seed money for TMAs. Also, see MTC (1985) for various recent employer-managed projects.

Factors for Success. Single, larger employers will have the greatest opportunities for success; mandatory return of survey/application forms from employees to employer for carpools and subsidized carpool parking; elimination of or limited access to free parking; level of staff resources available for program development, monitoring, and enforcement; continuous, long-term program promotion; mandatory or voluntary trip reduction programs; insurance policies to alleviate potential liability issues concerning company vanpool operations; management support is one of the most important factors...

Complementary Measures. Trip-reduction ordinances, parking management, park and ride lots, high occupancy vehicle lanes, pricing strategies (e.g., differential tolls), indirect source review/permit programs.

Examples. Numerous examples throughout the country, including Rockwell International of Golden, Colorado; Tennessee Valley Authority of Knoxville, Tennessee; Boeing Company of Seattle, Washington; ARCO of Los Angeles, California (Deakin, 1988).

Effectiveness. Assuming aggressive implementation, the likely range for potential VMT reductions appears to be 5 to 25 percent—5 percent for multiple employers at a single activity center and 25 percent for a single large employer. These VMT reductions refer to a TMA's target "market" focused on VMT associated with employee commuters. Individual programs may stand out as being particularly successful (e.g., the Tennessee Valley Authority program reportedly reduced the daily VMT of its employees by approximately 50 percent) (Deakin, 1988).

Recommended Information Sources. MTC, 1985; TRB, 1983.

High Occupancy Vehicle (HOV) Lanes

U.S. cities granted preferential lane use for vehicles with more than one occupant (transit and auto) as early as 1939 (Levinson, 1987); during the past 50 years, high occupancy vehicle lanes have been implemented in dozens of cities across the country. Referred to as transitways, busways, commuter lanes, and authorized vehicle lanes, HOV lanes cover a number of travel options. Implementation examples include

(1) exclusive facilities with separate rights of way, (2) exclusive facilities (during at least peak periods) on existing freeway systems but physically separated from other lanes, (3) concurrent flow lanes not physically separated from other lanes, (4) contra-flow lanes typically created using plastic cones/dividers and usually reserved for buses or vanpools, (5) curb lanes on arterials reserved for buses, (6) median lanes on arterials reserved for carpools and express buses (ITE, 1988a; Batchelder et al., 1983).

Innovative/Recent Implementation Efforts. Some of the most recent and comprehensively studied projects include the Route 55 Costa Mesa Freeway project in Orange County, California (see Greene and Associates, 1988; Klusza, 1987); I-394 in Minneapolis, Minnesota (see Crawford, 1987; SRF, 1987); and the I-10 Katy Freeway project in Houston, Texas (see Capelle and Greene, 1988; Mounce, 1987).

Factors for Success. Projects that generate at least 1 minute of travel time savings per mile of HOV facility are more successful in attracting users (ITE, 1988a)—total time savings to HOVs should exceed five minutes to encourage route diversions and exceed ten minutes to promote formation of new HOVs; bus priority measures require (1) a reasonable concentration of bus services, (2) visible bus and/or car congestion, (3) suitable street geometry/width, (4) public support of the HOV service (Levinson, 1987); arterial HOVs also require (1) provisions for turning traffic, (2) level of service D or worse during peak hours (though new construction should consider HOV lanes even if level of service is better than LOS-D), (3) nonsignalized intersections, (4) lanes carrying at least 30 buses during the peak hour (if a bus-only lane), or carrying more than their "fair share" of travelers (e.g., 33 percent or more of peak travelers if one of three lanes is reserved), (5) enforcement capabilities that will not disrupt traffic flow (Batchelder et al., 1983).

Complementary Measures. Park and ride and fringe parking lots; transit transfer centers (to facilitate bus-to-bus or bus-to-rail transfers); transit improvements; priority freeway access/egress for buses and carpools (e.g., via ramp metering by-passes or restricted HOV ramps); area-wide ridesharing; parking management (to facilitate arterial HOVs).

Examples. Among the many facilities are HOV-exclusive facilities in Pittsburgh, Houston, Los Angeles, Washington, D.C., and Ottawa, Canada; concurrent flow projects in Honolulu, Los Angeles, Miami, Seattle; and contraflow lanes in Honolulu, San Francisco, and New York City. Numerous projects are under way with completion dates scheduled for the early 1990s—these include HOV facilities in Denver, Houston, Miami/Fort Lauderdale, Seattle, Washington, D.C., and Norfolk, Virginia (ITE, 1988a).

Effectiveness. Effectiveness varies substantially from facility to facility. In general terms, HOV lanes have been credited with moving one-third or more of all peak hour freeway travelers; in most HOV lanes, the person-volume per lane exceeds the person-volume per lane in adjacent, non-HOV lanes (ITE, 1988a).

Recommended Information Sources. ITE, 1988a; Levinson, 1987; Batchelder et al., 1983; Pratt and Copple, 1981; DiRenzo and Rubin, 1978.

Park and Ride and Fringe Parking

Fringe parking facilities offer commuters opportunities to carpool/vanpool or utilize transit. Facilities are useful in suburban areas where low population density and irregularly designed traffic routes make it difficult to provide transit services; in remote areas along highway facilities; and at the fringe of the urban core (sometimes referred to as "interceptor lots"). Lots are typically free and provided by local and state agencies.

Innovative/Recent Implementation Efforts. Park and ride lots have been implemented throughout the country. A recent example of this approach is in New York City, where city officials are planning park and ride lot construction on the Manhattan periphery; the lots are targeted to reduce congestion in the central business district (CBD) and allow for increased interborough transit use (Soffian et al., 1988).

Factors for Success. Sites adjacent to arterials (convenience factor); lots placed on or very near transit routes; reliable transit service; safety and security of lots to attract patrons; congested roadways; long commute trips; existence of travel time savings (e.g., linking HOV lanes to park and ride facilities promotes travel time savings); cost (lots also encourage patrons by saving downtown parking charges).

Complementary Measures. HOV lanes; parking management programs; improved transit; employer-based transportation management programs; area-wide ridesharing programs; automobile use restrictions in the CBD; work schedule changes.

Examples. Facilities are in use throughout the country, with Connecticut, California, and Texas reported to have the most extensive programs (CSI, 1986).

Effectiveness. Park and ride facilities reduce VMT but keep the number of trip ends relatively constant (some reduction of trip ends occurs in congested areas); thus, cold start emissions (a substantial percent of short-trip emissions), remain an important factor. Also, lots located at the periphery of the CBD may relieve congestion but not substantially reduce VMT—though they reduce emissions that could contribute to hot spot carbon monoxide problems in the urban core. Suburban lots facilitating pooling arrangements and transit use for longer trips are the most effective at reducing area-wide emissions. An overview of park and ride programs reported potential work trip VMT reductions of 4.1 percent for five Texas cities, and a 1.0 percent work trip VMT reduction in Connecticut (CSI, 1986).

Recommended Information Sources. Bowler et al., 1986; CSI, 1986; Pratt and Copple, 1981.

Parking Management Programs (On- and Off-Street)

There are a wide range of parking management opportunities to reduce peak and off-peak period congestion, promote ridesharing and transit use, and discourage vehicle use. Parking management can involve reducing excessive zoning requirements for parking, pricing policies, supply restrictions, and increased enforcement efforts. Example measures include employer-sponsored preferential parking programs, on-street parking bans during peak hours, reserved parking for short-term use, and parking rate changes to reflect full market value. Implementation opportunities are available to both the public and private sectors.

Innovative/Recent Implementation Efforts. New York City, through Project SMART (Strategies for Mobility, Access, and Reduction of Traffic) and other programs, has decreasd illegal parking rates by simplifying parking signs (47 percent reduction in midtown Manhattan signs) and doubled the number of vehicles towed through increased enforcement (Soffian et al., 1988). Knoxville, Tennessee and Portland, Oregon allow carpoolers to park free on otherwise metered streets if they display a dashboard permit; Bank of America in San Francisco has a graduated parking fee program—free parking for four-plus carpools with increasing charges for smaller groups and single-occupant vehicles—with parking subsidies paid for by each bank department to encourage self-enforcement (MTC, 1985).

Factors for Success. Increased parking rates—coordination among public sector rate increases and private sector garage services; transit service availability; high parking occupancy rates (one suggested rule of thumb is that no more than 15 percent of off-street/all-day parking spaces should be vacant in the affected activity center to justify the policy); rate increases should apply to majority of available facilities to avoid shifting the parking location. On-street parking bans—need to coordinate bans with truck loading activities, taxi and transit use; limited reliance on parked cars to provide "pedestrian buffer" on heavily used sidewalks. Parking reserved for short-term use—need for good transit service; inadequate parking currently available for short-term users (indications of this need include: full lots or garages, 80 percent-plus occupancy of on-street spaces, drivers "cruising" for parking spaces). Reduced-rate carpool parking—requires limited parking options (see Batchelder et al., 1983; CSI, 1986).

Complementary Measures. Ridesharing programs, park and ride lots, improved transit, employer-based transportation management programs.

Examples. Numerous programs throughout country. CSI (1986) illustrates more than a dozen programs.

Effectiveness. The potential for air quality improvements is significant; it is difficult, however, to quantify air quality effects. Programs are implemented but often not monitored; difficult to separate the parking program's effects from the effects of other variables; previous parking controls were often implemented just to reduce traffic congestion, with no air quality benefits estimated.

Recommended Information Sources. CSI, 1986; MTC, 1985; DOT, 1983; Suhrbier et al., 1979.

Road Pricing

A number of pricing mechanisms (with widely varying political acceptability) are available to curtail single-occupant vehicle use, fund transportation system improvements and control measures, spatially and temporally shift driving patterns, and attempt to effect land use changes. Primary examples include increased peak period roadway, bridge, or tunnel tolls; and toll discounts for pooling arrangements.

Innovative/Recent Implementation Efforts. In November 1988, increasingly severe commute period congestion problems spurred voters in the San Francisco, California, area to approve "Regional Measure 1," an increase in bridge tolls to fund transportation improvements. New technologies are emerging to electronically "scan" and charge motor vehicles as they pass through toll booths.

Factors for Success. Toll increases will have little impact on timing and frequency of long-distance trips passing through a region—effectiveness of peak period pricing will be greater as the percentage of intraregional commuters increases; effectiveness will be improved by the use of complementary measures (e.g., express transit service, park and ride lots, reduced fares for pooling vehicles); pricing increases require political acceptability and public support to relieve traffic congestion—officials need to be willing to impose tolls to collect adequate revenues to cross-subsidize transit or reduce demand.

Complementary Measures. Transit fare reductions (or peak/off-peak fares); HOV lanes; improved transit; area-wide ridesharing; park and ride facilities; employer-based/subsidized transportation management programs; restricted peak-hour truck deliveries; sales tax increases to support transportation improvements; congestion pricing; other "user fees" (motor vehicle taxes, commercial parking taxes, gas taxes).

Examples. Numerous programs throughout the country offer discounted pricing policies for multiple-occupant vehicles. Peak period pricing examples include the Trans-Hudson Crossings (Port Authority of New York and New Jersey), and the East-West Expressway in Miami, Florida (Batchelder et al., 1983). At least 17 states operate toll facilities; New York, Philadelphia, and San Francisco finance transit services through tolls (Johnson and Hoel, 1987).

Effectiveness. VMT effects vary depending upon the magnitude of the price change and the alternative transportation options available. Substantial revenue can be raised, particularly when the roadway demand is inelastic, without necessarily lowering VMT.

Recommended Information Sources. Johnson and Hoel, 1987; Small, 1983; see also, discussion in institutional guidance section on TCM financing approaches.

Telecommuting and Teleconferencing

Telecommuting and teleconferencing are approaches to eliminate home-to-work and work-to-work trips and substitute them with work-at-home or conferencing options. Telecommuting employees usually work at home; they may telecommute full-time, but typical arrangements for a worker involve both normal commuting and telecommuting periods. Teleconferencing (which can include computer communications and audio or video conferencing) targets work-to-work trips and eliminates or lessens the need for face-to-face business meetings. Related options include allowing employees to use satellite work centers (run by single employers) or neighborhood work centers (run by multiple employers); both options reduce work trip length by limiting the commute distance.

Innovative/Recent Implementation Efforts. The Washington State Energy Office is planning a Puget Sound Telecommuting Demonstration and Research Project to involve 10 to 15 of the area's major employers. The State of California's Department of General Services manages a telecommuting pilot project that began in mid-1987; telecommuter training took place in January and May of 1988, with some 230 participants; the project ends January 1990.

Factors for Success. Experience from California's pilot project suggests the following factors: support of senior management; the active "championing" of telecommuting by a lead figure during the initial phases of launching a telecommuting program; the voluntary participation of both telecommuters and their supervisors; pre-program screening to insure that appropriate personnel are selected to telecommute; training for both supervisors and telecommuters prior to beginning a telecommute program; minimal capital investment (many telecommuters do not use computers; those that do use computers often move them from their office to their home) (JALA, 1989). Additional issues may require that employers address cottage industry inspection laws, union work rules, liability for injuries occurring while working at home, and the application of OSHA regulations (CSI, 1986).

Complementary Measures. Work schedule changes; trip reduction ordinances; employer-based transportation management programs; road pricing; "no drive" days.

Examples. Government programs include the Telecommuting Pilot Project for the Southern California Association of Governments and the State of California Telecommuting Pilot Project; the U.S. Air Force and the U.S. General Services Administration are planning pilot projects to begin in 1990 (Gordon, 1989). Numerous corporate programs have been in place since the early to mid-1980s, for example Blue Cross/Blue Shield of South Carolina (16 computer staff); Control Data Corporation of Minneapolis, Minnesota (their Alternative Worksite Program has 100 participants); and NYNEX (New York Bell System), which has made sophisticated electronic equipment accessible to its telecommuting employees (SCAG, 1985).

Effectiveness. Little data is available quantifying the transportation or air quality effects of telecommuting projects. A review of some early (1973-1975) telecommuting studies noted that 14 to 22 percent of work-trip vehicle miles are potentially substitutable with telecommutes, and also noted Southern California Association of Government estimates that a 12 percent work-trip substitution would result in a 3 percent overall person-trip reduction and a 3.4 percent reduction in overall VMT (CSI, 1986). One potential problem associated with telecommuting is the opportunity for increased non-work trips. Little research is available, however, to document the potential effects telecommuting might have on non-work trips. In California, the South Coast Air Quality Management District's recently approved Air Quality Management Plan assumes that a 20 percent reduction in work trips due to telecommuting will result in a net 5 percent increase in non-work trips (SCAG, 1989). Preliminary results from the State of California's Telecommuting Pilot Project indicate that the average daily number of non-work trips might actually decrease among telecommuters; findings are preliminary and further research is needed (SCAG, 1989). Another study noted that a teleconference attracted more participants than "normal" conferences, thus generating an increase in VMT; however, since the increased travel was geographically distributed over a larger than normal area, it was not readily apparent what air quality effects resulted (Mokhtarian, 1988).

Recommended Information Sources. Fleming, 1989; JALA, 1989; Mokhtarian, 1988; Gordon and Kelly, 1986. Two newsletter sources are "Telecommuting Review: The Gordon Report," available from Gil Gordon Associates, Monmouth Junction, New Jersey (201-329-2266); and "Telecommunity," available from the Southern California Association of Governments (213-236-1881).

Traffic Flow Improvements

Measures improving traffic flow generally fall into two categories: those affecting traffic signalization, and/or improvements in traffic operations (e.g., street system improvements such as intersection widening, lane restriping, adding turning lanes, lane use restrictions). The measures are usually low-cost and seek to reduce delays and stops by increasing roadway capacity or smoothing out traffic speeds. However, from an air quality perspective, large-scale flow improvements may yield neutral or even negative results if the improvement induces more traffic in an area. Planners should carefully examine flow improvement proposals which would improve operations by approximately half a level of service, or which would reduce delays by approximately five or more minutes overall. Lane additions should be examined particularly closely (any proposed freeway additions; proposals to add lanes for more than a few blocks on surface streets).

Innovative/Recent Implementation Efforts. California's Fuel-Efficient Traffic Signal Timing Program (FETSIM). The program has retimed more than 5,000 signals across the state, producing, on average, 15 percent reductions in stops and delays; 7.2 percent reductions in travel time; and 8.6 percent reductions in fuel use. The retiming program has yielded 5-8 percent reductions in carbon monoxide and hydrocarbon emissions (Deakin, 1988).

Factors for Success. Success factors are specific to measures; for example, (1) for signal timing projects, it is necessary to have equipment capable of multiple timing plans and coordination (or the budget to install new equipment); also, signal retiming may be appropriate for areas with traffic growth in which signals have not been retimed within 3-5 years; and (2) improvement potential depends upon the availability of streets whose abutting land uses are suited to higher levels of through-traffic (e.g., it may not be appropriate to improve traffic flow in a residential area or in a shopping district).

Complementary Measures. Restricting movements and/or cross traffic; removing or restricting parking to off-peak periods; removing unnecessary stop signs; removing bottlenecks from congested roadways (e.g., loading zones, bus stops); implementing motorist advisory systems to warn drivers of congested routes; establishing programs to expedite removal of disabled vehicles; providing pull-outs for disabled vehicles; and implementing peak period pricing.

Examples. Traffic flow improvements have been widely implemented throughout the United States. Parking restrictions that improve traffic flow (e.g., limited on-street parking) are reported to be working particularly well in several major cities including San Francisco, New York, and Washington, D.C.

Effectiveness. Conducted regularly (every 3-5 years), signal retiming could reduce emissions 4-5 percent on the affected roadways (40 percent of all urban travel in California occurs on signalized roadways; few data are available for other states). Other measures must be analyzed on a case-by-case basis (Deakin, 1988).

Recommended Information Sources. ITE, 1988b; CSI, 1986; Batchelder et al., 1983.

Transit Improvements

Transit improvements broadly include measures to improve transit operations and transit management. Example operational improvements include changes involving bus routes and scheduling, express bus service, bus traffic signal preemption, simplified fare collection, long-range transit improvements, and paratransit (individualized service in small vehicles including "dial-a-ride," vans and vanpools, taxis). Example management improvements include marketing programs, maintenance changes, vehicle fleet upgrading, transfer improvements, fare changes. Both conventional, public-agency-sponsored transit services and private sector transit services are available.

Innovative/Recent Implementation Efforts. Timed transfer systems have greatly improved the quality of suburban service in many areas, including Portland, Oregon. Experiments have been conducted to offer free or reduced rate taxi service to transit users who must unexpectedly work late or leave the office early; some efforts are under way to provide service centers (e.g., for dry cleaning, child day care, banking, food shopping) near transit stops and park and ride lots. In New York City, an organization called Transit Center prepares transit vouchers (called TransitCheks) that businesses can distribute to encourage employees to use transit and allow them to take advantage of the federal government's $15.00 a month tax-free transit fringe benefit program (Soffian et al., 1988).

Factors for Success. Varies considerably depending upon measure; examples (from Batchelder et al., 1983) include

Bus transfer stations. Will attract more riders if located within walking distance of activity centers such as shopping malls or office complexes; also important to locate near existing trunk transit routes to decrease costs associated with extra running time; streets leading to activity centers should have limited congestion, and/or might include signal preemption for buses; information signage in and around transfer stations is important as are maps showing where nearby stops are located.

Expanded regular-route bus service. Generally, residential areas within a quarter mile of the bus route should have 4,000 or more people per square mile to generate enough passengers (20-25 passengers per hour); a density of 2,000 people per square mile will be acceptable if passengers can be drawn from within a half-mile on either side of a route.

Shared ride taxi. Intermediate service between transit and taxi service applicable to areas where a dispatcher can (80 percent of the time) combine rider requests within 15 minutes; usually requires a population density over 3,000 per square mile; best if trips are to serve major destination centers (e.g., airports, downtown areas, shopping centers).

Complementary Measures. Park and ride facilities, signal timing/preemption, pricing strategies (e.g., tolls), high occupancy vehicle lanes, parking restrictions.

Examples. Virtually all urban areas have transit services.

Effectiveness. The extent to which improved transit services may or may not reduce vehicle emissions will depend on the proportion of new riders using the new service instead of (1) a single-occupancy vehicle, (2) another transit service, or (3) walking or bicycling; the emissions associated with the new transit service; the characteristics of the vehicle trips being replaced by the transit service and the degree to which those trips' emissions are reduced (e.g., whether cold start emissions are reduced if short trips are still taken to the transit service facility) (see Appendix D for past experience summaries for specific transit program rules of thumb).

Recommended Information Sources. Batchelder et al., 1983; Pratt and Copple, 1981; DiRenzo and Rubin, 1978.

Trip-Reduction Ordinances (TROs)

TROs are local government actions designed to reduce VMT and trips. Example TRO components seek to encourage or require ridesharing; employer-based transportation management programs; developer-based intersection, roadway and public facilities improvements; employer completion of transportation surveys; impact or benefit assessment fees to fund expanded transit or transportation system operations; and trip-reduction requirements to offset zoning changes made to facilitate development plans. Most provisions apply to work trips. Implementation varies depending upon local government authority. For example, some TROs require peak-period trip reductions; others require reductions in total trips or VMT. TROs are appealing to EPA because (1) they are rules whose implementation can be enforced, (2) they apply to employers (sources attracting the vehicle emissions) but target single-occupant vehicles, and (3) employee participation is voluntary, encouraged through employer programs (Hawthorne, 1988).

Innovative/Recent Implementation Efforts. Perhaps one of the most widely publicized trip-reduction ordinances has been the transportation management ordinance implemented in Pleasanton, California beginning in 1984. (Despite its title, the ordinance actually sets out to keep traffic growth within acceptable limits, not to "reduce" trips.) Program success has been attributed, in part, to the fact that the TRO was cooperatively drafted by the city, employees, and developers (Gilpin, 1989).

Factors for Success. Coordinated area-wide programs (e.g., rideshare matching, parking management, HOV lanes, parking policies); equitable application of ordinances to entire classes of employers and developers; established procedures to monitor and improve program effectiveness; coverage to include existing and new employers, multi-employer buildings and complexes; small minimum employer size (e.g., 50-100 people); required annual employee survey and annually updated trip reduction plan; ongoing information (including guidance) and promotion program; performance standards based on area-specific data; minimal paperwork; oversight committee with broad representation from employers, developers, employees, and city (Deakin, 1988); strong enforcement to avoid "paper" compliance.

Complementary Measures. Area-wide ridesharing, park and ride lots, employer-based transportation management programs, parking management, HOV lanes, transit improvements, bicycle and pedestrian facilities, flexible/staggered work hours.

Examples. More than 50 TROs have been adopted around the country; earliest example covering existing employment centers is in Pleasanton, California; one of the most recent and comprehensive has been adopted in the Los Angeles, California region ("Regulation XV") by the South Coast Air Quality Management District.

Effectiveness. TROs are relatively new and there is limited information on their effectiveness to date. Effectiveness will be determined by TRO's focus—if focused on peak hour trips from large (e.g., more than 500 people) employers, only 2-5 percent of an area's trips are targeted; an ordinance focusing on the peak commute period (three-hour periods for commute traffic in morning and evening) and employers of 100 or more people might target 15-20 percent of area trips. VMT and trip reductions will depend on the effectiveness of individual programs (Deakin, 1988). However, TROs may come as close as any TCM to providing "enforceable" VMT reductions.

Recommended Information Sources. Caltrans, 1989 (this is a directory of TROs in California); Pultz, 1988; DOT, 1986; MTC, 1985; Brittle et al., 1984.

Voluntary No-Drive Days

Programs to encourage "no-drive" days seek to lower VMT during seasons when pollutant problems occur, and/or during specific high pollutant concentration episodes. Programs typically market the need to reduce nonessential trips and to find alternative work transportation for one weekday. Programs usually "assign" no-drive days to drivers on the basis of license plate numbers. For example, the Denver Better Air Campaign (BAC) asks drivers to leave cars at home on the basis of the last number in their license plate: Monday, 0-1 and personalized plates; Tuesday, 2-3; Wednesday, 4-5; Thursday, 6-7; Friday, 8-9 (Market Analysis Professionals, 1988).

Innovative/Recent Implementation Efforts. Opportunities exist for public/private partnerships to jointly promote and sponsor a "no-drive" program. In Arizona, the Phoenix Chamber of Commerce and the Arizona Broadcasters Association started a "Clean Air Force Campaign," including a "Don't Drive One in Five" theme. Various local and state public agencies (the Regional Public Transportation Authority, the Arizona Energy Office, the Arizona Department of Environmental Quality) later joined with these private groups to promote and expand the program. Arizona's program was modeled on programs in Denver and Colorado Springs, Colorado.

Factors for Success. Coordination among all agencies/groups; business community participation and support; advertising and promotion through all media; public awareness of the interrelationships between air quality and vehicle use, and public commitment to improved air quality goals.

Complementary Measures. Ridesharing programs; telecommuting programs; transit and paratransit improvements; alternative work schedules; trip-reduction ordinances; employer-based transportation management programs; HOV lanes; park and ride lots; pricing strategies.

Examples. "Clean Air Force Campaign, Don't Drive One in Five" (Maricopa County Arizona); and the Colorado Department of Health's "Better Air Campaign" for Denver, Colorado. Both programs target winter-month driving to reduce carbon monoxide levels.

Effectiveness. Effectiveness of voluntary programs varies substantially from region to region depending on the level of commitment and effort expended to educate the driving public and market the importance of the "no-drive" program. Maricopa County, Arizona's program apparently achieved a 2.8 percent reduction in VMT for November-January (1988-89). Although initially thought to result in substantial trip reductions, recent data indicate the Denver BAC may achieve about a 1 percent VMT reduction (Scheuernstuhl, 1989). Tools to measure effectiveness include before and after traffic counts, transit patronage statistics, rideshare application trends, and survey results monitoring public awareness and participation rates (MAGTPO, 1988). It is important to note that it is very difficult to predict the effectiveness of a voluntary no-drive program prior to its implementation. EPA will only grant emission reduction credit to a program after several years of data have been collected that demonstrate the program's effectiveness.

Recommended Information Sources. Grady, 1989; supplemental readings that focus on marketing efforts, for example: Murray, 1986; Lovelock et al., 1987.

Work Schedule Changes

"Flex Time" or flexible work hours (the opportunity to vary work schedules) and staggered work hours (the opportunity to work a set schedule at times other than the routine work schedule) can help to spread work trip traffic patterns over a wider commute period and thus reduce congestion during normally peak periods (transit crowding can also be relieved). Similarly, "4/40" programs or compressed work weeks allow employees to work a week's worth of hours during a period less than five days, thus shifting traffic to nonpeak periods and completely eliminating some trips on certain days. All three schedule-changing measures can reduce congestion-producing emissions (i.e., decreased emissions due to reduced stop-and-go traffic and slower speeds); compressed schedules can also reduce VMT (though increased nonwork trips may result during the extra days off). A potential problem with work schedule changes is that they may reduce the number of "matches" for carpools.

Innovative/Recent Implementation Efforts. Lockheed Company in Sunnyvale, California implemented an aggressive "find-a-rideshare-replacement program" along with its staggered work hours plan; since work schedule changes can disrupt ridesharing arrangements, the replacement program helped to maintain rideshare levels as work hour changes occurred (MTC, 1985).

Factors for Success. In general, for schedule changes to be successful, (1) 15-30 minute periods of relatively low density traffic should be consistently observable during acceptable commute periods; (2) an activity center should contain at least 40 percent of the employment within a 1-2 mile radius if congestion is to be relieved on the surrounding street or transit network; (3) alternating hours in one firm of 1,000 or more employees may be sufficient and more practical than staggering hours for a number of smaller firms; (4) transit to the work area should service all times under alternative schedules (Batchelder et al., 1983). For specific program options, the following factors are important:

> Staggered Hours. Works well in a variety of environments, particularly assembly line and multiple shift production facilities.
>
> Flex Time. Works well with office environments; difficulties arise when business involves face-to-face communications, inter-employee/departmental interactions, or assembly line work, or when it requires continuous coverage. Priority should be given to individuals who use flex-time to rideshare.
>
> Compressed Week. Works best in manufacturing settings, though there has been some success with government worker office settings. Of the three options, this has the highest failure rate because of worker fatigue, scheduling difficulties, and employee dissatisfaction (MTC, 1985).

Complementary Measures. Employer-based transportation management programs; trip-reduction ordinances; improved transit; increased area-wide ridesharing efforts; HOV lanes; ramp metering.

Examples. Numerous programs exist throughout the country; a study in the late 1970s indicated over 12 percent of United States private sector businesses with 50 or more employees had alternative work schedule options, with approximately 6 percent of all employees adopting alternative hours (Nollen and Martin, 1978).

Effectiveness. Flex time lets workers adjust schedules to match transit services and enter into pooling arrangements (though some studies show that transit use actually decreases as workers switch to carpools or other modes); few or no mode shifts occur with staggered and compressed schedules; compressed schedules appear to lower total VMT (i.e., both work and nonwork VMT); little data is available describing VMT reductions achieved; results from four cities show a 10-50 percent reduction in peak-period (i.e., 15-minute to 1-hour peak period) employee arrivals with flex/staggered time; travel time savings vary considerably among participants (CSI, 1986).

Recommended Information Sources. MTC, 1985; Dynatrend, Inc., 1983; Pratt and Copple, 1981.

SAMPLE PACKAGING ARRANGEMENTS

This section broadly summarizes and identifies information concerning which measures appear to work best with one another. As identified in the TCM descriptions, many measures complement one another though there are also some situations when jointly implemented measures detract from their individual effectiveness. On occasion, depending upon local conditions, packaged measures might or might not act to improve their aggregate effectiveness.

An important consideration is the need to package incentives for TCM use with, in some cases, disincentives to single occupant vehicle (SOV) use. The mere provision of a measure may not mean that travelers will use alternate transportation modes. For example: numerous park and ride facilities have been provided in the Denver area over the past five years in part to encourage transit use; however, the number of individuals riding Denver's express bus system has failed to increase during this period (Scheuernstuhl, 1989). The implication is that the Denver measures need to be packaged with further incentives (or disincentives). Whenever possible, planners should examine the potential to use packaging arrangements to increase TCM effectiveness.

Several analytical approaches are available to planners who need to package measures. One approach involves using professional judgment; another relies on network simulations (and the use of travel demand models as described in the technical guidance section); a third option combines network simulation with benefit-cost analysis to rank the implementation order for measures. From a practical standpoint, the most useful approaches are likely to combine quantitative and qualitative analysis to determine which TCMs to package together.

The TCM literature provides guidance that can make the analytical task easier. This information falls into two categories: (1) generally observable synergies that suggest packaging arrangements (e.g., linking ridesharing programs with park and ride lots); and (2) more complex arrangements targeted to specific traffic or demographic conditions.

Generally Observed Packaging Strategies

As suggested by the TCM descriptions presented earlier in this section, general observations are readily made as to which measures work well together. A summation of these findings is presented by Rosenbloom (1978):

> In general, it was found that improvements in driving conditions work counter to efforts to shift commuters from their own cars onto public transit or to participate in ridesharing programs. Penalties associated with driving, on the other hand, support these efforts, as well as attempts to reduce overall travel by changing land uses and substituting communications for work trips. All transit improvement and incentive techniques are mutually supportive to a high degree. Carpooling, which in itself appears to be a moderately effective and inexpensive approach, does not blend well with many other approaches; efforts to reduce travel demand by changing land use, to spread peak commuting times, to provide transit alternatives, or to improve traffic flow through improvements to roadways all reduce the motivation for participating in prearranged ride-sharing.

Figure 2-1 presents a summary of the general compatibility of the 12 measures profiled in this guidance document. The figure represents a broad summary of the findings presented in the literature and reviewed for each of these 12 measures--individual cases may require different packaging strategies.

Packaging Arrangements Targeted to Specific Problems or Demographic Conditions

Specific problems are best approached by constructing packages tailored to the site's needs. The city of Boston is one example of an area that took a tailored-package approach. Boston planners established an auto-restricted-zone (ARZ) to meet a variety of site-specific traffic mitigation goals. The Boston ARZ package included parking restrictions, pedestrian-only streets, intersection realignments, traffic light signalization changes, revised one-way street patterns, and bus route modifications designed iteratively until an optimum approach was identified (Weisbrod, 1982).

Two examples in the literature that offer suggested packaging approaches for specific problems are Rosenbloom (1978) and Batchelder et al. (1983). In Rosenbloom, eight TCMs are cross-matched to determine their compatibility. They are then ranked as to their capability for solving congestion problems in five scenarios: large city CBDs, small city CBDs, urban freeways and arterials, roadways with strong one-directional flow, and roadways with limited options for alternative routes. For example, transit improvements are identified as the top-ranked approach for solving congestion problems in large city CBDs and on urban freeways and arterials; transit improvements are also identified as being compatible with work

	Area-wide Ridesharing	Bicycling	Employer Programs	HOV Lanes	Park and Ride	Parking Management	Road Pricing	Traffic Flow Improvements	Transit Improvements	TROs	No-Drive Days	Work Schedule Changes
Area-wide Ridesharing		0	+	+	+	+	+	—	—	+	+	?
Bicycling	0		+	0	0	0	0	0	0	+	0	+
Employer-based Transportation Management	+	+		+	+	+	+	—	+	+	+	+
HOV Lanes	+	0	+		+	+	+	—	+	+	+	?
Park and Ride	+	0	+	+		+	+	—	+	+	+	+
Parking Management	+	0	+	+	+		+	0	+	+	+	0
Road Pricing	+	0	+	+	+	+		—	+	+	+	0
Traffic Flow Improvements	—	0	—	—	—	0	—		—	—	—	0
Transit Improvements	—	0	+	+	+	+	+	—		+	+	?
Trip-Reduction Ordinances	+	+	+	+	+	+	+	—	+		+	+
Voluntary No-Drive Days	+	0	+	+	+	+	+	—	+	+		+
Work Schedule Changes	?	+	+	?	+	0	0	0	?	+	+	

Key

+	Mutually supportive measures	0	Limited or no interaction
—	Conflicting measures	?	Will vary with situation

FIGURE 2-1. Example packaging considerations among selected TCMs (note these associations are general; individual cases may vary).*

* For further examples and discussion, see Rosenbloom, 1978; Wilbur Smith & Associates, 1981; Horowitz, 1977.

hour changes, pricing techniques, and restricting roadway access, but they are incompatible with ridesharing and traffic engineering (Rosenbloom, 1978). Figures 2-2 and 2-3 show Rosenbloom's findings.

In a more comprehensive review, Batchelder and co-workers identify six broad problem categories and packages of transportation system management options appropriate for specific problems within each category. The categories include problems (1) at intersections or on street segments, (2) in corridors, (3) in residential communities, (4) in employment centers, (5) at commercial centers, and (6) at regional, state, and national levels (Batchelder et al., 1983). The findings are too extensive to summarize in this document; readers are referred directly to the Batchelder report.

RECOMMENDED SOURCES FOR MORE SPECIFIC INFORMATION

This review has highlighted the type of information available concerning specific measures, their effectiveness, locations where they have been implemented, and their compatibility with other TCM strategies. Table 2-4 identifies seven references that provide detailed descriptive material for a number of TCMs. In addition, one of the documents identified in Table 2-4 (ITE, 1988) includes a detailed bibliography of additional source material for specific measures. Appendix C profiles examples of actual TCM identification, analysis, and implementation. Appendix D lists past experience and potential "rules of thumb" for forecasting the effectiveness of nine broad TCM categories.

Basic Package	Supplementary Package							
	Work-hour changes	Pricing techniques	Restricting access	Changing land use	Prearranged ridesharing	Communications substitutes	Traffic engineering	Transit treatments
Work-hour changes		+	0	0	-	+	-	+
Pricing techniques	+		0	+	-	0	-	+
Restricting access	0	0		+	-	0	+	+
Changing land use	0	+	+		0	+	-	-
Prearranged ridesharing	-	0	0	0		0	-	-
Communications substitutes	0	+	0	+	-		-	-
Traffic engineering	+	0	-	+	-	0		-
Transit treatments	+	+	+	0	-	0	-	

Key	
+	Supportive
0	Neutral
-	Conflicting

FIGURE 2-2. Packaging opportunities for eight measures proposed by Rosenbloom (1978).

	Major Problem Areas			Special Problem Areas	
	CBD's of Large Citites	CBD's of Small Cities	Urban Freeways and Arterials	Roadways with Strong One-Directional Flow	Roadways with Limited Options for Alternative Routes
Work-hour changes	5	7	5	5	5
Pricing techniques	2	1	8	7	1
Access restriction	4	2	6	8	6
Land-use changes	3	5	3	4	3
Prearranged ridesharing	6	6	4	3	4
Communications substitutes for travel	8	8	7	6	8
Traffic engineering techniques	7	3	2	1	7
Transit treatments	1	4	1	2	2

Key
1 = Most effective
8 = Least effective

FIGURE 2-3. Ranking of the proposed packages' applicability to five traffic congestion locations.

Source: Rosenbloom, 1978.

TABLE 2-4. Recommended documents to examine that provide descriptive information for a number of TCMs.

Reference	Description	Availability
"Measures of Effectiveness for TSM Strategies"; FHWA/RD-81/177 (Abrams et al., 1981).	This study provides a comprehensive look at 60 transportation system management tactics. The report classifies the tactics by major characteristics (effect on mode choice, primary population group to which tactic applies, how tactic affects trip-making characteristics, geographic application, time requirements, and institutional elements); an appendix also provides a complete description of each tactic. The document also identifies "measures of effectiveness" (MOEs) for each tactic, and reviews analytical tools to weigh changes in MOEs once TSMs have been implemented. Case studies and data collection procedures are also included. Though somewhat outdated, this is still a valuable reference.	Available through the National Technical Information Service (NTIS), 5285 Port Royal Road Springfield, VA 22161. 703-487-4650
"Traveler Response to Transportation System Changes." Second Edition (Pratt and Copple, 1981).	This is another comprehensive text describing nine categories of TCMs (including numerous examples of individual measures within each category) and their expected impacts on traveler behavior. The materials summarize the principal findings of all major TCM literature available at the time the report was written. The chief drawback to this report is that no documents published after January 1980 are considered. However, given the substantial body of information available during the late 1970s, this document reflects a wealth of knowledge concerning TCMs. The document includes examples of measure implementation, quantifies effectiveness, offers rules of thumb for estimating future effectiveness, provides an annotated bibliography of TCM source materials, and details numerous insights into what promotes TCM effectiveness.	Available from the Federal Highway Administration, Highway Performance Analysis Branch, Local Assistance Program, Washington, D.C. 202-366-4071.
"Simplified Procedures for Evaluating Low-Cost TSM Projects"; NCHRP Report 263 (J. H. Batchelder et al., October 1983).	This report includes profiles of 37 specific transportation system management (TSM) projects; profiles include a brief discussion of the project, the types of problems the project can address, criteria for successful application, potential implementation problems, evaluation factors, and further references. The report provides valuable additional information including a framework for project implementation, impact estimation procedures, and TSM screening aids. A companion training manual is also available (NCHRP Report 283; J. M. Mason et al., April 1986).	Both documents are available from the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue N.W., Washington, DC 20418. 202-334-3214

continued

TABLE 2-4. Concluded.

Reference	Description	Availability
"Commute Alternatives, A Manual for Transportation Coordinators" (MTC, 1985).	This manual offers descriptions of five TCM categories (ridesharing, transit, cycling/walking, alternative work schedules, and parking management), pros and cons of various implementation options, and key considerations to successfully implement commute alternatives. Though covering only northern California employers, the manual's sample success stories are also informative.	Available from the Metropolitan Transportation Commission, Metrocenter, 101 8th Street, Oakland, California 94607. 415-464-7836
"Improved Air Quality in Maricopa and Pima Counties--The Applicability of Transportation Measures" (CSI, 1986).	For each of 12 TCM categories, this study describes each measure; reviews U.S. implementation experiences relative to the measure's effectiveness in reducing emissions and improving air quality; and describes factors influencing successful implementation and program compliance issues. Though developed for two Arizona urban areas, general project findings have national relevance.	Available from the U.S. Environmental Protection Agency, Air and Toxics Division, Region IX, A-2-1 75 Hawthorne Street, San Francisco, California 94105. 415-744-1210 (ask for TCM contact)
"Strategies to Alleviate Traffic Congestion," Proceedings of ITE's 1987 National Conference (ITE, 1988).	Part 1 includes conference presentations; Part 2 includes a reader developed to accompany the proceedings. Together, both parts constitute an overview of numerous transportation control strategies and implementation concerns. The reader (Part 2) also includes a supplemental reading list that serves as a useful bibliography for specific TCMs.	Available from the Institute of Transportation Engineers, 525 School St. S.W., Suite 410, Washington, DC 20024. 202-554-8050
"A Toolbox for Alleviating Traffic Congestion" (Meyer et al., 1989).	This report examines the causes behind growing traffic congestion problems and describes specific actions that can help solve these problems. For each action, the report presents a description, costs and benefits, a discussion concerning implementation, and references for further information. The report often cites examples where these actions have been implemented to date, and in some cases describes their long-term effectiveness. The report covers nearly 40 traffic control options (other than building new capacity), and also includes a discussion on funding and institutional measures.	Available from the Institute of Transportation Engineers, 525 School St., S.W., Suite 410, Washington, D.C. 20024. 202-554-8050

89058r2 3

3 INSTITUTIONAL GUIDANCE

INTRODUCTION

This section focuses on institutional guidance; it is designed to help government officials evaluate the suitability of a transportation control measure or package of measures for a particular area, determine who should take the lead on and be involved with TCM planning, and assess and devise funding strategies to support planning and implementation.

There is a considerable body of experience from which to distill examples of TCMs. TCM planning and implementation were carried out in the early and mid-1970s under the 1970 Clean Air Act Amendments; TCM plans and programs were updated and elaborated upon under the 1977 Amendments. Parallel work was carried out in the 1970s as a major element of energy conservation and energy contingency efforts, as well as under the transportation systems management (TSM) regulations promulgated by the Federal Highway Administration and the Urban Mass Transportation Administration in 1975. Recent initiatives in congestion management and traffic mitigation provide additional examples.

One insight gained from this body of experience is that the "fit" between a TCM and the area in which it would be implemented, organizational arrangements and assignments of responsibility for the TCM, its political acceptability, and the amount and quality of the resources available for its implementation are as important to the TCM's success as its technical feasibility. Indeed, one of the stumbling blocks reducing implementation effectiveness has been a tendency to assume that the institutional issues* will "take care of themselves" or will be easily dealt with through a top-down, command-and-control approach. Another lesson from experience has been that institutional considerations need to be an integral part of the evaluation of TCMs, both because they are strong determinants of effectiveness and because an

---

* As used in this discussion, the term "institutional issues" is a shorthand for the set of interrelated factors affecting implementation, including organizational authority and assignments of responsibility, locus of professional skills and expertise, financing availability and control, decision-making structure, and formal and informal relationships among organizations, as well as relations with the broader public and responsiveness to public concerns.

implementation strategy must be developed through careful, explicit planning of institutional as well as technical aspects. Whenever possible, strategy should be developed with the participation of those who will be responsible for implementation activities.

These matters are the focus of this discussion. The material presented here provides an overview of implementation issues and then considers a series of specific issues that will need to be confronted in assessing TCM implementability and devising implementation strategies. Examples are then presented to illustrate the points for several commonly considered TCMs.

TCM IMPLEMENTATION ISSUES: AN OVERVIEW

TCM planning usually begins with an initial screening of a comprehensive list of alternatives, with the focus of the analysis on potential effectiveness. A variety of analysis techniques have been developed to assess TCMs, ranging from detailed modeling and forecasting methods to first-cut estimates made by applying simple rules of thumb or by drawing comparisons to experiences in similar cases (Section 4 discusses these approaches). Regardless of the level of analytical complexity, a shared feature of many of these methods is that they identify TCMs' emissions reduction potential, assuming that implementation will occur ubiquitously and will be fully effective as proposed. For example, free parking for carpools and vanpools might be modeled as a reduction in vehicle operating costs available to all shared-ride vehicles; coordinated traffic signal timing might be assumed to be carried out in every jurisdiction and to be as effective there as its average effectiveness in reported cases.

Practical considerations often preclude ubiquitous implementation of a particular TCM or limit its effectiveness. In the free parking for carpools and vanpools example, some parking operators may resist providing even a discount unless they are compensated for lost revenues; however, public funds to provide such compensation may be unavailable, and public authority to impose the free-parking-for-poolers mandate may be lacking or uncertain. In the traffic signal timing example, some jurisdictions may lack the kinds of signal equipment needed to effectively coordinate signal timing. In either case, implementation would likely fall short of that assumed in the technical analysis.

Interactions among TCMs also may affect their impact in ways not always fully reflected in first-cut technical analyses. For example, the availability of parking facilities at suburban transit stations may substantially increase the feasibility of transit use for many commuters, but may also reduce the viability of suburban bus services by cutting into the market for feeder services. Flextime and telecommuting programs could reduce not only auto traffic but transit ridership as well, making higher levels of transit service impractical. Traffic flow improvements may reduce congestion-related emissions but simultaneously reduce the incentive for a shift away from solo commuting.

Coordination of various TCMs to minimize contradictory results and maximize mutually supportive outcomes can be particularly complicated, since implementation responsibilities are usually scattered among a number of public and private organizations. One transit agency may run the rail system, and another, the suburban bus system; the two may not coordinate services and may think of themselves as competitors. Employers may reschedule work hours to suit business and employee needs and to reduce commutation during congested periods, but offer free parking to all who wish it and expect employees to have a car available for work-related trips. Traffic engineers may seek to make it easier for commuters to travel by auto at the same time that planners are implementing parking prices to discourage auto commutes.

Finally, political and institutional acceptability can be a primary determinant of whether a TCM moves from a "paper exercise" to implementation. For example, analyses of road pricing and parking pricing almost always find these strategies to be highly effective; yet their implementation has been extremely limited because many decision makers are convinced that their constituents would not tolerate the use of price as a restraint on access to, or use of, public facilities. City staff may also believe auto restrictions will hurt the local economy and refuse to implement certain transit priority and parking management measures.

A critical step in the TCM planning process is to identify and assess the implementation environment for each TCM or package of TCMs, both to adjust estimates of TCM effectiveness and to aid in the development of effective implementation strategies. Such an assessment must address several considerations:

- TCM scope and "fit" in the particular implementation context;
- Responsibility for TCM implementation;
- Funding needs and resources; and
- The TCM's political and institutional acceptability.

Each of these considerations is discussed in some detail in the pages that follow. Table 3-1 provides an overview of issues to be considered under each major heading.

ASSESSING TCM SCOPE AND "FIT"

How much emissions reduction any one TCM actually accomplishes depends on several factors. The initial screening usually will have determined the mode(s) of travel the measure affects, the type(s) of trips affected, and the resulting effect on

TABLE 3-1. TCM implementation issues.

Relationships Among TCMS

- complementarity among measures
- conflicting actions; assessment of degree to which they can be controlled or managed
- opportunity to "piggyback" on other programs, objectives (congestion relief, energy conservation,...)

TCM Effectiveness

- likely size and location of the market(s) for the TCM (e.g., trip purpose(s) affected, mode(s) affected, percent of trips affected, geographic scope of implementation)
- local experience with the TCM; level of success
- distribution of costs and benefits from the measure; time required for benefits to begin; duration of benefits; performance over time

Resource Requirements (Personnel and Funding)

- identification of legal authority for the TCM; need for change in legislation or regulations to provide clear authority or remove impediments
- identification of organization(s), if any, with responsibility for the TCM; organizations whose cooperation and consent (or acquiescence) would be needed; degree of support or resistance likely
- identification of skills needed to develop detailed implementation plans (engineering, planning, economics, legal, ...); resources and time required
- fundability of the TCM: possible sources of funding for the TCM; decision process for allocation of funding (decision locus, amount of discretion, etc.); time required to obtain funds

---

continued

TABLE 3-1. concluded

Acceptability
• probable political acceptability of the TCM; likely sources of support; likely sources of opposition/resistance
• degree of compatibility/conflict with established organizational objectives, procedures; compatibility/conflict with other desired projects or actions

emissions. Implementation experience may differ from forecasts for reasons beyond the direct control of planners and engineers. Changes in exogenous factors such as the rate of population growth, the mix of employment type, and transportation prices can undermine measures' effectiveness; cheap fuel has had this effect in recent years. While such changes cannot always be fully anticipated, sensitivity of the forecasts can usually be tested. Institutional issues, in comparison, often can be anticipated and plans made to take advantage of opportunities or overcome barriers. Among the issues to be considered are (1) whether there is a broad market for the TCM or a small one, (2) how widely the measure will be implemented, and (3) whether there is full or only partial compliance.

Market Potential

If it has not already been done as part of the technical analysis, it is important to assess the market potential for the TCM, in particular, the number and types of trips and percentage of travel that the TCM is likely to affect. For example, many of the measures included in transportation-air quality plans, and particularly the demand-oriented ones, apply only to work travel. Ridesharing programs, flextime, and, to a large extent, transit services and incentives, are aimed at commuters.

The trip to work is a natural target, both because it is the most susceptible to shifts to alternative modes and because it is most likely to occur in congested conditions and during critical periods for air standards violations. Work trips, however, account for only a third of the vehicle miles traveled (VMT) and 20 to 25 percent of the trips in most cities. This factor needs to be recognized both in estimating the TCM's overall impact on emissions and in considering the magnitude of the TCM's effects on travel.

Suppose that 70 percent of the workers in a community drive alone. Shifting fully half of these commuters to alternative modes would affect only about 11 percent of the VMT and less than 8 percent of the trips. Since a more likely shift would involve less than 10 to 15 percent of the drive-alone trips (Horowitz, 1982), net benefits per work-trip-oriented measure probably would not exceed a few percentage points in overall air pollution reduction.

Many TCMs, moveover, tend to be most beneficial during peak periods. Flexible work hours, for example, are valuable as a TCM primarily because they may reduce peaking (hence congestion); offered outside of the peaks, flextime may provide a social, but not necessarily transportation, benefit. A number of traffic engineering and operations measures are also peak-oriented. Some, e.g., ramp metering, may operate only during peaks. Others, such as added intersection capacity, may not be particularly needed at other times of the day. It is necessary in these cases to account for the share of trips that occur during non-peak periods.

Many TCMs target specific types of urban environments (e.g., CBDs) or specific kinds of facilities. The scope of implementation of the TCM determines the percent of targeted trips affected. For example, auto-restricted zones (ARZs) can reduce emissions and exposure levels in areas that otherwise would be heavily congested (although emissions may simply be diverted to other, unrestricted routes). However, ARZs are suited to a relatively few places, mostly central business districts and other concentrated areas of activity. Only trips that would otherwise have entered such areas would be directly affected. Similarly, freeway traffic flow improvements have an effect only on those trips using the freeway and perhaps using parallel routes (where the effect could be positive if trips switch to the better-flowing freeway, or negative if trips are stored on arterials in order to keep the freeway moving).

Market Size

The size of the target market is also important. To illustrate, substitution of a bicycle trip for an auto trip is extremely effective in eliminating emissions, but is realistic and attractive for relatively few people. As another example, a city-wide tax on parking would affect the travel choices of only those commuters for whom the tax raised the cost. If employers or businesses were to pay for the parking, reductions in travel would be highly unlikely. In many areas the affected market segment would be very small; only 10 to 20 percent of all employees, and virtually no customers or clients, pay for parking.

This sort of review of analysis results and qualitative assessment of TCM market potential can have at least two beneficial effects. First, estimates developed through the technical analysis can be refined. Second, the assessment may point to ways to address a broader range of trip types and/or off-peak travel, thus leading to a new round of analysis of a broader or farther-reaching set of alternatives. Several iterations of quantitative analysis and qualitative assessment of the results can be carried out to refine TCM strategies. Together, this information can help analysts and policy makers set priorities for detailed planning and implementation.

DETERMINING RESPONSIBILITY FOR TCM IMPLEMENTATION

Clear assignments of responsibility for detailed TCM planning and implementation are critical to the success of a transportation-air quality program. Some TCMs are clearly the responsibility of one agency or require a specific and well-defined set of disciplinary skills; traffic signal timing, a traditional traffic engineering responsibility, is an example. However, other TCMs (such as parking management) cut across planning, engineering, and finance expertise and organizational lines of responsibility, and a few TCMs (such as road pricing) are not clearly within the scope of authority of any organization or set of organizations.

A useful way of sorting through these issues is to begin by grouping TCMs according to their effect on transportation system functions. TCMs can be grouped into four categories, according to their primary objective or effect:

- Operational improvements for emissions reduction. These measures are intended to directly reduce vehicular emissions without necessarily changing the amount of auto use by (1) improving the operating conditions for autos through traffic flow improvements, (2) shifting trips to less congested routes through route guidance or route restrictions, and (3) shifting travel to less congested time periods.

- Improvements to alternative modes. These measures increase the attractiveness of transit, carpools and vanpools, bicycling, and walking in comparison to the single-occupant auto through (1) direct investments in the alternatives, (2) investments in support facilities, and (3) subsidies and other incentives.

- Disincentives to auto use. These TCMs are designed to discourage auto travel (or often, single-occupant vehicle (SOV) travel, usually by restricting vehicular or SOV movements at certain times or in certain places, or by removing subsidies, increasing costs, or decreasing convenience.

- Reducing the need for travel. These measures allow individuals to engage in desired activities with less travel, e.g., by substituting communications technologies or arranging land uses so that trips can be consolidated or shortened.

A more detailed listing of TCMs for each of the four categories is presented in Table 3-2, along with a preliminary identification of common assignments of responsibility for each category and subcategory.

The first category includes measures that are intended to reduce emissions without significantly changing travel behavior or reducing VMT. The strategies are supply- and operations-oriented and would require traffic engineering skills for implementation.

Categories 2 and 3, in contrast, are intended to reduce emissions by reducing VMT. They explicitly intend to alter travel behavior, through incentives in some cases and disincentives in others. They are demand- and market-oriented, and their implementation would require skills in planning and economics as well as more traditional engineering.

TABLE 3-2. Transportation control measures: Examples and typical responsibilities.

(1) Operational improvements for emissions reduction: traffic flow improvements

(a) Improving traffic flow conditions through road improvements and better utilization of existing capacity

Responsibility: traffic engineers and operations specialists in local and state agencies

Examples:

- new roads; added lanes
- intersection widenings; over- or underpasses
- provision of left- and right-turn lanes
- peak period on-street parking bans
- efficient signal timing
- freeway ramp metering and flow metering
- timely accident removal

(b) Shifting trips to less congested routes

Responsibility: traffic engineers and operations specialists; currently primarily a research and demonstration activity)

- route guidance
- route restrictions
- corridor management

(c) Shifting trips to less congested times of day/days of week

Responsibility: employers, for work rescheduling (often for purposes other than transportation impact); other strategies are not well institutionalized; primarily a research and demonstration activity with state, regional, local, and private sector examples

- flextime programs
- staggered work hours
- staggered work weeks
- congestion pricing
- peak period restrictions on travel, deliveries

continued

TABLE 3-2. continued

---

(2) Improvements to alternative modes: shifting travel to less polluting modes

(a) Provision of/improvements to commute alternatives

Responsibility: transit agencies; ridesharing agencies; some regional and state participation; increasing local and private sector activity)

- better transit: denser networks, increased frequency, direct service, express service, timed transfers

- specialized services: shuttles, club buses, shared taxis

- programs to market, promote, and assist carpooling, vanpooling, bicycling, walking

(b) Provision of related facilities

Responsibility: traffic engineers and operations specialists; planning offices and private sector for transit, bike, pedestrian facilities

- HOV lanes, bypasses on freeways and local streets
- HOV signal preemption on-ramps, major intersections
- improved transit stops, shelters, stations
- park-and-ride lots
- parking facilities for carpools, vanpools
- bike paths and parking
- walking paths and sidewalks

(c) Subsidies/other incentives:

Responsibility: transit and ridesharing offices; increasing local government and private sector activity

- transit passes, employer provided or subsidized vehicles for pooling, mileage payments for bike, walk use

- preferential parking allocation, location, and price for HOVs

- guaranteed rides home; midday transportation; short-term auto rentals

---

continued

TABLE 3-2. concluded

(3) Disincentives to auto use: reducing auto use and removing auto subsidies

Responsibility: varies with measure--ridesharing and transit agencies, local planning departments, private sector; pricing measures not well institutionalized

- promotion of voluntary no-drive days
- vehicle-free zones, transit malls
- area entry licenses
- parking by permit only
- congestion tolls, entry tolls
- parking pricing
- control of parking supply, location, use, rates
- no free employee parking for solo commuters

(4) Reducing the need for travel: eliminating some trips altogether

(Responsibility: not well institutionalized; primarily a research and demonstration activity with state, regional, local, and private sector examples)

- telecommuting
- teleconferencing
- delivery services
- automatic payroll deposits

The final category emphasizes control of emissions without necessarily altering either transportation facilities or travel demand through substitution of telecommunications for travel. Although this latter strategy raises questions of technological readiness and cost, it does not require change in travel behavior, nor in the investment patterns that transportation agencies follow.

As Table 3-2 indicates, TCMs that are primarily oriented toward improving streets and highways tend to be implemented by engineering organizations and groups, while alternatives to private vehicular travel are provided by transit agencies, ridesharing organizations, and employers. Pricing, auto restrictions, and other demand-reducing strategies are more often the responsibility of planning departments (and sometimes, finance or budget departments), although in some cases no clear assignment of responsibility has emerged. Employers are the main decision makers for temporal shifts of travel, although some R & D activity on this front is beginning to be carried out. Finally, several kinds of TCMs have not yet become part of the ordinary business of government or the private sector, and responsibilities for detailed planning and action simply have not been determined.

Table 3-3 summarizes typical assignments of responsibility for selected types of TCMs, using a list developed by EPA in 1987. It shows that a high percentage of these measures are the responsibility of local governments (cities and counties), whose staff in traffic engineering (or public works), planning, and finance (primarily for parking) all may have responsibilities for specific measures. In addition, developers and employers may play significant roles, in many cases because of local government requirements and incentives. Regional and state agencies tend to be significantly involved only for facilities they own and for those programs (such as rideshare matching) that are offered regionally.

Readers should be aware that differences in practice exist from region to region within states, as well as from state to state. The best way to get to know who does what in a particular region is to work with the metropolitan planning organization (MPO), which will be able to provide information on current plans and programs supported by federal or state grants, and will be able to outline state-regional-local organizational arrangements and assignments of responsibility for planning and implementation. Most MPOs also keep track of traffic management and commute alternative activities organized and funded by local government and the private sector.

IDENTIFYING RESOURCE REQUIREMENTS

Implementation of TCMs requires human resources as well as dollar resources. The most pragmatic strategy is to make use of what is available. For funding, this means tapping existing sources: fuel taxes, special transportation sales taxes and assessments, and private sector finance. Recruiting people means marshalling the efforts of numerous experts in local, regional, and state agencies and in the private sector.

TABLE 3-3. Typical TCM responsibilities.

	Private Sector		Government		
	Developer	Employer	Local	Regional	State
Voluntary No-Drive Days	*	*	*	X	
Trip Reduction Ordinances	*	*	X	*	
Employer-Based Transportation Management		X	X	X	
Work Schedule Changes		X	X	X	
Rideshare Incentives	X	X	X	X	X
Improved Public Transit:					
Facilities, Services	X	*	X	X	
Supplementary User Subsidies	*	X	*	X	*
Traffic Flow Improvements	X		X		X
Road Pricing/Tolls			*	*	X
Parking Management Programs	X	X	X		
Park & Ride/Fringe Parking	*	*	*	*	X

X = major responsibility in establishing program requirements or program implementation.

* = secondary or occasional responsibility in establishing or implementing measures in this category.

"Developer" includes building owners/managers.

"Local" includes city and county (air pollution control agencies, planning, traffic engineering, public works, finance departments).

"Regional" includes area-wide transit and ridesharing agencies, Metropolitan Planning Organizations, Regional Planning Councils; may include air quality management districts.

"State" includes state Departments of Transportation; may include environmental agencies.

Finding funds for TCMs can be problematic; even when sources can be identified, they may be committed for 5 to 10 years into the future. Persistence in pursuing conventional funding sources and creative financing is necessary.

Commonly used funding sources for TCMs include federal and state fuel taxes, transit funds (federal, state, regional), and special-purpose funds at the local level. Development exactions and impact fees are an increasingly important funding source in growing areas, but can be used only for those facilities and services necessitated by the development (unless voluntary contributions are made).

It should be noted that the impending expiration of the Interstate Highway Program (in 1991) has led to a rethinking of transportation finance and policy, and significant changes to programs (toward less federal involvement, with a focus of federal funds on Interstate and other major highways) is a real possibility. Similarly, reauthorization of the federal Clean Air Act, and the changes in state pollution laws that may result in response, could substantially alter current funding (as well as overall responsibilities). Over the next several years it will be especially important for planners with TCM responsibilities to track these changes, since there is a distinct possibility that new funding avenues will be opened up, and existing ones significantly modified.

Human resources for TCM implementation are perhaps less scarce than dollars. Many agencies at the state, regional, and local levels have both expertise and experience with TCMs, although at the local level additional staff development is clearly needed. Private sector organizations also have skills and experience—not just consultants, but increasingly, major developers and employers have staff with TCM talent.

Federal

Federal agencies play a major role in funding and overseeing the planning and implementation of transportation projects and programs. Their direct planning activities are usually limited to research-oriented projects and demonstration projects.

The U.S. Department of Transportation (DOT) is the umbrella organization with primary responsibility for transportation. Funds are mostly distributed through modal agencies—for urban passenger transportation, principally the Federal Highway Administration and the Urban Mass Transportation Administration. Major changes under consideration include a significant restructuring of programs; possible turnback of programs for local roads, TSM, and other local-oriented investments to the states; and more flexible funding. Use of fuel taxes for nontransportation purposes (especially deficit reduction) is also being discussed.

The Federal Highway Administration participates in state road programs both financially and technically. Most FHWA funds are distributed by formula and by category of project (principally Interstate, other primary, secondary (rural), federal aid urban (FAU), and safety). Headquarters, regional, and district offices have some discretion over funds that could be used for TCM planning and implementation; traffic operations and certain ridesharing projects are possible candidates, particularly if folded into other capital projects.

The Urban Mass Transportation Administration (UMTA) funds transit and other commute alternatives. Funding for transit operations and for some capital programs is allocated by formula. Transit planning and analysis, rail transit capital grants, demonstration projects, and some traffic management planning studies are funded at the discretion of headquarters in Washington, DC. Regional offices have small amounts of funds for some discretionary planning and operations projects. So-called Urban Mobility Grants are currently funding a number of initiatives and experiments with TCMs and transportation-land use planning, principally for the suburbs.

In past years EPA also funded TCM planning using monies from Section 175 of the Clean Air Act Amendments of 1977. Section 175 funding is currently unavailable, but EPA still provides $100 million a year in Section 105 funds. While these funds go to state and local air quality agencies and are used primarily for enforcement, monitoring, and other basic activities, some funding is also used for planning. Regional planning councils, MPOs, and other transportation agencies can work with the state or local Section 105 grantee to obtain pass-throughs of Section 105 dollars.

The Department of Energy is another possible source of occasional funds. At the moment, Petroleum Violation Escrow Account Funds, returned to the state proportional to its share of the account, are in some states the most readily available for transportation management and mitigation.

For the most part, funds provided by federal agencies are earmarked for particular types of projects (categorical grants) or even for specific projects (rail extension X). For the most part there is little ability to move funds from one category or project to another, i.e., highway funds cannot usually be spent on rail projects, and Interstate highway funds usually cannot be spent on arterials.

State

State DOTs (Highway Departments) are the FHWA's partners in funding projects on major highways. Most state funds are earmarked for categorical grant programs, especially to match federal funding categories. Planning funds are in short supply but could be spent, in part, on efforts that might fold into transportation/air quality planning. Major changes in funding may result from restructuring of federal programs post-Interstate (i.e., post-1991 expiration of the Interstate Highway Program), and many states are now undertaking planning and policy studies to determine how to proceed.

State DOTs' responsibilities make them major TCM players. State DOTs are usually responsible for major HOV lanes, freeway ramp metering, park-and-ride facilities along major routes, and (for state-owned arterials) operations such as signal timing and on-street parking policy. Some also fund ridesharing agencies or operate ride-sharing programs themselves. An increasing number provide funds for transit and are involved in rail planning and finance.

State air pollution control agencies (sometimes, branches within environment or natural resources departments) are responsible for promulgating state pollution control requirements, putting together State Implementation Plans (SIPs), and coordinating efforts at the regional level. They receive funds from EPA and state sources; the latter vary substantially by state. Some resources for transportation-air quality planning may be available, but in most agencies transportation has not been a major focus (except, perhaps, for motor vehicle controls, inspection-maintenance, and fuels programs). With very few exceptions, funds are insufficient to cover implementation costs for transportation projects.

In some states an energy agency may fund certain transportation planning efforts or projects that are compatible with air quality goals. Energy conservation plans and fuel-efficient traffic signal timing are examples.

Just as federal funding provided to the states tends to be earmarked, so does state funding. Moreover, the earmarks and categories may not fully match those attaching to federal funds.

Regional/Special District

Regional organizations and special districts (which usually are area-wide) have major planning responsibilities, and sometimes have transportation operations duties as well. Most such organizations receive federal and state planning funds, either directly or passed through state agency counterparts. Most have limited local funding from dues and contributions. Some also have sales tax, property tax, or toll revenue funding. Funds tend to be heavily earmarked or constrained as to eligible expenditure items.

Metropolitan Planning Organizations (MPOs) are in charge of programming transportation funds in major metropolitan areas, and may have other funding and decision responsibilities. Currently, FHWA funding plus UMTA grants for specific studies are the major source of funds for MPOs. Some also have local government dues or a small tax earmark, but these are a small share of overall funds. Much of the planning work done by MPOs is of great importance to TCM planning, both in providing baseline data and in directly analyzing TCMs and other projects of air quality significance. However, it should be noted that MPOs hardly ever have implementation or operating responsibility; those are left to the state DOT, transit operators, and local government.

County transportation commissions are another common entity; some (but not all) are also MPOs. In California, these commissions frequently have special sales taxes for financing a specified list of highway, transit, and operations projects. These taxes must be approved by voters, however, and the specified list of projects generally requires most, if not all, of the funding available. Some TCM funding is available in most cases, although previous commitments may limit access to these funds for new projects.

Transit agencies are another regional or areawide entity of direct importance to TCM planning. They are funded by operating revenues, local property and/or sales taxes, state grants (in some states), and (in declining amounts) UMTA funds. Most have few dollars to spend on planning—even for transit. However, many are managing to put together restructured route plans, concepts on how to serve suburban markets, and fare innovations. Consequently, they too are important actors from a TCM perspective.

Air districts at the regional level increasingly are adding staff to carry out some transportation analysis for air quality purposes. For the most part, their resources mandate that they work with the transportation agencies to effect TCM planning and analysis, rather than do it in-house.

Local

Local governments are directly responsible for planning, decision making, and implementation of many of the activities commonly considered in TCM work. Traditional responsibilities include on- and off-street parking management and traffic flow improvements on local streets (with traffic engineering, public works, and finance departments—for parking—taking the lead). Increasingly, local governments are also getting involved in planning-oriented strategies such as ridesharing, transit promotion, and park and ride, and many now impose a variety of trip reduction requirements on new development. Trip reduction ordinances, while new, are also receiving considerable attention in California and several eastern states.

Most local governments have extremely limited funds, although there are exceptions. Funds available for transportation may include (1) federal and state pass-throughs and earmarks, discussed above (mostly for specific projects/types of activity); (2) local general funds; (3) development fees (mostly expendable only for impact mitigation and other development-related purposes); and (4) special taxes, user fees, and similar direct revenues (mostly restricted as to expenditure). The funding sources, levels, expenditure authorities, and restrictions are highly specific, varying not only from state to state but from locality to locality within a state.

Here again, MPOs often can provide an overview, but there is no substitute for direct contact with local officials.

Private Sector

Increasingly, the private sector is becoming involved in the planning and finance of transportation facilities and services, including major capital projects such as freeway ramps and transit stations as well as TCM-type projects. Developers (and later, building owners and managers) and employers sometimes participate voluntarily, and sometimes are required to participate by local government.

The sources of funding available from the private sector depend heavily on the circumstances, but may include impact fees or ongoing funding for such projects as traffic flow improvements, transit improvements, shuttle buses, pedestrian and bike facilities, and ridesharing programs. Alternatively, the developer or employer may be required or may choose to produce the facilities or offer the services directly. Many offer on-site transit pass sales, rideshare matching, vanpool subsidies, and the like, with or without government participation (financial or otherwise) or oversight. It should be noted that developer and employer participation in transportation finance is a phenomenon of affluent, growing areas; less favored communities and those that are no longer growing substantially cannot count on such funds.

Table 3-4 summarizes funding by activity for major categories of actions. Together with the earlier tables, it provides a preliminary indication of who does what. Periodically, USDOT and many state DOTs publish guides providing an overview of the current funding situation and organizational responsibilities, and these documents can be very good starting points. However, there simply is no substitute for knowledge of the local situation; direct contact with the officials in key agencies is the way to start developing such knowledge.

ASSESSING POLITICAL ACCEPTABILITY

In general, it has been easier to implement transportation measures that add choice and flexibility than to restrict facilities or take away benefits. Some TCMs that are widely acknowledged to have solid potential effectiveness—road pricing, e.g.—have not been seriously considered because they simply are not acceptable from a political perspective. Although attitudes toward the use of pricing for demand management may be softening, there still is sufficient concern about the equity of pricing strategies that they should be flagged and considered very carefully. Rationing strategies and strategies that restrict autos from certain facilities or areas also have been quite likely to arouse opposition that could easily block implementation.

TABLE 3-4. Major organizations and financing sources for TCM planning and implementation.

	Type of Funding			
	Planning	Capital	Operations	Demonstration/ Other
US DOT				
FHWA	E,D	E	E	d
UMTA	E,D	E,D	E	D
EPA	*	-	-	*
State DOT	E,D	E,d	E,d	d
State AQ Agency	*	-	-	*
MPO	E,D	#	#	#,d
Special District	*	*	*	*
Transit Agency	E,d	E,d	E,d	d
Local				
Traffic Eng.	d	E,D	D,e	*
Planning	D	*	*	*
Private	*	*	*	*

Upper case letter means major funding; lower case means minor funding.
E,e means funds are earmarked.
D,d means substantial discretion over use of funds.
* means funds may be available on occasion.

Some TCMs have been able to generate substantial public support for implementation, but those affected resist the measures or find ways to circumvent them once implemented. Examples include parking in nearby residential neighborhoods to avoid parking fees and restrictions, successfully lobbying for discount tolls for regular commuters, and purchasing a vehicle just before a new engine or emissions control technology is introduced to avoid having to use the new equipment for some years.

EXAMPLES

To develop a better understanding of TCM effectiveness and implementation issues, it is instructive to look at several TCMs in some detail. Commute alternatives (transit and ridesharing), traffic flow improvements (especially signal timing), and parking management are considered here.

Commute Alternatives

Transit Improvements

Transit improvements include a wide variety of actions designed to attract riders by providing fast, safe, convenient, comfortable, financially attractive services. Transit improvements may be made by providers of conventional public transit services, by public agencies in charge of highways and streets, by private transportation companies, or by employers, businesses, and/or neighborhood organizations. Common actions include

- New routes and services (by the major provider, or by encouraging additional providers to enter markets);
- Increased frequency of service;
- Reduced in-vehicle times, accomplished by providing non-stop or limited-stop service and/or reducing route circuity;
- Direct service (no transfers) or speedier, "timed" transfers;
- Reductions in access time, accomplished by route restructuring, provision of door-to-door collector and distributor services linked to line-haul services, development of park-and-ride lots, etc.;
- Transit-only streets, lanes and ramps, signal preemption, and similar infrastructure and operations designed to increase transit speed and reduce delays due to traffic conditions;

- Transit information centers, ticket sales, etc. at convenient locations;
- Adequate lighting, security, and protection from the elements at stations and stops;
- Fare discounts and/or subsidies, especially for regular users (provided by government, employers, retailers, or others);
- Special services (subscription buses, shuttles, luxury buses, etc.) designed for specific market segments; and
- Joint development at transit stations, both to build a market for transit and to help cover the cost of providing it.

Experiments are regularly being carried out to test new strategies for encouraging transit use. For example, several areas are offering free taxi rides to the transit user who unexpectedly must work late or leave work midday for a family emergency, and a few are testing the effectiveness of providing services such as child care, dry cleaners, banking facilities, and convenience food shops at transit stations and park-and-ride lots.

Literally hundreds of examples of transit improvements have been documented, thanks in large part to the Urban Mass Transportation Administration's active Services and Methods Demonstration Program of a few years back. A few examples are provided in the following paragraphs.

<u>Improvements in Routes and Frequencies of Conventional Transit Services</u>

Portland, Oregon has implemented an extensive timed-transfer system for its suburban areas, wherein buses converge at well-designed transfer centers, allowing passengers to change vehicles with a minimum of delay or difficulty. The suburban services also are well coordinated with the new light rail system. In the downtown, a transit mall emphasizes the city's commitment to public transportation while reducing traffic delays for transit users.

<u>Fare Subsidies and Other Incentives</u>

In the San Francisco Bay Area, numerous programs are in place to provide additional financial incentives for transit use. For example, the city of San Francisco requires on-site transit pass sales at most major developments built in the last five years. In Berkeley, California, the city's commute alternatives program sells transit tickets and passes at its downtown Transportation Store, encourages employers to subsidize transit users, and works with state and regional agencies to identify and develop park and ride sites.

Special Services for Targeted Markets

Large developers and employers in such diverse suburban areas as Woodland Hills, Texas, Montgomery County, Maryland, and San Ramon, California have assisted in the establishment of subscription buses, shuttles to transit stations, and luxury van services.

The success of such programs varies widely and often is subject to debate. Between 1970 and 1980, almost all major metropolitan areas experienced a decline in transit's share of travel, and some systems also experienced a net loss of ridership. The losses occurred despite massive expenditures on operating subsidies, rolling stock, and in some areas, fixed guideways. They were largely due to a combination of increasing auto ownership and use, decentralization of housing and workplaces, and rising household incomes; they also reflected federal, state, and local funding cutbacks that in many areas necessitated fare hikes and service reductions. Declines in transit's share of urban trips have continued through the 1980s, a time of low gas prices but ever-worsening traffic congestion.

Individual improvements such as those listed above often have had significant impacts in the markets they influence. Some argue that overall, investments in transit have stemmed its decline from what it might otherwise have been, and have reduced the need for additional highway capacity as well. In general, however, the high cost of providing transit, and questions about its effectiveness, mean that improvements will be scrutinized closely and will increasingly have to demonstrate strong benefit-cost ratios.

Many transit agencies and regional planning organizations continue to forecast increased transit mode shares in their long-term plans. The forecasts often are based on projections of increased transit capacity, continued low, heavily subsidized fares, and (in a number of cases) significantly increased auto operating costs and travel times. The transit agencies admit that their ridership projections reflect hopes for the future rather than trend projections; many find themselves developing cutback strategies. However, in earlier air quality plans the transit forecasts generally were taken at face value and adopted as a TCM. On the basis of forecasts and projections, air quality improvements of 3 to 5 percent often were estimated. Such benefits clearly cannot occur unless both the broader social and economic trends and funding difficulties are reversed.

Transit improvements will reduce emissions to the extent that they (1) attract riders away from automobiles, or (2) result in more efficient operation of the transit vehicle itself, and therefore reduce transit vehicle emissions. Some transit measures may do both--preferential treatment through reserved lanes or signal preemption is an example--but other measures risk less efficient operations in hopes of attracting riders. In such cases a careful assessment is imperative. For example, if the frequency of diesel bus services is increased in hopes of attracting more riders, diesel emissions will increase proportionately; ridership increases obtained from former auto users will be needed to offset the emissions increases.

Analysts also should be aware that various kinds of transit services can and do compete with one another (and with walking and biking in some environments), not just with single-occupant autos. Examples of express buses and vans attracting a substantial portion of their ridership from competing rail service have been reported in the New York and San Francisco metropolitan areas.

Finally, if transit service depends on park-and-ride, attention should be given to cold-start emissions. On a seven-mile trip, as much as 90 percent of the emissions occur in the first mile. Thus, express buses from park-and-ride lots may attract more riders than comparatively circuitous, slow neighborhood services, but there may not be a net improvement in emissions.

Transit services have other benefits and costs that should be noted. Well-designed transit improvements can reduce operating costs for the transit provider, and/or help attract other sources of income, e.g., from joint development. This sometimes is as important to the operator as an increase in ridership. Transit improvements also provide much needed mobility and access to those who lack an auto, cannot drive, or choose not to do so. And in some cases, transit improvements can help shape a denser, more pedestrian-oriented, more urban (and urbane) environment.

Transit services are costly, however. Rarely can services be provided for less than $25.00 per hour, and costs frequently are twice that, or even more. Furthermore, since transit vehicles get only 3 to 5 miles per gallon of fuel and usually travel on circuitous routes with underutilized "backhaul" trips, they must carry some 7 to 15 passengers to compete with autos on a per-passenger fuel efficiency basis. In addition, transit vehicles tend to be noisy and to maneuver poorly in heavy traffic or narrow streets; these characteristics may generate complaints from residents and even from business owners, particularly if the vehicles are carrying few passengers.

Emissions changes due to transit improvements cannot be estimated very meaningfully in the abstract. Earlier modeling efforts are often hard to interpret because they assumed parking surcharges and/or gas price increases would accompany the transit measures (see, e.g., Horowitz, 1977, p. 249). Actual experiences must be interpreted in light of the significant decrease in automotive fuel prices of recent years. Very roughly, however, emissions reductions of less than 1 percent to as much as 20 percent have been estimated for particular corridors. Area-wide effects on the order of 5 percent might be possible at the upper end of the spectrum of changes.

Transit benefits of any sort will not be realized unless some means of implementing transit improvements is found. This will require careful and realistic planning, reflecting what has been learned about traveler behavior and mode choice. Transit is not likely to be successful in reducing auto use unless it can offer travel times, costs, and comfort levels at least comparable to, and probably better than, those of the auto. Today, with funding for transit a major concern, wishful thinking about transit can be destructive, since "disasters" may undermine public confidence and reduce willingness to support transit.

Funding considerations suggest another aspect of effective implementation: joint public-private approaches are becoming increasingly important. Private sector involvement in transit improvements may offer cost-saving ways of providing facilities and services, new sources of funding for publicly provided transit, mechanisms for encouraging increased transit use, and/or market-making opportunities through land development projects. Private firms' willingness to get involved in the transit arena is by no means assured, however, nor are benefits from involvement automatic.

Probably the most important point is that transit needs to be tailored to meet the needs of the markets it wishes to serve. Today, in many of these markets, an auto is always available, out-of-pocket costs of travel are not a concern, travelers' time is short, and flexibility is needed. Serving such markets will require a broader conception of transit, encompassing subscription services, taxis and dial-a-rides, vans and shuttles, as well as conventional buses and trains.

Ridesharing

Ridesharing programs promote, assist, and provide incentives for sharing rides to and from work. Increasingly, transit is considered a form of ridesharing, along with carpools and vanpools; however, most ridesharing programs still focus on the latter two, as we do here.

Ridesharing programs have placed thousands of commuters in carpools and vanpools in urban areas across the country. Ridesharing is relatively inexpensive compared to transit since it is largely a self-service mode with public costs limited to matching and coordination assistance. It can work in low-density areas that are not efficiently served by transit, especially when the other trip end is a considerable distance away, in a congested area where parking also may be scarce and expensive. Ridesharing has been considerably less successful when congestion is absent, parking is inexpensive to provide or obtain, or trips are short. The major market for rideshare programs thus has been among suburban commuters who make relatively long trips along congested routes into major employment centers with costly or limited parking. Whether ridesharing can be made to work in suburban job centers with little congestion and plentiful parking is still an open question, although a number of attempts to do so are under way.

Ridesharing has been implemented in a variety of ways. Early programs, established to reduce VMT and hence improve air quality and conserve energy, operated through special-purpose, region-wide agencies. At first, freeway signs, radio announcements, and other area-wide marketing strategies were used to reach potential customers. Experience soon taught that efforts were more effective when programs were offered with employer endorsement, assistance and incentives. Today, most programs work with major employers to encourage their employees to join pools, and areawide promotions play a secondary role.

Many transportation-air quality plans produced in past years projected major area-wide increases in auto occupancy due to ridesharing programs. In areas with established programs, the calculations in support of these estimates often were based on an assumption that pool formation rates would be maintained at the same or higher levels than obtained when the programs were started. In areas with little ridesharing activity, the assumption often was that new programs would be established and would prove to be as successful as those in other cities, even though conditions might be substantially less promising. As in the case of transit, the assumptions made about future utilization of ridesharing may be overly optimistic.

Surveys of operating ridesharing programs offer more concrete evidence on effectiveness. An early study of 38 metropolitan areas (Wagner, 1980) found that work VMT had been reduced .03 percent to 3.6 percent. This would translate into smaller emissions reductions, however, because of cold starts. More recent work, reflecting today's low fuel prices, suburban travel orientation, and free parking, indicates that area-wide emissions reductions on the order of 0.8 percent might be expected.

Transportation agencies often support ridesharing as an alternative for congestion relief because it is cheaper than capital-intensive highway expansions or capital- and operations-subsidized transit. Their efforts include provision of complementary facilities and services, such as priority high-occupancy vehicle lanes and mass transit. Nevertheless, few states provide significant levels of funding for ridesharing programs.

Employers participate in ridesharing programs for a variety of reasons. Some, worried about traffic congestion and its adverse effects on community relations, consider ridesharing programs a "good neighbor" policy. Some also view ridesharing as an employee benefit, although others question how important it is as such. Increasingly, however, employer participation in ridesharing is a matter of government incentives and requirements. Some communities offer density bonuses or reductions in parking requirements to employers (and/or developers) that agree to aggressive commute alternatives programs. Other areas require ridesharing as a traffic mitigation strategy. Federal, state, and local tax incentives also have been provided to employers who assist employee ridesharing.

Ridesharing programs' impacts can be notable at the level of a particular travel corridor, a single employer, or a small downtown. For example, pooling over the San Francisco Bay Bridge has permitted peak-period passenger counts to increase while vehicle counts have remained stable. However, impacts are often too small to be reflected in area-wide auto occupancy data or vehicle counts. For example, in a typical urban area, the number of vanpools operating is counted by the hundreds, and agency- or employer-formed carpools (those above the natural or "base case" level that occurs without special efforts) typically amount to a few thousand.

How effective ridesharing can be in reducing emissions depends on several factors. An important issue is whether trips are eliminated or merely shortened. In the latter case (for example, when the pool meets at a park-and-ride lot), cold start emissions offset a part of the gain from pooling, and the overall effect will depend on trip length and congestion levels. If some of the poolers were former transit users, effectiveness may be further reduced.

Some researchers question whether existing ridesharing programs might not have already saturated their primary markets, so that future growth would require much higher levels of effort. For example, it might be increasingly necessary to offer large financial incentives for ridesharing, such as subsidized use of a vehicle; to work with employers that have so far been considered too small to have much ridesharing potential; or to implement substantial disincentives to driving alone. Such efforts are under way in some areas, especially where traffic congestion is severe. Transportation management associations have been formed to provide ridesharing services and incentives to all employers, large and small, in an area; trip reduction ordinances have been enacted to require employers to offer commute alternatives and sufficient incentives for their use to achieve specified mode shares or participation rates.

Nevertheless, ridesharing is likely to remain primarily of interest to employees who live a long way from work—roundtrips averaging about 25 miles or more for carpools, and 30 miles or more for vanpools. For shorter trips, the added time to pick up and drop off passengers and the inconvenience of conforming to a fixed travel schedule will probably outweigh any cost savings or other incentives. In addition, in many areas large numbers of employees use their cars for work-related trips, or make child care, shopping, and personal business trips on the way to and from work and at lunch. On-site facilities and services and compensatory transportation (such as shuttles, taxi vouchers, and short-term car rentals) may remove some of the need for the car, but are still in the experimental stages.

Traffic Flow Improvements

Traffic flow improvements are measures, usually relatively low-cost and small-scale, which increase roadway capacity, increase or smooth out speeds, and/or reduce delays and stops. Traffic flow improvements can be accomplished in a variety of ways. Retiming traffic signals as a system can improve efficiency of operations significantly; retiming is especially effective when signal timings have not been reviewed in a number of years, but has proven successful for new signal systems as well. Streets' traffic-carrying capacity also can be enhanced by restriping for additional lanes, adding turning bays, restricting turning movements and/or cross-traffic, and eliminating pedestrian crossings at critical locations; removing parking or restricting its use to off-peak periods; removing unwarranted stop signs, improving sight distances, and eliminating roadside hazards or distractions; relocating bus stops and loading zones to remove bottlenecks; limiting curb cuts and restricting peak period use of those that create excessive "friction"; and using one-way street couplets. Metering access to roadways, use of shoulders and medians for additional travel lanes during periods of heavy flow, provision of motorist advisory systems to even out traffic loadings and direct travelers away from tie-ups, establishment of programs to quickly remove disabled vehicles from the traffic stream, and even peak period pricing strategies are other means of improving traffic flow.

The objective of these traffic flow improvements is to maximize the carrying capacity of the roadways rather than to reduce overall travel, shorten trips, or otherwise affect the pattern of demand. Thus, although measures that lead to shifts in the frequency, mode, time, or destination of travel also may improve traffic flow, they are not considered here.

Examples of traffic flow improvement projects are plentiful; traffic engineers have a long record of accomplishment. Most urban areas can identify numerous examples of low-cost projects that were implemented under FHWA's TOPICS program in the 1960s. Typical projects included channelization, installation of turning bays, and use of medians to reduce cross-traffic and/or parking lane "friction."

On-street parking management also has been widely implemented, and is reported to have proven extremely beneficial in Washington, DC; San Francisco; Boston; and other major cities (Ellis, 1986). Measures include curb-lane parking bans during peak periods, selective removal of parking spaces to improve intersection capacity, and better enforcement of existing parking regulations.

Computer-assisted traffic signal timing has been emphasized in recent years. Probably the most prominent example is California's Fuel-Efficient Traffic Signal Timing Program (FETSIM), a multi-year, multi-million-dollar effort, which, to date has retimed nearly 4000 signals in urban areas across the state. The FETSIM projects, on average, have produced stop reductions of 16 percent, delay reductions of 15 percent, travel time reductions of 7.2 percent, and fuel use reductions of 8.6 percent for the affected travel (Deakin and Skabardonis, 1986). Recent software additions permit emissions estimates, and show reductions of up to 8 percent in both CO and HC in the affected traffic streams (Skabardonis, 1986).

There also has been considerable analysis of other strategies for improving traffic operations. Deakin and Skabardonis (1985) present an analysis of improvements including the addition of turning lanes and lane restriping in a dense downtown network; Schwartz and Home (1983) discuss metering strategies being used in Manhattan. The effects of such programs are extremely site-specific, and it is somewhat risky to attempt generalizations. Reported improvements in speeds, delays, and stops—presumably for the corridor rather than area-wide—have ranged from 2 to 10 percent.

It is noteworthy that most of these projects stop at jurisdictional boundaries, even though neither the traffic problem not the transportation facility does so. In a few places state or regional agencies have taken steps to encourage multi-jurisdictional projects, but have faced a host of difficulties ranging from inadequate funding to lack of follow-through after the project has ended.

Effectiveness at reducing emissions depends in large part on context. Traffic flow improvements reduce emissions by reducing stops and starts, speed changes, and idling. The amount of emissions reduction will depend both on the design of the measure being implemented and on the specific characteristics of the implementation environment. Computer programs and hand calculation procedures are available for a wide range of measures and conditions, although most methods require substantial amounts of data for accuracy.

Extensive modeling and some direct emissions measurements have been carried out for signal retiming; this work suggests that emissions reductions on the order of 4 to 5 percent could be obtained within a typical range of affected networks. In California, about 40 percent of urban travel occurs on signalized networks, suggesting that ubiquitous signal retiming might reduce area-wide emissions by up to 2 percent. (The numbers would vary considerably among communities.)

For other traffic flow improvement measures, fewer reliable studies of effectiveness are available. Few SIPs included detailed analyses of these measures; in any event, a case-specific analysis would be in order. A very rough estimate, accounting for the fact that traffic would be affected on only a subset of an area's network, is that emissions reductions of 1 to 2 percent might be attainable from aggressive, widely implemented programs to improve traffic flow.

Other benefits accrue. Traffic flow improvements tend to reduce fuel consumption, noise, and vehicle wear and tear. First-year savings from reduced fuel consumption alone often exceed project costs. Most traffic flow improvements also improve safety, and indeed, a number of these projects are funded under federal and state highway safety programs.

However, some traffic flow improvements have drawbacks that require careful consideration. Removal of on-street parking in areas where the spaces are relied upon by abutting retail shops or residents will, at minimum, cause inconvenience; in some cases more drastic adverse economic impacts could result. Similarly, restrictions on turning movements may improve traffic flow but reduce accessibility and force travelers to make circuitous trips to reach businesses and residences. Improvements in vehicle flow can sometimes degrade the pedestrian environment, for example by increasing traffic speeds to uncomfortable levels or cutting short pedestrian crossing times at intersections. The potential for such negative effects underscores the need for context-specific evaluation. Measures can sometimes be devised to minimize adverse impacts or to compensate for them.

Concerns are sometimes voiced that traffic flow improvements may induce additional trips and/or affect mode choice by producing better operating conditions for motorists. For the types of measures considered here, the travel time improvements for any one trip are usually less than a minute in total. Such improvements are likely to be important for short trips (under 10 min, e.g.) but not for long trips (over 30 min). In addition, because bus transit receives benefits as well, this strategy generally would not offer a modal advantage to autos. Nevertheless, a number of air quality planners have voiced concerns that over time and cumulatively traffic flow improvements may be at least partially offset by their own growth induction.

The effectiveness of traffic flow improvements thus requires case-specific analysis since their effects depend very strongly on the implementation context. At the same time, to avoid counterproductive results, traffic flow improvements need to be considered from a system perspective rather than on an intersection-by-intersection or street-by-street basis. For example, some cities have retimed their signals to give preference to through traffic, basing their studies on main-street travel times only. Subsequent analysis of the street system as a whole has often found that operation is suboptimal; excessive delays for side streets and turning movements more than offset the benefits to the main street travelers. Similar counterproductive results may be produced if ramp metering or other strategies to protect freeway capacity divert motorists to longer, slower, more congested routes; the benefits to the protected route must be weighed against such disbenefits.

In addition, most traffic flow improvements should be reviewed on a regular basis. Many traffic flow improvements are sensitive to changes in traffic patterns or volumes; it has been estimated that signal retiming improvements are effective for only two to three years in the typical city, for example (Wagner, 1980). Even moderate traffic growth usually results in a need for signal retiming in three to five years. Introduction of a major new traffic generator or other changes that alter spatial or temporal patterns of travel may require modifications to the traffic control system on a much shorter time frame (Deakin and Skabardonis, 1985).

Ironically, this traditional transportation improvement strategy has no programmatic source of funding in most areas (except for such streets that happen to be on a federal or state "system"), so that a major barrier to implementation is paying for the improvements. An exception in California is traffic signal retiming for systems of 10 or more interconnected signals, which are eligible for state grants from the Fuel-Efficient Traffic Signal Timing (FETSIM) Program (funded with Petroleum Violation Escrow Account monies).

Parking Management

Parking management is a good example of a measure that analyses indicate to be highly effective at congestion relief, energy conservation, and emissions reduction, but which has been implemented in only a few areas. While parking management includes many strategies, such as preferential locations for HOVs and resident permit programs, here we will consider the supply and price of parking provided for employee (commuter) use and its impact on travel choices.

Parking is provided by many cities in municipal lots and garages. Because local governments do not pay taxes themselves and most have access to relatively inexpensive money (tax revenues, on-street parking fees and fines, low-interest or interest-free bonds), they can provide parking at less than what it would ordinarily cost the private sector. When costs are low—or revenues from other sources are commingled with parking revenues--cities often appear to make money on their parking supply activities while charging low rates (not considering alternative uses of the land). Even if municipal parking loses money, however, many localities justify it on the grounds that a convenient supply of parking supports economic development and business retention.

Parking also is provided voluntarily by the private sector. Depending on land prices, parking demand patterns, and prevailing parking rates, some companies apparently generate a profit by providing parking as a principal use. More often, parking serves as an important interim use during land assembly and building design and approval, bringing in at least enough revenue to cover land holding costs.

With few exceptions, most employment centers provide three to five parking spaces per thousand square feet of building floor area. (Large CBDs are often exceptions, especially in older cities, but CBDs constitute a minority share of employment in U.S. metropolitan areas.) There are several reasons to provide this parking:

- City zoning usually requires it. Most cities, concerned about the problems that might result from inadequate off-site parking, have established requirements that would protect them from maximum demand at an assumed zero price.
- Banks often require parking even if zoning does not. While this in not an iron-clad rule, developers report that proposals lacking plentiful parking are seen as riskier, require justification, and may raise the cost of the loan.
- Plentiful parking is seen as an important competitive factor in the marketing of buildings and retention of tenants.
- Parking is seen as necessary from a public relations perspective, to avoid problems from spillover into others' parking facilities or to the on-street spaces in residential neighborhoods.
- Finally, parking can occasionally be a good money-maker, although profit does not appear to be common.

In some cases, tradition is probably the best explanation of why developers provide so much parking—they have not really considered why. Furthermore, why is parking provided to employees free of charge? Here, too, there are several explanations, including most of those listed above. Some of the particulars reported by developers and employers are as follows:

- In some areas, parking can be provided at little cost in surface lots. Collecting fees and the responsibilities it entails (hiring and supervising employees, monitoring and controlling cash, providing security, etc.) can be more effort than appears to be worthwhile.

- Zoning restrictions such as setbacks, maximum lot coverage regulations, etc. may prevent alternative profitable use for the land. Providing surface parking may be cheaper than landscaping if a manicured, irrigated landscape would be the alternative.

- For garage spaces within the building, separate cost accounting may not have been done. Allocation of costs of shared foundations, etc. may appear unduly complicated to the developer. Even if costs are known, however, they are not necessarily presented to the lessee as a separate cost item.

Free parking is widely viewed as an important tenant amenity and employee benefit. Parking costs thus are embedded in lease terms and absorbed as a tax-deductible operating expense rather than charged to employees. It is estimated that nationwide, about 90 percent of all employees receive free parking, and still more pay only a portion of the cost. (Again, major CBDs are exceptions.)

Free parking is not, however, free in any real sense of the word. A 320-sq-ft space in a surface lot, financed over a 30-year period at a 10 percent interest rate (or alternatively, assessed an annual land rent), would cost $20.00 to $25.00 per month (including costs of pavement, striping, maintenance, etc.) at land prices of only $5.00 per sq ft. Land prices of $20.00 per square foot would push the monthly parking cost up to $60.00 to $70.00. A space in a garage would cost much more: in most markets, $10,000.00 to $15,000.00 if the structure is above-ground, and $20,000.00 or even more if below-ground spaces are considered. Such spaces, considering amortization and operating expenses, would need to rent at $120.00 to $250.00 per month to cover costs.

Analyses and a few experiences indicate the size of the effect that charging for parking would have. Modeling results suggest price cross-elasticities (how many would shift modes) are low, in the .1 to .3 range for most commuters, so that a doubling of the perceived costs of drive-alone travel would reduce traffic by 10 to 30 percent. But even a moderate parking charge could double drive-alone commute costs. Commuters behave as though their trips cost them 6 to 9 cents a mile excluding parking (fuel at 3 to 5 cents plus a little for oil, maintenance, etc.). At the median U.S. commute trip length of 10 miles one way, operating costs are some $1.20 to $1.80 a day. Thus, parking at $30.00 to $35.00 per 20-day working month would more than double the cost of the drive-alone commute--which should in turn cut drive-alone commuting by 10 to 30 percent. (It should be noted that extrapolation of observed elasticities to the higher ranges of parking charges might not be warranted. Also, lower response would be expected among higher income workers and vice versa; and less response than predicted might occur if people see themselves as having no reasonable alternatives, e.g., because they need the car at work or to pick a child up on the way home.)

Studies in Los Angeles have reported that a 30 percent decline in drive-alone did, indeed, occur under conditions fairly similar to those discussed above (Shoup, 1982). Some analysts have suggested that parking pricing may be a second-best approach to rationalizing transport costs. (Direct road pricing reflecting miles driven, and the amount of congestion and air pollution caused, is clearly preferable from an economist's point of view.) However, there are several barriers to change, and caution is in order.

First, the federal tax code is not supportive of a change in policy. Free parking is classified as a working-condition fringe benefit to employees, much as would be a sofa in the office. As such, parking is a tax-deductible expense for employers. Furthermore, the value of these tax benefits has no ceiling, and as indicated above can exceed $200.00 per month per employee in some areas.

On the other hand, vanpool and carpool subsidies are considered taxable income, and transit pass subsidies are deductible only up to $15.00 per month. Any subsidy above that amount results in the entire subsidy being treated as taxable income, costing the employee some 28 percent (the marginal tax rate for most) and requiring that the employer undertake additional record-keeping and reporting. Alternate treatments, such as a commute allowance rather than a direct subsidy of any mode of commuting, also would result in taxable income.

Attempts to redress this disparate treatment have so far failed. Given the federal budget deficit, any change would probably have to be tax-neutral. Thus, proposals simply to raise the permissible subsidy to commute alternatives have so far been rejected. UMTA has suggested that an alternative revenue-neutral approach would be to exempt all commute subsidies up to $60.00 and to tax all over that amount, but they note that the taxes would fall principally on core areas of major cities and hardly at all on suburbs.

It has been argued that the vanpool/carpool taxable benefit is unenforceable in any practical sense because of the trail of audits that would be needed, as well as difficulties in determining "market value" of the subsidized trips under many common circumstances. Market value of parking spaces also could be hard to establish given current cost accounting and leasing practices. Nevertheless, in the current situation some employers are undoubtedly dissuaded from providing rideshare financial assistance; and the sizable benefit to those who drive and park undermines spending for commute alternatives.

Another reason for caution in addressing this inequity is that commuters may find any of several ways to circumvent a parking surcharge. Many will make use of off-site free parking if it's within walking distance--and sometimes if it's not. For example, in the central areas of Berkeley, where free employer-provided parking is rare and off-street spaces cost $35.00 to $65.00 per month, a severe problem with spillover into residential neighborhoods has developed. Resident permit parking programs are being instituted to cope with the problem. In a number of other cities, commuters reportedly park in residential districts near transit stops and take the bus or train the last few blocks to avoid paying for parking; in suburban areas, shopping center parking lots reputedly are used as rendezvous for formation of "carpools" to take advantage of preferential parking.

Being among the first developers, employers, or cities to forego free parking could be uncomfortable. For developers or building owners/managers, competition from other buildings would be a concern, and banks might be reluctant to lend if the competition would provide better parking. For employers, taking away a benefit is usually impossible; also, parking could become a labor negotiation issue. Not providing parking in the first place (new employers, or employers at a new site) may be somewhat easier, but could be problematic in a tight labor market. For cities, the threat that a developer would merely "go next door," taking away desired tax base (and possibly, major employers as well), is frightening. Overall, then, getting started could be difficult.

It has been suggested that market-rate parking needs to be included as part of a state or regional measure in order to avoid some of these problems. However, implementation of such a measure would not necessarily be straightforward, involving such issues as how to define the "market rate" in areas where parking is free, how to deal with sunk costs vs. recent costs, the possibility of becoming entangled in abrogation of contract issues (affecting leases, labor agreements, and so on). In addition, this measure would seem to be a likely candidate for widespread political opposition to block enactment, or for resistance behaviors (employers simply paying the cost for the employee, employees parking in residential neighborhoods, and so on). Hence, a more promising, if more difficult to implement, approach might be to work with individual employers, employer associations, building managers, developers, and local governments to stimulate awareness of the monetary and social costs involved and to encourage experimentation with pricing schemes.

SUMMARY

The typical TCMs such as ridesharing, transit, and traffic flow improvements have been found to produce emissions reductions, in favorable implementation environments, on the order of 1 to 3 percent each, with higher percent reductions feasible in particularly salutary circumstances. The effects of all of the measures are heavily context-specific, however, emphasizing the importance of careful technical analysis followed by careful qualitative assessment of markets, finance, and political acceptance issues.

A typical program of such measures could produce total emission reduction benefits of some 5 to 10 percent. The results are not strictly additive because of interactions among TCMs. Particular measures may serve several objectives: restriction of on-street parking may simultaneously act as a disincentive to auto use and lower emissions from those cars still on the road by reducing stops and delays. Measures also can be combined so that they complement each other—an increase in parking fees can be used to fund rideshare matching services, and HOV lanes can provide a time-savings incentive. Occasionally, however, TCMs compete with one another. For example, in some areas, carpool and vanpool programs find that substantial numbers of their members are former transit users.

Since the SIP regulatory approach has emphasized development of specific estimates of percent reduction in emissions overall and on an annual basis, resources are often focused on detailed analysis activities. It is hoped that this discussion makes the need for additional assessments of market issues, financing, and acceptability less quantitative but no less important. The lesson of the earlier TCM efforts should be kept clearly in mind: to clean the air it is necessary to implement TCMs, not just study them.

EMERGING DIRECTIONS: NEW INSTITUTIONAL ARRANGEMENTS AND IMPLEMENTATION APPROACHES

Transportation control measures have been found to be useful in reducing emissions. Although individually, measures produce modest results, integrated packages of measures can be more effective than many stationary source controls, especially since many of the "big-hitter" stationary source controls have been adopted already. With the longer-term orientation that appears to be emerging in discussions of air quality planning and management, a more rigorous, systematic implementation of TCMs is possible. In addition, a wider range of options, including land use strategies and new technologies, may be available. Nevertheless, prospects for further reductions of transportation emissions will be difficult for several reasons:

- If measures such as ridesharing, traffic flow improvements, and improved public transit are indeed already widely deployed in their "easy" (low cost/voluntary/incentive) forms and in their most obvious markets, additional benefits from these measures will likely depend on finding new ways to increase their effectiveness. This might include packaging them together to capture synergistic effects, and widening their reach, e.g., applying them in smaller, thinner markets. The new organizational approaches to implementation and enforcement—employer based and publicly mandated—are being counted on to help accomplish that, but how well they will perform remains to be seen. Many transportation planners are concluding that a broader range of strategies, including land use strategies, will be needed to have a substantial effect on air quality problems.

- Land use-transportation strategies can make sense if a longer-run perspective is adopted (in the five- to ten-year frameworks of earlier TCM planning, they were rarely considered useful). Judging from actions being pursued for congestion relief, greater emphasis on transit-oriented site design, cluster development and density bonuses, traffic management tied to development approvals, jobs/housing balance approaches, and area-wide growth management seems likely. This, too, raises uncertainties, however. Understanding of land use-transportation measures is incomplete, and in some cases the available evidence on their effects is contradictory (Deakin, 1989). Better information will be needed.

- Finally, changes are occurring that may significantly alter the context in which transportation-air quality planning takes place over the coming years. In particular, pending Clean Air Act amendments and post-Interstate transportation policies may create a substantially different decision process, perhaps involving a different set of actors, different alternatives, and different financing mechanisms from those of today. At the same time, changes in a host of other factors—demographic, social, political, economic, technological—may also create new opportunities, or new problems, for transportation and air quality planning. The institutional framework of both transportation and air quality planning must respond to these changes in order to meet their common goals. Understanding and anticipating and even shaping them, where possible, will be a challenge for all those concerned with transportation.

Overall, the next round of TCM planning will probably require (1) a more integrated, programmatic approach (with greater regional agency visibility and action), (2) a willingness to try new options, (3) sensitivity and responsiveness to changing conditions, opportunities and problems, and (4) greater attention to evaluation and course corrections. It may also be necessary to recognize the difficulties of changing travel behavior, and to be more explicit about requirements and performance than in the past.

Programs of TCMs

For many TSM measures--ridesharing, traffic signal timing, flextime, and several others--implementation has been sufficiently widespread that the question is not "What can be done?" but rather, "What more can be done?" To obtain additional benefits from these measures, it may be necessary to

- Increase the funds available for their implementation--probably by finding new sources of funding;
- Increase their market penetration;
- Introduce them into "thinner" markets; and
- Implement them in integrated programs rather than individually.

Since it is often hard to predict with much confidence what will work and what will not, it also will be necessary to monitor the results and make adjustments as needed.

Funding is likely to be an immediate problem. As noted earlier, federal and state assistance for TSM activities is limited, and few local governments feel they can afford it on their own. Consequently, attention will have to be focused on the development of new funding mechanisms, including ways to tap existing sources that in the past have not been fully exploited. These might include public finance mechanisms such as assessment districts, or earmarked vehicle registration fees. Private sector funding strategies also will be extremely important: development fees, impact fees, and direct project or program implementation by the private sector will be vital, and other sources, such as business license fees and payroll taxes, may need to be considered.

Increased market penetration and introduction into "thinner" markets will require a sound understanding of those markets and consumers' choice processes. Studies addressing such issues as who participates in commute alternative programs, and how commuters respond to changes in their travel conditions, will be needed, along with demonstration projects. Work on the design and assessment of transportation services and programs for low density, suburban-oriented commutes and for smaller employers will be particularly helpful.

Equally important will be work on how to put together and implement packages of measures that have a strong likelihood of being effective. An important development is the emergence of new institutional arrangements and organizational structures for program implementation. Three such approaches currently receiving attention are trip reduction ordinances, multijurisdictional planning efforts, and transportation management organizations. In each case, the TSM measures being considered are not new--ridesharing programs are the core of most of these efforts--but the means of implementing them are.

Trip reduction ordinances (TROs), used primarily as local government requirements for actions designed to moderate the transportation impacts associated with development in a particular area or community, will almost certainly see more use. While early TROs focused on work trips to new commercial developments, an increasing number of the newer ones apply to all employers. Some apply to other trip types and land uses as well.

Typically, a TRO establishes specific goals (e.g., level of service D, or a 10 percent reduction in auto use) and requires that responsive commute alternative programs and incentives be developed, promoted, and monitored. Failure to devise or carry out the programs usually results in a fine or the withholding of building or occupancy permits. Lack of effectiveness usually leads to required program revisions. So far, most communities have shied away from imposing other penalties, although some would limit future business expansions in cases where acceptable success levels have not been achieved.

An important function of TROs is to utilize private resources to implement commute alternative programs. In almost all cases, employers are responsible for funding their in-house programs or for contracting for services, although there may be government funding as well. (For more information on TROs, see page 26.)

Multijurisdictional transportation planning efforts are gaining popularity in areas where attempts to reduce traffic on a strictly local basis have proven inadequate to the problem, and where local governments have been reluctant to move separately in imposing new requirements on developers. Carried out under memoranda of understanding and/or joint powers agreements, these efforts often include area-wide transportation planning, consolidated ridesharing and transit programs, and coordinated improvements to major arterials. A few have also looked at area-wide land-use policies.

Supporters argue that joint efforts can be more ambitious, less expensive, and more equitable than city-by-city TSM programs. However, because the multijurisdictional arrangements are largely ad hoc, their stability is uncertain. Some observers argue that they are a poor substitute for formal regional and/or state planning requirements for coordination and consistency.

Funding has been a severe problem for most of these efforts since the dollars or staff time for the multijurisdictional work must come from individual cities' budgets. In California, legislation has been proposed that would encourage multijurisdictional planning, but it does not yet address the critical funding issue.

Transportation management organizations (TMOs) (or TMAs--transportation management associations) are a private-sector variation of the multijurisdictional efforts—they are most often established by developers and employers as a way to provide joint ridesharing programs, shuttle buses, and the like. Some TMOs also involve public agencies or elected officials, and may even involve public-private cost-sharing. Arguments in support of TMOs parallel those for multi-jurisdictional government efforts (Schreffler, 1986). However, because some TMOs have been more active as lobbying organizations than as service agencies, they are not uniformly admired.

TMOs commonly are nonprofit organizations, but some include, or are affiliated with, certain for-profit operations. Many operate as corporations, but some prefer to act as voluntary organizations (with or without a formal agreement), and some conduct business under contractual arrangements. The approach taken in any particular case will usually reflect tax considerations, liability issues (especially if services are offered directly by the organization), funding concerns, the activities and interest of existing organizations such as a Chamber of Commerce, and indeed, the amount of trust that exists between the parties. A small staff is common, although the staff may be sizable if services such as planning studies, annual employee surveys, carpool matching, transit pass sales, etc. are offered. Decision making usually is shared among the members (though major contributors may constitute an executive committee or board with authority to establish the agenda—or veto items).

TMOs are often financed by membership dues or by assessments (per employee or per square foot). Public funding may also be provided to the TMO, whether or not there are public members. The approaches taken to accomplish this vary widely (depending on the mandates and restrictions of state law, as well as local practice). Public funds may come in the form of contracts or grants, in-kind services (office space, staff assistance, etc.), waiver of fees and charges, or direct cost-sharing. Benefit assessment districts, joint powers agreements, and similar legal mechanisms may apply.

The activities carried out by TMOs may include information dissemination and advocacy to members, input into public sector policy making, sponsorship or carrying out of planning studies, financing of transportation infrastructure and services, and even direct construction and operation of facilities and services. Needless to say, this wide range of activities is matched by a wide range in the mission statement, scope, and activity level of the TMOs.

Approaches such as these seem likely to be the focus of considerable activity in the next few years, as urban areas struggle to cope with congestion, and transportation-air quality planning may be able to benefit by linking up with these efforts. However, whether performance will live up to expectations remains to be seen. This clearly is an area where considerable work remains to be done, from development of strategies for effective TROs, TMOs, and multijurisdictional programs, to assessment of whether they in fact work as intended. (For more information, see the discussion on "Employer-Based Transportation Management," page 16.)

Land Use-Transportation Strategies

Likely to receive considerably more attention in future TCM planning efforts than in the past are transportation-land use strategies such as jobs-housing balance efforts and traffic-minimizing site designs. Perceptions of these types of strategies have changed recently. Once viewed as long-term and of uncertain value even then, such land use strategies are now being actively pursued in a number of jurisdictions.

Table 3-5 lists a number of land use-transportation strategies. Although a number of these measures are in use in various parts of the United States, there is little concrete information on their effects on congestion or air quality, nor on their feasibility, acceptability, or efficacy in other areas. Following are some of the more commonly raised questions:

- How and under what circumstances does trip-making associated with mixed use development differ from that associated with more conventional single use development?
- Do on-site transportation amenities such as pedestrian paths, bikeways, or showers and lockers make any difference in mode choice?
- Under what circumstances does the mode shift potential created by higher building densities and clustering of buildings offset the congestion effects also produced?
- Does the availability of on-site services reduce midday vehicle trips significantly, and/or increase employee willingness to commute by modes other than the single-occupant auto?
- Will suburbanization of employment, over time, help reduce trip lengths or increase them?
- How much will policies encouraging additional housing development in parallel with job growth help reduce commute trip lengths, congestion, and related problems?
- Will growth management strategies such as urban limit lines, infill incentives, and growth-pacing controls aid in traffic management?
- What other benefits and costs, direct and indirect, are associated with these strategies?

TABLE 3-5. Land use-transportation strategies with TCM potential.

(1) Matching land development to transportation capacity

- exactions and fees for on- and off-site transportation facilities and services
- transportation/land use consistency (General Plan)
- transportation/land use consistency (zoning, transportation improvement program)
- adequate public facilities requirements
- transportation conditions of approval for new developments
- conditional zoning tied to traffic mitigation
- annexations tied to infrastructure and service availability
- restrictions on traffic-intensive uses

(2) Directing development to areas with adequate transportation capacity, services

- urban limit lines
- infill policies
- transfer of development rights

(3) Developing land use patterns which offer opportunities to engage in activities without having to travel far

- clustering of buildings
- on-site/near-site services (convenience stores, banking facilities, child care centers)
- jobs-housing balance
- mixed use development

(4) Creating environments that support the provision of, and encourage use of, commute alternatives

- density increases/bonuses in areas served by transit
- compact development, cluster development
- subdivision/zoning/site design requirements for transit
- pull-outs, transit shelters, park-and-ride, preferential parking, etc.
- annual development quotas, caps

(5) Encouraging land uses and designs that permit trips to be eliminated

- offices in the home
- "smart buildings"

Currently, researchers disagree on these matters. For example, some argue for strong policies to encourage housing development in closer proximity to jobs, and vice versa; others assert that proximity is less important than clustering (so that transit and ridesharing are facilitated), and argue that jobs-housing balance absent such clustering might even lead to more auto use and more sprawl (since trips in the 2- to 10-mile range are in general too short for pooling and too long for walking and cycling). Studies to date have suggested positive results (up to 10 percent in reduction in emissions for jobs/housing balance, e.g.) but have been based on very simple assumptions (e.g., that a certain percentage of jobs and housing can simply be "shifted" from one part of a region to another). Both additional research and monitoring efforts will be needed to establish a body of reliable information and to address questions of where and under what conditions the land use strategies are likely to be effective. Clearly, implementation attempts in Los Angeles' South Coast Air Quality Management District should be monitored, demonstration projects should be encouraged, and research should be supported.

Investigations of changing demographic, social, and economic factors may provide new insights into the ways in which individuals and households make travel choices. Among the considerations relevant to transportation-air quality planning are the following:

- Effects of changing population characteristics, household composition, and lifestyle choices on location decisions and travel behavior;
- Impact of two-worker households on location choice and travel choices;
- Child care as a consideration in location and travel choices, and the effects of public policy on child care and school hours on these decisions; and
- Impacts of time constraints on trip chaining, and hence on mode choice, number of trips generated, and resulting emissions.

Some research has been done on each of these matters, but additional work will be needed before the implications are clear. While only some of the findings will speak to matters of immediate import to those developing TCMs, a better understanding of travel behavior ultimately should help transportation-air quality planners (and transportation planners in general) to devise more relevant, effective strategies.

Strategies Based on New Technologies

Finally, strategies based on new technologies, including computer-aided traffic control and management and telecommunications-based strategies, also will receive active consideration. These new-tech options have moved from being thought of as risky, impractical, and excessively costly to being the focus of major R & D efforts and, in several cases, demonstration projects. Advocates for full-scale implementation are increasingly heard.

Better information dissemination is probably in order concerning the extent to which these strategies are, in fact, "proven and available." For many of the newer technologies—"smart" highways, for instance—considerable research remains to be done, and the main role for transportation-air quality staff may be to keep abreast of developments and encourage adequate consideration of air quality implications as the strategies are developed and refined.

The next round of TCM planning will require considerable creativity and willingness to explore new options. Nevertheless, there are opportunities for important advances, using new institutional arrangements, new financing approaches, and a greater willingness to experiment with transportation controls.

4 TECHNICAL GUIDANCE

INTRODUCTION

The goal of this section is to help planners locate and use analytical tools to evaluate TCM effectiveness in reducing auto use and traffic congestion and improving air quality. Ultimately, the analytical steps discussed in this section should enable the user to conduct air quality modeling analyses of TCMs for SIP development. Although EPA's primary concern (and legislative mandate) is air quality improvement, the guidance facilitates the selection of TCMs that both improve air quality and help to relieve traffic congestion. Although this section can be read and used independently, actions taken to evaluate a TCM's political, technical, and economic feasibility and effectiveness should be performed in concert.

OVERVIEW OF TECHNICAL GUIDANCE

To keep this guidance as succinct as possible, this section refers to analytical approaches without explaining in detail how to conduct specific analyses. The advantages and disadvantages of an approach are discussed, data needs are identified, and references are given for obtaining more detailed instructions.

This section discusses each step in the analytical process—describing what should be accomplished, what data are needed to conduct the traffic and air quality analyses, and where to go for more information on specific tools. Where possible, implementation examples are cited to help the reader understand how these approaches have been used and with what degree of success. The analytical steps covered include

- Step 1: Technical Screening. Identifying the nature and extent of the region's traffic and air quality problems and inventorying existing TCMs. Identifying TCMs that could work well in a given geographic area, and identifying the extent to which these TCMs might be implemented (e.g., the number of traffic corridors in which high occupancy vehicle lanes might be implemented). Note that this step also involves institutional considerations covered in the institutional guidance section.

- Step 2: Evaluating TCM Traffic Effects. Identifying and using modeling or sketch planning resources to analyze how measures alter traffic volumes and speeds.

- Step 3: Evaluating Emission Changes. Estimating the effects of traffic changes on vehicle emissions over an urban area and/or at localized sites.

- Step 4: Evaluating Ozone and Carbon Monoxide Air Quality Changes. Identifying and discussing options to evaluate the effects of emission changes on ozone and carbon monoxide concentrations. (Appendix A addresses PM-10.)

Figure 4-1 illustrates these 4 broad steps required to evaluate the air quality effects of specific TCMs (or TCM packages).

Documents to Examine Before Performing Technical Analyses

It may prove useful to obtain several documents prior to conducting the technical TCM evaluations. Several of these documents are referenced extensively throughout this guidance document and many are already available to air quality staff. See especially Table 2-4; also see "Traffic Effects Analyses," "Evaluating Emission Effects," and "Evaluating Air Quality Effects" sections in Appendix B.

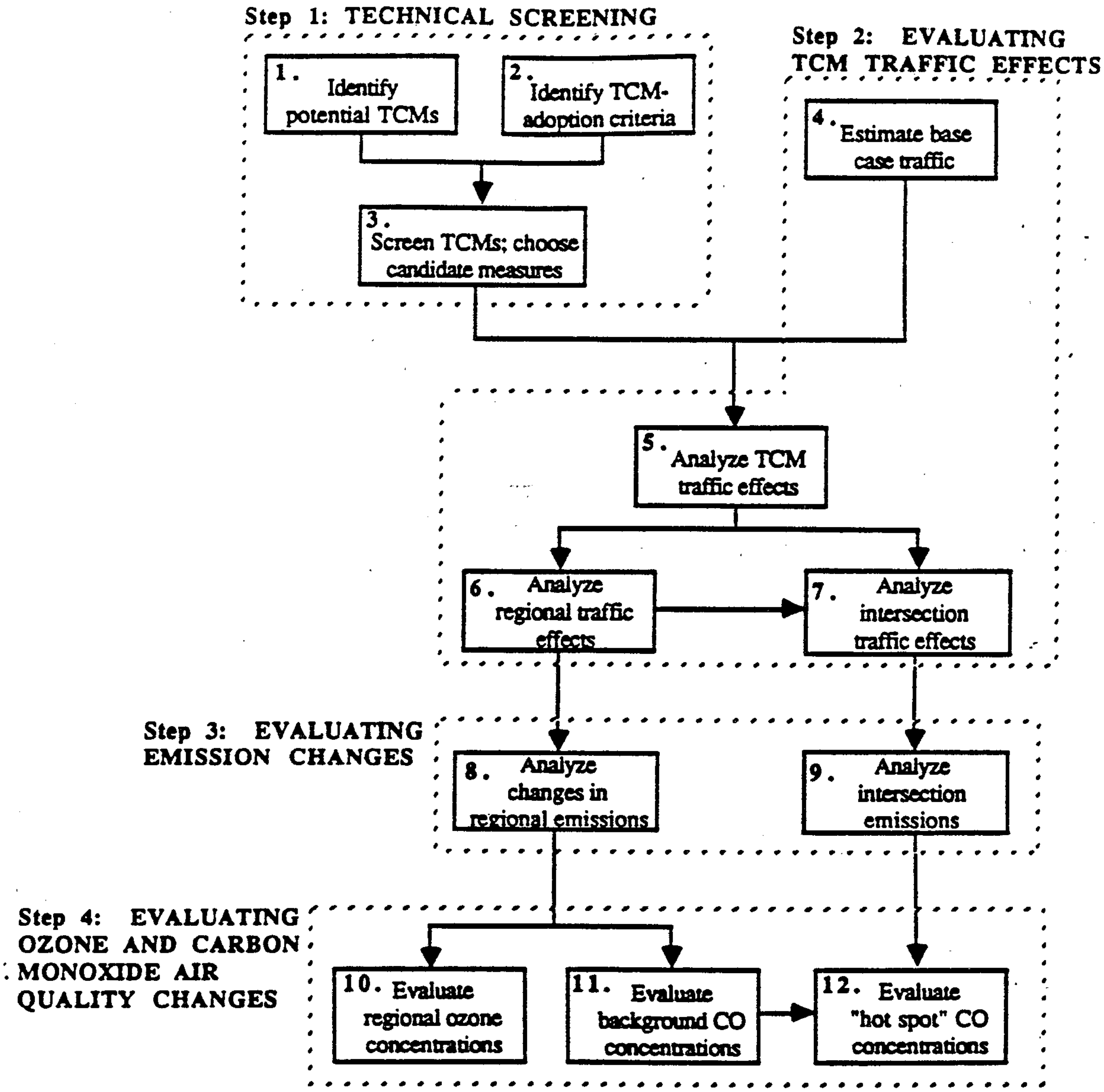


FIGURE 4-1. Overview of technical analyses to be performed, and their relationship to the four steps described in the guidance document.

STEP 1: TECHNICAL SCREENING

Technical screening identifies measures that merit in-depth evaluation for a given area. Screening identifies measures that (1) are best applied given the spatial air quality problems involved (i.e., regional or local problems); (2) can potentially relieve specific traffic congestion problems and thus improve air quality; and (3) appear to be appropriate given the urban area's population and transportation infrastructure. It is important to note that the screening process is both technical and institutional; institutional screening considerations (e.g., the extent to which TCMs have been previously and successfully applied in the region; financial resources available for implementation and enforcement) are discussed in the institutional guidance section of this document. In addition, useful screening information is included in the TCM descriptions section of this guidance. The descriptions include TCM packaging considerations important to review when weighing transportation control options.

It is important to begin this step by reviewing the nature and extent of the region's traffic and air quality problems (to determine which problems TCMs should target) and to inventory existing TCMs. The TCM inventory is essential since most areas will be building on previous TCM implementation efforts.*

Screening Measures Targeted to Air Quality Problems (Regional or Local)

From an air quality perspective, measures target two problem groups: (1) regional ozone and carbon monoxide problems best addressed by TCMs that reduce regional VMT/trips (e.g., transit improvements, car and vanpooling incentives, bicycling, HOV lanes, park and ride facilities, trip reduction ordinances, compressed work weeks, and "no-drive" days); and (2) "hot spot" carbon monoxide problems best addressed by measures reducing VMT/trips and relieving congestion in a specific area (e.g., HOV lanes, improved traffic signalization, parking management programs, metered freeway ramps, work schedule changes). (Carbon monoxide "hot spots" are localized areas of high CO concentrations that result from sources in the immediate area, such as

---

* Other measures often included as TCMs are vehicle inspection and maintenance; control of extended vehicle idling; reduction of cold start emissions; use of gasoline fuel additives, reformulated gasoline or diesel fuel, or alcohol fuels; conversion of fleet vehicles to cleaner fuels or engines; and mandatory retirement or restricted use of high-emission vehicles. However, because this study is concerned primarily with measures that ordinarily fall within transportation agencies' responsibilities, these vehicle and fuel measures are not specifically considered here.

major intersections contributing to traffic congestion.) Consideration should also be given to the seasonality of specific air quality problems (i.e., summer ozone problems, winter CO problems) when choosing potential TCMs. Table 4-1 highlights categories of control measures applicable to regional and local air quality problems.

In areas experiencing exceedances of the 8-hour average ambient air quality standard for CO, it is important to realize that "hot spot" concentrations almost certainly include a substantial urban-scale contribution. Typically, maximum 8-hour average concentrations occur in the evening or morning hours when traffic congestion is greatest, and atmospheric dispersion is limited. Concentrations during these periods are likely to remain high, with one-hour peak concentrations being perhaps only twice the 8-hour average. This pattern is an indication of a relatively widespread buildup of concentrations over much of the urban area. The fraction of the "hot spot" concentration contributed by nearby roadways may be as small as 20 percent of the total. Therefore, TCMs aimed specifically at localized congestion relief, although perhaps more cost-effective than measures implemented on a wider basis, may not by themselves achieve significant reductions in "hot spot" concentrations. Corridor- or roadway-specific measures combined with urban-scale measures are needed for such areas.

Screening Measures Targeted to Traffic Problems

When screening TCMs, analysts should also look for measures that link air quality improvement with congestion relief; these measures will be doubly effective--facilitating closer working relationships between transportation and air quality planners (see discussions in the institutional guidance section) and increasing the ability to obtain local support for air quality improvements.

A common approach to linking TCMs with specific traffic problems is to categorize geographic areas in which traffic problems occur, and then link specific measures applicable to these geographic areas. Urban traffic problems are typically categorized as occurring in one of about a half dozen areas--in or near "hot spots" or local intersections, along arterials, along freeways, along corridors, in localized areas (e.g., employment centers, residential areas, commercial centers), and in the region as a whole. Table 4-2 provides examples of measures that apply to these specific problem sites. (The measures described in Section 3 of this report were categorized as to their geographic applicability in Table 3-3.) Another approach is to target a measure to a specific problem type. Table 4-3 offers three examples from the analysis of Batchelder and co-workers (1983), who identified how individual measures apply to specific problems.

TABLE 4-1. Applicability of measures to local or regional air quality problems (note that this characterization is very general; depending on the specific implementation conditions, a measure could be local or regional).

Measures Applicable to Local Carbon Monoxide Problems

1. Traffic operations (e.g., intersection and roadway widening, one-way turn streets, turn lane installation, turning movement and lane use restrictions, new freeway lanes using shoulders)

2. Traffic signalization (e.g., local intersection signal improvements, arterial signal systems, area signal systems, freeway diversion and advisory signing, freeway surveillance and control, express bus preemption of traffic signals)

3. Pedestrian and bicycle activity (e.g., sidewalk widening, pedestrian barriers, bikeways, bike storage)

4. Commercial vehicle restrictions (e.g., peak-period, on-street loading restrictions, truck rerouting)

5. Roadway assignment strategies (e.g., bus and pool HOV lanes, park and ride lots, reversible lanes, contra-flow bus lanes, metered freeway access ramps with HOV by-pass)

6. Transit improvements (e.g., expanded radial express bus service, reduced fare bus service, express bus service with reserved median lane, marketing programs, security and facilities improvements, expanded service)

---

continued

TABLE 4-1. Concluded.

Measures Applicable to Regional Ozone and Carbon Monoxide Problems

1. Ridesharing and paratransit (e.g., employer-oriented and area-wide carpool and vanpool matching programs, HOV lanes/ramps, park and ride lots, dial-a-ride, taxi-group riding programs, jitney service, elderly and handicapped services, pooling promotion programs)

2. Transit improvements (e.g., marketing programs, maintenance improvements, vehicle fleet improvements, operations monitoring programs)

3. Parking management (e.g., preferential parking for HOVs, lower parking rates for HOVs)

Measures Potentially Applicable to Both Regional and Local Problems

1. Route diversion (e.g., area licensing, auto restricted zones, pedestrian malls, residential traffic control)

2. Parking management (e.g., curb parking restrictions, residential parking control, off-street parking restrictions, HOV preferential parking, parking rate changes)

3. Transit improvements (e.g., bus route and schedule modifications, express bus service, bus traffic signal preemption, bus terminals, simplified fare collection, park and ride facilities)

4. Work schedule changes (e.g., staggered and flexible work hours, compressed work week)

5. "No-drive" programs (either voluntary or mandatory)

6. Roadway pricing (e.g., peak-hour tolls, low-occupancy vehicle tolls, gasoline tax, peak/off-peak transit fares, elderly and handicapped fares, reduced transit fares)

Sources: Albersheim, 1982; DiRenzo, 1979; DiRenzo and Rubin, 1978.

89058pl 3

TABLE 4-2. TCM applicability to traffic problem sites.

Traffic Problem Site	Example Transportation Control Measures Applicable to Site
Spots, intersections, or street segments	Parking bans during peak hours, two-way left-turn lanes, signal phases for left turns, rerouting turning traffic, intersection and roadway widening, signalization improvements, curb parking restrictions, widening sidewalks/pedestrian grade separation and control barriers, restricted on-street loading zones, peak-hour loading prohibitions, bus stop improvements
Arterial street corridors	Spot/intersection improvements, park and ride lots, one-way streets to improve flow, new street segments, arterial street lanes reserved for express bus or carpools, bus transfer stations, expanded regular-route bus service, contra-flow bus lane, reversible lane system, bus traffic signal preemption, peak-hour tolls (HOV tolls), jitney service, bus route and schedule modifications
Freeway corridors	Increased peak-period roadway, bridge, or tunnel tolls; toll discounts for carpools during peak periods; park and ride lots along transit routes; freeway ramp control or closure; travel on freeway shoulders during peak periods; priority freeway access/egress for buses or carpools; bus transfer stations; new freeway lanes; surveillance and control efforts; express bus service; HOV lanes
Employment centers	Staggered and flexible work hours, compressed work week, on-street parking bans during peak periods, parking reserved for short-term use, increased parking rates, parking rate adjustments (e.g, fines, time limits), expanded off-street parking, freeway ramp closure, one-way streets to improve flow, reversible lanes, new street segments, signal phases for left turns, rerouting turning traffic, use of fleet vehicles for carpooling, employer-based programs (matching, vanpools), priority freeway access for HOVs and buses, shuttle buses or vans, circulation buses or vans
Commercial centers	Parking reserved for short-term use, parking rate adjustments, expanded off-street parking, freeway ramp closure, one-way streets to improve flow, rerouting turning traffic, shuttle buses or vans, bus transfer stations, pedestrian malls

continued

89058 3

TABLE 4-2. concluded

Residential areas	Residential parking permits, neighborhood traffic barriers, parking rate adjustments, one-way access to impede flow, expanded bus service, shared-ride taxi, community transit services, area signal system improvements, bikeway program
Major area or region	Spot, residential, employment, and commercial area improvements; carpool matching; dial-a-ride system; area licensing; auto restricted zones; area-wide signal systems; elderly and handicapped paratransit services; transit fare collection changes; transit management changes; gasoline taxes; peak/off-peak transit fares; reduced transit fares.

Sources: Batchelder et al., 1983; Abrams et al., 1981.

89058 3

TABLE 4-3. Example problems addressed by specific measures.

Measure	Problems Measure Addresses
Staggered work hours	Areas that experience traffic congestion during peak periods, in or near employment centers
	Areas where congestion is projected to increase due to increasing employment activity
	Areas where current transit services are oversubscribed during part or all of the peak commute period
Increased parking rates near a major activity center	Consistent traffic congestion near activity center during peak periods
	Unacceptable air pollutant concentrations in/near the activity center during peak periods
	Long-term parking that excludes short-term parking users
	Current street capacities that will be insufficient to handle expected growth in traffic volumes
HOV lanes for freeways	Peak period traffic congestion along freeway or its corridors and/or near workplaces of those using freeway
	Unacceptable air quality along freeway and its corridors that can be linked to traffic flows

Source: Batchelder et al., 1983. This is a brief example of the more detailed information provided in the reference.

Screening Measures Targeted to Urban Area Size and Characteristics

Although larger urban areas can choose from among virtually all TCMs, smaller areas may have to be more selective. Discussed here are two general approaches found in the TCM literature that can help analysts consider demographics when screening measures. The first approach identifies the applicability of TCMs based solely on an area's population; the second weighs several variables to tie demographics into a more comprehensive screening approach.

Screening Measures on the Basis of Population

Smaller cities (i.e., areas with less than 50,000 people) do not necessarily have the characteristics to support certain TCMs. For example, transit services in smaller cities may not warrant setting aside HOV lanes for buses (see the description section for a discussion on HOVs). Freeway surveillance, work schedule changes, and certain parking constraints are further examples of measures that might not be appropriate for smaller areas (DOT, 1981). Figure 4-2, reproduced from a U.S. Department of Transportation-sponsored study of transportation system management strategies, describes in general terms the applicability of measures to areas based on their population. The figure provides a general checklist—analysts in smaller areas can use the figure to highlight measures they may wish to screen more carefully before deciding on their potential appropriateness.

Screening Measures on the Basis of Population and Other Variables

An alternative approach to using demographics sets up a matrix of screening considerations that incorporates area population as one variable. One example of such an approach classifies four urban area types and their subregions; identifies three transportation control objectives that could apply to any area; and designs a "TCM-applicability matrix" (Wagner and Gilbert, 1978). The remainder of this discussion focuses on the Wagner and Gilbert approach.

Urban Classification Scheme

Four urban area types are defined on the basis of population, transit use, and average auto speed:

- Type 1. Larger cities with lower highway speeds, higher levels of congestion, and higher levels of transit use.

- Type 2. Smaller versions of Type 1.

Strategy	Tactic	Applicable City Size, Population <50,000	<250,000	<1,000,000	>1,000,000
Traffic Operations	Intersection & roadway widening	X	X	X	X
	One-way streets	X	X	X	X
	Turn lane installation	X	X	X	X
	Turning movement & lane use restrictions	X	X	X	X
	New freeway lane using shoulders		X	X	X
Traffic Signalization	Local intersection signal improvement	X	X	X	X
	Arterial signal system	X	X	X	X
	Area signal system	X	X	X	X
	Freeway diversion & advisory signing			X	X
	Freeway surveillance & control			X	X
Pedestrian and Bicycle	Widen sidewalks	X	X	X	X
	Pedestrian grade separation	X	X	X	X
	Bikeways	X	X	X	X
	Bike storage		X	X	X
	Pedestrian control barriers			X	X
Roadway Assignment	Exclusive bus lane-arterial				
	– take-a-lane		X	X	X
	– add-a-lane		X	X	X
	Bus-only street			X	X
	Contra-flow bus lane		X	X	X
	Reversible lane systems		X	X	X
	Freeway HOV bypass			X	X
	Exclusive HOV lane-freeway				
	– take-a-lane			X	X
	– add-a-lane			X	X
Route Diversion	Area licensing			X	X
	Auto restricted zones				X
	Pedestrian malls		X	X	X
	Residential traffic control	X	X	X	X
Parking Management	Curb parking restrictions	X	X	X	X
	Residential parking control		X	X	X
	Off-street parking restrictions			X	X
	HOV preferential parking			X	X
	Parking rate changes		X	X	X
Transit Operations	Bus route & schedule modifications	X	X	X	X
	Express bus service		X	X	X
	Bus traffic signal preemption			X	X
	Bus terminals	X	X	X	X
	Simplified fare collection	X	X	X	X
Transit Management	Marketing program	X	X	X	X
	Maintenance improvements	X	X	X	X
	Vehicle fleet improvement	X	X	X	X
	Operations monitoring program		X	X	X
Intermodal Coordination	Park-ride facilities		X	X	X
	Transfer improvements	X	X	X	X
Commercial Vehicles	On-street loading zones		X	X	X
	Off-street loading areas		X	X	X
	Peak hour on-street loading prohibition		X	X	X
	Truck route system	X	X	X	X
Work Schedule	Staggered work hours & flex time			X	X
	4-day week			X	X
Pricing	Peak-hour tolls				X
	Low-occupancy vehicle tolls				X
	Gasoline tax	X	X	X	X
	Peak-off-peak transit fares		X	X	X
	Elderly & handicapped fares	X	X	X	X
	Reduce transit fares	X	X	X	X
Paratransit	Carpool matching programs		X	X	X
	Vanpool programs	X	X	X	X
	Taxi/group riding programs			X	X
	Dial-a-ride	X	X	X	X
	Jitney service		X	X	X
	Elderly & handicapped service	X	X	X	X

FIGURE 4-2. Applicability of transportation control measures to areas on the basis of population. Source: C. M. Abrams, J. F. DiRenzo, S. A. Smith, and R. A. Ferlis. 1981. "Measures of Effectiveness for TSM Strategies." Offices of Research and Development, Federal Highway Administration, Department of Transportation, Washington, DC (FHWA/RD-81/177).

- Type 3. Larger cities, but less congested and less transit-oriented.

- Type 4. Smaller versions of Type 3.

Subareas are identified that apply to all four city types; these include the Central Business District (CBD), older high activity centers, new high activity centers, residential areas, radial corridors, crosstown corridors, and secondary streets.

Transportation Control Objectives

Transportation control goals are classified as predominantly concerned with mobility improvements, environmental/energy saving (or "conservation") improvements, or a mixture of the two. This last category, the mixture of conservation and congestion-relieving goals, is of particular interest—analysts can use this category to help screen for measures that will both improve air quality and relieve traffic congestion.

TCM-Applicability Matrix

The approach establishes a matrix that matches applicable transportation management strategies to cities in each of these categories (based on city types, subareas, and traffic control goals). The matrix, reproduced as Figure 4-3, provides an additional screening tool for choosing appropriate TCMs.

Goal Mix	Action	CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
		Applications Context						
A: Mobility	General traffic engineering	■	■	■	■	■	■	■
	Ride-sharing	■	■	■				
	Pricing	■	▒			■	▒	
	Freeway management					■	▒	
	Express bus, park-ride					■	▒	
	Local transit improvements	■	▒	▒	■	■	■	▒
	4-day week	■	■	■				
	Truck restrictions, enhancements	■	■		▒			
	Work rescheduling	■	■	■				
	Bicycle facility improvements	■	■	■	■	■	■	■
	Pedestrian facility improvements	■	■	■	■			
	Paratransit	▒	■	■	■	▒	▒	▒
	Add-a-lane HOV facilities					■		
B: Conservation	Pricing	■	▒			■	▒	
	ARZ, parking management	■	■					
	Ridesharing	■	■	■				
	Express bus, park-ride					■	▒	
	Local transit improvements	■	▒	▒	■	■	■	▒
	4-day week	■	■	■				
	Comprehensive HOV treatment	■	■			■	▒	
	Bicycle facility improvements	■	■	■	■	■	■	■
	Pedestrian facility improvements	■	■	■	■			■
	Paratransit facility improvements	▒	■	■	■	▒	▒	▒
	Add-a-lane HOV facilities					■		
C: Balanced	Pricing	■	▒			■	▒	
	General traffic engineering	■	■	■	■	■	■	■
	ARZ, parking management	■	■					
	Ridesharing	■	■	■				
	Freeway management					■	▒	
	Express bus, park-ride					■	▒	
	Local transit improvements	■	▒	▒	■	■	■	▒
	Work rescheduling	■	■	■				
	Comprehensive HOV treatment	■	■	■				
	4-day week	■	■	■				
	Truck restrictions, enhancements	■	■		▒			
	Bicycle facility improvements	■	■	■	■	■	■	■
	Pedestrian facility improvements	■	■	■	■			■
	Paratransit facility improvements	▒	■	■	■	▒	▒	▒
	Add-a-lane HOV facilities					■		

KEY
- ■ Definitely applicable
- ▒ Possibly applicable
- Not applicable

FIGURE 4-3a. Prototypical TSM program. City type 1: larger, more congested, transit-intensive. Source: F.A. Wagner and K. Gilbert. 1978. "Transportation System Management: An Assessment of Impacts." Interim Report. Office of Policy and Program Development, Urban Mass Transportation Administration, U.S. Department of Transportation, Washington, D.C.

(Definition of abbreviations appears on last page of figure.)

PPP89058

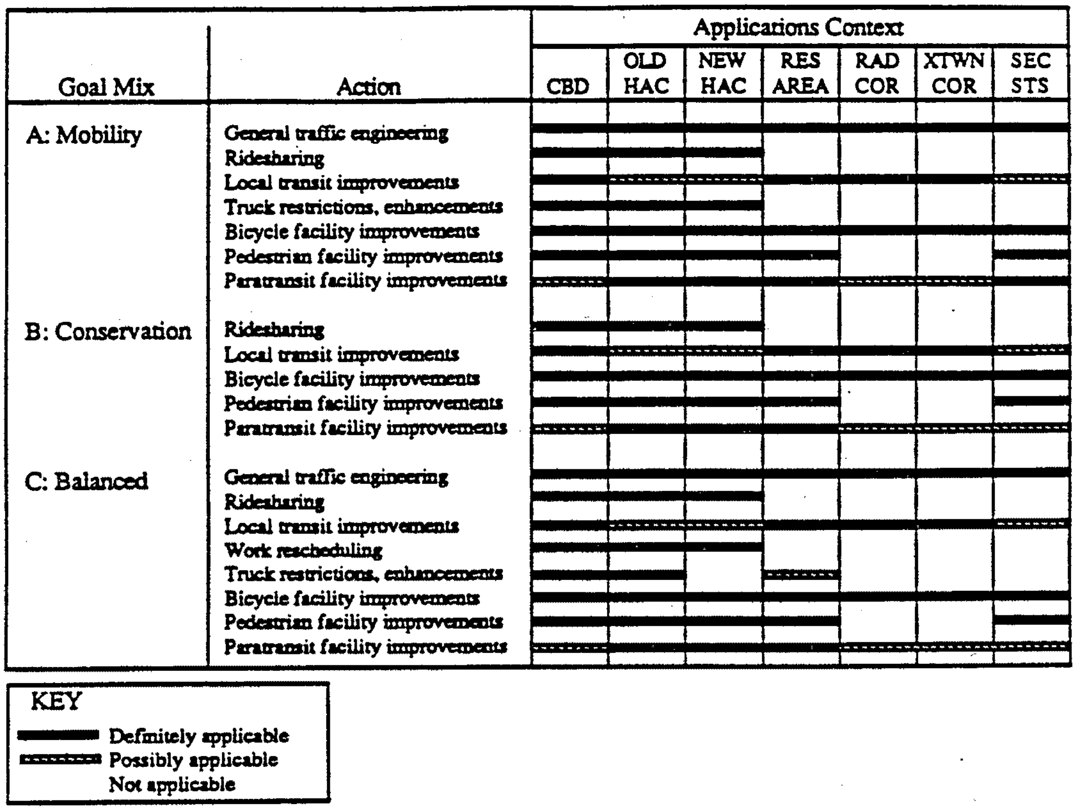


FIGURE 4-3b. Prototypical TSM program. City type 2: smaller, more congested, higher transit use.

(Definition of abbreviations appears on last page of figure.)

PPP89058

Goal Mix	Action	Applications Context						
		CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
A: Mobility	General traffic engineering	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Ridesharing	Definitely	Definitely	Definitely				
	Pricing	Definitely	Possibly			Definitely		
	Freeway management					Definitely		
	Express bus, park-ride					Definitely		
	Local transit improvements	Definitely	Possibly	Possibly	Definitely	Definitely	Definitely	Possibly
	4-day week	Definitely	Definitely	Definitely				
	Truck restrictions, enhancements	Definitely	Definitely		Possibly			
	Work rescheduling	Definitely	Definitely	Definitely				
	Bicycle facility improvements	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Pedestrian facility improvements	Definitely	Definitely	Definitely	Definitely			
	Paratransit facility improvements	Possibly	Definitely	Definitely	Definitely	Possibly	Possibly	Possibly
	Add-a-lane HOV facilities					Definitely		
B: Conservation	Pricing	Definitely	Possibly			Definitely		
	ARZ, parking management	Definitely	Definitely					
	Ridesharing	Definitely	Definitely	Definitely				
	Express bus, park-ride					Definitely		
	Local transit improvements	Definitely	Possibly	Possibly	Definitely	Definitely	Definitely	Possibly
	4-day week	Definitely	Definitely	Definitely				
	Comprehensive HOV treatments	Definitely	Definitely			Definitely		
	Bicycle facility improvements	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Pedestrian facility improvements	Definitely	Definitely	Definitely	Definitely			Definitely
	Paratransit facility improvements	Possibly	Definitely	Definitely	Definitely	Possibly	Possibly	Possibly
	Add-a-lane HOV facilities					Definitely		
C: Balanced	Pricing	Definitely	Possibly			Definitely		
	General traffic engineering	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	ARZ, parking management	Definitely	Definitely					
	Ridesharing	Definitely	Definitely	Definitely				
	Freeway management					Definitely		
	Express bus, park-ride					Definitely		
	Local transit improvements	Definitely	Possibly	Possibly	Definitely	Definitely	Definitely	Possibly
	Work rescheduling	Definitely	Definitely	Definitely				
	Comprehensive HOV treatment	Definitely	Definitely	Definitely				
	4-day week	Definitely	Definitely	Definitely				
	Truck restrictions, enhancements	Definitely	Definitely		Possibly			
	Bicycle facility improvements	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Pedestrian facility improvements	Definitely	Definitely	Definitely	Definitely			Definitely
	Paratransit facility improvements	Possibly	Definitely	Definitely	Definitely	Possibly	Possibly	Possibly
	Add-a-lane HOV facilities					Definitely		

KEY
- Definitely applicable
- Possibly applicable
- Not applicable

FIGURE 4-3c. Prototypical TSM program. City type 3: larger, less congested, lower transit use.

(Definition of abbreviations appears on last page of figure.)

Goal Mix	Action	Applications Context: CBD	OLD HAC	NEW HAC	RES AREA	RAD COR	XTWN COR	SEC STS
A: Mobility	General traffic engineering	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Ridesharing	Definitely	Definitely	Definitely				
	Local transit improvements	Definitely	Possibly	Possibly	Definitely	Definitely	Possibly	Possibly
	Bicycle facility improvements	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Pedestrian facility improvements	Definitely	Definitely	Definitely	Definitely			Definitely
	Paratransit facility improvements	Possibly	Definitely	Definitely	Definitely	Possibly	Possibly	Possibly
B: Conservation	Ridesharing	Definitely	Definitely	Definitely				
	Local transit improvements	Definitely	Possibly	Possibly	Definitely	Definitely	Possibly	Possibly
	Bicycle facility improvements	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Pedestrian facility improvements	Definitely	Definitely	Definitely	Definitely			Definitely
	Paratransit facility improvements	Possibly	Definitely	Definitely	Definitely	Possibly	Possibly	Possibly
C: Balanced	General traffic engineering	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Ridesharing	Definitely	Definitely	Definitely				
	Local transit improvements	Definitely	Possibly	Possibly	Definitely	Definitely	Possibly	Possibly
	Bicycle facility improvements	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely	Definitely
	Pedestrian facility improvements	Definitely	Definitely	Definitely	Definitely			Definitely
	Paratransit facility improvements	Possibly	Definitely	Definitely	Definitely	Possibly	Possibly	Possibly

KEY
- Definitely applicable
- Possibly applicable
- Not applicable

Definition of abbreviations:
- CBD = central business district
- OLD HAC = older high activity centers
- NEW HAC = new high activity centers
- RES AREA = residential areas
- RAD COR = radial corridors
- XTWN COR = crosstown corridors
- SEC STS = secondary streets

FIGURE 4-3d. Prototypical TSM program. City type 4: less congested, lower bus use.

STEP 2: EVALUATING TCM TRAFFIC EFFECTS

OVERVIEW

Three quantitative analyses--traffic effects, emissions, and air quality--are needed to evaluate TCM appropriateness for State Implementation Plan (SIP) submittal. This section discusses approaches to evaluating TCM traffic effects. For SIP submittals, TCM traffic evaluations should be utilized to obtain the data needed to complete the emissions and air quality analyses. Table 4-4 highlights these requirements by identifying broad categories of traffic-related data needed to conduct emissions and air quality TCM studies.

We first discuss the objectives of transportation demand analyses and identify and discuss the tools available to conduct these analyses. Next we examine how to characterize individual TCMs for these analyses, and present source documents that can be referenced for more detailed information. We also identify tools that are tailored to specific TCMs and implementation situations.

ANALYTICAL OBJECTIVES AND CAVEATS

Studies forecasting the traffic effects of transportation controls should assess whether control measures reduce the number of trips taking place, reorient where trips occur, and/or change the traveler's mode choice. These factors control the key variables determining vehicular emissions—travel time of day, mode choice, trip length, trip frequency, and travel speed. The transportation demand analysis process allows planners to evaluate how TCMs affect these variables.

Before we discuss tools to estimate TCM impacts, however, some important caveats need to be addressed. Like all predictions, transportation forecasts are vulnerable to a number of factors that remain outside the forecasting process but are known to have significant influence upon travel decisions. Changes in lifestyle; in personal income; in fuel prices and other direct transport costs; in job characteristics and location; and in housing availability, price, and location are some of the factors that can significantly alter travel behavior. Because transportation control measures for the most part induce modest shifts in trip rates, mode used, destinations chosen, and/or speed of travel, it often is difficult to distinguish TCM-induced changes from those induced by exogenous trends. When these outside trends move in the opposite direction to a TCM's desired effect (e.g., income growth and cheap fuel inducing higher trip rates at the same time TCMs are being applied to reduce travel), it may be difficult to discern TCMs' effects. The approaches outlined in this section should help analysts estimate TCM effects.

TABLE 4-4. General traffic-related data and calculations required to conduct mobile source emissions and air quality analyses.

Traffic Data	Emissions and Air Quality Models Accepting Traffic Data Inputs									
	Emissions (1)			CO Hot Spot			CO Regional		Ozone	
	MOBILE4 (U.S.)	EMFAC7E (California)	DTIM	CO Hot Spot Guidelines	EPA Volume 9	CALINE3	UAM (8) or	RAM (9)	EKMA (10)	UAM (8)
Traffic Volume										
24 hour			x	x	x					
Peak hour/design hour			x	x	x	x				
8 hour			x		x	x				
Trip Starts/Ends										
24 hour			x							
Peak hour/design hour			x							
8 hour			x							
Roadway Capacity				x (2)	x					
Roadway Characteristics										
Number of lanes				x	x (5)	x (7)				
Segment length				x		x				
Grades										
Traffic Speed										
Average running speed	x	x	x		x					
Operating speed			x	x	x (3)	x				
Idle Time				x	x					
Idle Emission Factor						x (11)				

continued

89058r2 3

TABLE 4-4. Continued.

Traffic Data	Emissions (1) MOBILE4 (U.S.)	Emissions (1) EMFAC7E (California)	Emissions (1) DTIM	CO Hot Spot: CO Hot Spot Guidelines	CO Hot Spot: EPA Volume 9	CO Hot Spot: CALINE3	CO Regional: UAM or RAM (8) (9)	Ozone: EKMA (10)	Ozone: UAM (8)
Stops				x	x				
Queue Length				x	x				
Traffic Signals									
Phasing				x	x				
Cycle length				x	x				
Green/cycle time ratio				x	x				
Diurnal Distribution (a.m. and p.m. peaking)			x						
Vehicle Age Distribution	x	x		x	x	x (6)			
Vehicle Type Classification									
Auto	x	x	x	x	x				
Light trucks	x	x	x	x	x				
Medium trucks		x	x		x				
Heavy trucks					x				
Gas	x	x	x	x					
Diesel	x	x	x	x					
Motorcyles	x	x	x	x					
Other					x (4)	x (6)			

continued

89058r2 3

TABLE 4-4. Concluded.

Traffic Data	Emissions and Air Quality Models Accepting Traffic Data Inputs									
	Emissions (1)			CO Hot Spot			CO Regional		Ozone	
	MOBILE4 (U.S.)	EMFAC7E (California)	DTIM	CO Hot Spot Guidelines	EPA Volume 9	CALINE3	UAM or (8)	RAM (9)	EKMA (10)	UAM (8)
Percent Hot/Cold Starts	x	x	x	x		x (6)				
Receptors										
Distance to road				x		x				
Height						x				
Angle of observation						x				

NOTES:

(1) MOBILE4 and EMFAC7E are emission factors models; DTIM produces gridded emissions (with gridded traffic volume inputs).

(2) For each approach.

(3) Also requires design speed.

(4) Buses and age mix.

(5) Plus row.

(6) Emission factor must be supplied as fleet composite.

(7) Width.

(8) Urban Airshed Model (UAM) accepts spatially and hourly varying gridded, speciated emissions; mobile source emission models contribute to the UAM model inputs.

(9) RAM accepts spatially gridded and temporally varying emissions; mobile source emission models contribute to RAM model inputs. (Note that UAM provides better treatment of time dependent changes.)

(10) EKMA accepts hourly, region-wide VOC and NO_x stationary and mobile source emissions; mobile source emission models contribute to the EKMA model inputs.

(11) MOBILE4 idle emission factor must be adjusted for temperature and operational mode.

SOURCES: Seitz and Baishiki, 1988; CARB, 1986; Pedersen and Samdahl, 1982 (guidance sources for individual emissions air quality models are referenced in the text).

89058r2 3

THE TRANSPORTATION DEMAND ANALYSIS PROCESS

Transportation demand analyses translate TCM implementation into variables directly affecting vehicular emissions. Agencies responsible for conducting these analyses include state departments of transportation (DOTs); metropolitan planning organizations (MPOs), which do most analyses for large areas and are thus the most relevant agency for most nonattainment areas; district DOT offices; and local planning agencies. Typically, a transportation demand analysis outputs traffic volumes and speeds on each roadway link for peak and off-peak periods, and estimates the region's resulting daily vehicle miles traveled (VMT). These outputs can be used as inputs to emissions and air quality analyses.

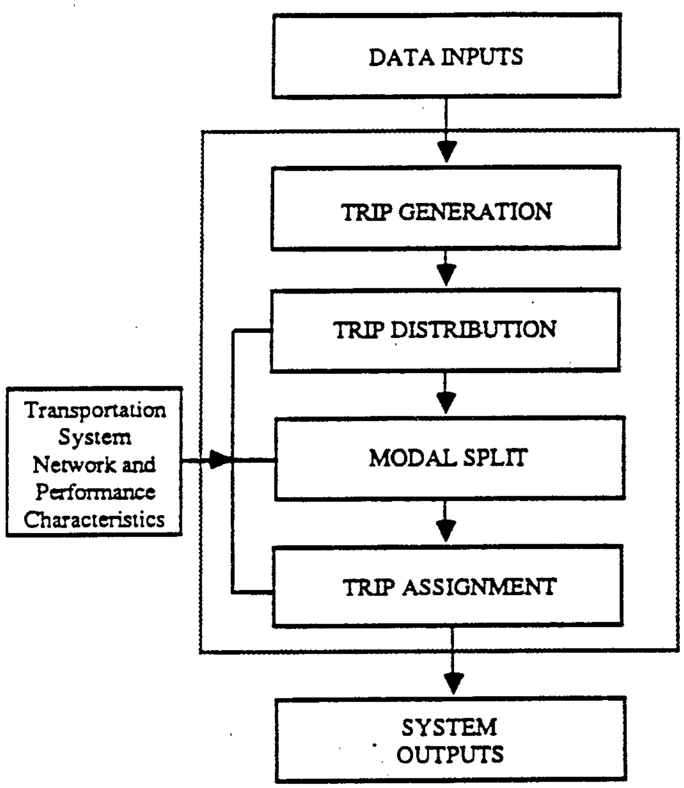
Transportation demand analyses are an essential part of what has been referred to as the three stages of the transportation planning process: (1) an inventory of existing land use, population, travel behavior, and transportation infrastructure, including an inventory of existing TCMs; (2) forecasted changes in land use, population growth, and travel demand; and (3) transportation analyses evaluating vehicular movement and mode choice options (e.g., see Stopher and Meyburg, 1975). Although land-use inventories and forecasts are essential to the transportation demand analysis, they are not addressed in this guidance document (forecasts for specific areas should be available from regional or local planning and transportation agencies). It is essential to note, however, that planners should pay close attention to the land-use forecasting assumptions used to establish future year vehicle emission scenarios. The lack of high quality land-use forecasts has been cited as a central weakness in the traffic-forecasting process (Pedersen and Samdahl, 1982).

Transportation demand analyses include four broad steps: estimating trip generation, trip distribution, mode choice, and trip assignment; these four steps are often referred to as the "urban transportation planning, or modeling system" (e.g., see Meyer and Miller, 1984). Figure 4-4 identifies these steps and notes their relationship to the key variables determining vehicular emissions (travel time of day, mode choice, trip length, trip frequency, and travel speed). Table 4-5 summarizes data inputs and outputs for each of these four steps.

ANALYTICAL APPROACHES

Both manual and computerized approaches are available to conduct transportation demand analyses. Computer models are widely available but vary in the way they have been calibrated and applied to specific regions. Manual procedures include sketch planning methods that substitute for computer tools, and manual adjustments to "post-process" computer modeling results.

SCHEMATIC | DESCRIPTION



Data inputs: Inventories and forecasts (population, travel demand, land use)

Trip generation: Predicts number of trips produced by, and attracted to, each zone--predicts flows, but not origin or destination (estimates trip frequency)

Trip distribution: Predicts origin-destination (O-D) of traffic movements--links trip ends produced by trip generation component (estimates trip length based on O-D)

Modal split: Predicts percent of traffic movement using each mode option (transit, car, walking, etc.) for each O-D pair (determines mode choice)

Trip assignment: Predicts placement of each O-D flow, by mode, on specific travel routes (estimates travel route use by time of day)

System outputs: Predicts route volumes and travel speeds for each network link, by mode, by a.m. and p.m. peak and off-peak periods

FIGURE 4-4. Urban transportation planning system and typical inputs/outputs.

TABLE 4-5. Summary inputs and outputs for each of the four principal transportation demand analysis steps.

Trip Generation	
Inputs:	Socioeconomic data, e.g., geography, population, housing (from census tract data), income, employment.
Outputs:	Number of trips originating per day in a traffic analysis zone (TAZ) (by land use type); trips are broken down by trip type (examples: home to work, home to shopping, home to other, other to work, other to other); in some cases, trips are broken down by peak or off-peak period.
Trip Distribution	
Inputs:	Trip generation data for TAZs from a large area.
Outputs:	Distributes the trips generated in individual zones into "origin-destination" pairs (known as "productions and attractions").
Mode Choice	
Inputs:	Costs, travel times, and traveler characteristics.
Outputs:	Determines which travel mode a person chooses to make a trip; assigns motor vehicle trips and forecasts transit ridership; choices vary depending upon model and region (sample choices: driving alone, two-person carpool, three-person carpool, transit/walk, transit/auto).
Highway and Transit Trip Assignment	
Inputs:	Trip generation estimates of travel demand from one TAZ to another; data (computer code) of available networks; and mode choice. Other inputs: roadway characteristics (e.g., capacity, travel time from "node to node"), trips per day (for given roadways), road locations, road changes.
Outputs:	Trip types are aggregated into time periods (a.m. peak, p.m. peak, off-peak); models then assign each trip to a roadway link(s) and produce daily traffic volumes and speeds, broken down by peak and off-peak periods (i.e., emission "activity" factors); note that traffic engineers are primarily concerned with peak period travel—local model systems/data may not produce hourly or weekend traffic forecasts.

89058 3

Choosing Between Computerized and Manual Tools

When deciding whether to conduct computerized or manual transportation demand assessments, analysts evaluating TCMs should base their choice on two primary criteria:

1. Whether tools are available to the analyst through local, regional, or state transportation agencies (including accurate data to run a model, and the status of the model's calibration to local traffic conditions); and

2. The characteristics of the measure(s) to be evaluated (i.e., local or regional applications, measure complexity, number of alternatives to be evaluated).

Consideration should also be given to the financial resources available for the analyses (see also, discussion on funding TCMs in the institutional guidance section). Generally, computerized tools are preferable as the number and complexity of the measures to be evaluated increases. They are also preferable in evaluating larger geographic areas (e.g., corridors, CBDs, entire regions) (Levinson et al., 1987; Abrams et al., 1981).

Computerized Transportation Demand Modeling

With the advent of less costly mainframe, micro, and personal computers over the past decade, numerous computerized transportation demand modeling packages are now readily available to most transportation agencies (e.g., most MPOs have access to a system of transportation models called the Urban Transportation Planning System—UTPS—or to equivalent systems). Although analysts evaluating TCMs are likely to have little choice in selecting a computerized travel demand model (their options will be limited to the tools already available to local transportation planners), most will have some computer tools at their disposal.

Important Considerations in Using Computer Models

To be most useful, computer models should be thoroughly documented; their ability to simulate the local network should be validated; and accurate, recent data (e.g., trip tables, network information, demographics) should be available in a format suitable for input to the modeling system (Abrams et al., 1981). Each of these considerations should be weighed with transportation staff to fully identify expected modeling limitations and benefits before TCM analyses are conducted.

Computer tools available to analysts vary substantially, and it is important to bear in mind the reasons for these differences and their effects on TCM analyses. In a comprehensive survey of traffic forecasting procedures used around the country, Pedersen and Samdahl (1982) identified eight reasons forecasting results vary and are less than adequate:

1. The level of detail and precision of computer traffic forecasts varies from project to project.

2. A lack of quality land-use forecasts (and wide variability among land-use data collection and formating methods) limits the ability to develop high quality traffic forecasts.

3. Computerized traffic assignment processes differ from area to area.

4. Computer assignments are not always available for all highways or for all areas under study (particularly areas where new growth is occurring and TCMs are especially important).

5. Traffic data needs differ for transportation system planning and design evaluations and environmental analyses.

6. The responsibility for producing traffic data is often fragmented among different agencies.

7. Traffic data production requires substantial time, effort, and experienced judgment.

8. All traffic forecasts include numerous explicit and implicit assumptions.

Another significant problem is the lack of home-based survey information regarding non-work trips; in some areas, little work has been done since the early 1970s to update this information (Ligas, 1989). It is important to note that these variables mean that different mode choice modeling approaches may yield different effectiveness results for similar strategies. For example, one study used three different mode choice models to estimate the effects of increased tolls on roadways in the Boston area—each model incorporated different user elasticities for travel times and costs, with varying results (Gomez-Ibanez and Fauth, 1980). Effectiveness may diminish over time if travelers "adjust" to increased travel costs. Analysts should bear in mind these considerations when assessing TCMs and evaluating the accuracy of their travel demand analyses.

Computer model output can also vary due to a particular modeling system's choice of analytical algorithms. Table 4-6 illustrates some of the different approaches available and their relative strengths and weaknesses. Analysts should learn which

TABLE 4-6. Sample pros and cons to alternative techniques to conduct trip generation, distribution, mode choice, and trip assignment analyses.

Demand Modeling Step and Alternative Approaches	Discussion
Trip Generation	
linear regression models	**Pros:** easy and inexpensive to assemble data from planning studies and build model. **Cons:** (1) estimation problems can result from correlation among variables (e.g., income and auto ownership); (2) relationships between variables and trip generation may not be linear and additive; (3) relative importance of variables may shift over time; (4) "best fit" regression equations may not properly characterize variables' true importance; (5) averaging of effects may hide important socioeconomic variability.
cross-classification (or category analysis) models	**Pros:** Avoid regression model's assumptions about linear and additive relationships between generation and explanatory variables: calculates trip productions by (1) grouping households by socioeconomic status (rather than just by spatial considerations), and (2) computing production rates for each group from observed data; calculate trip attractions by similarly grouping and observing attractors by employment type (e.g., manufacturing, retail, office) and employment density (number of employees per acre). **Cons:** require considerably more data than do regression models (both to construct the model and predict future trip generation); as with regression models, estimating ability may weaken over time; production models are more accurate than attraction models.

continued

89058 3

TABLE 4-6. continued

Trip Distribution	
gravity model	Pros: universally used; long-term experience among users (has been in existence over 100 years); ability to balance observed trip productions/attractions and number of trips predicted to leave and enter a zone. Cons: relies on ability to accurately assess travel "costs" as represented by travel times, distances, and out-of-pocket costs associated with travel between zones; predictive capabilities are unclear; amount of error in gravity models shown to be large, even in "good fitting" models.
other options	A number of other options are available (though for general applications they are less satisfactory than the gravity model); for example: growth factor techniques (which are applied mostly to short-term updating of trip tables and estimation of urban area "through trips"), and intervening opportunities models (these models work fine but are more complex and cumbersome to use than gravity models).
Mode Choice (or Split)	
disaggregate, or individual, choice models	Disaggregate models (e.g., the multinomial logit model) employ microeconomic "utility maximization" theory to predict traveler behavior. Pros: particularly important for TCM analyses, these models facilitate analysis of potential new mode choice alternatives; calibrate easily using currently available mode choices; require less quantity of data than aggregate models; opportunities exist to transfer models and model data to similar regions; Cons: require higher quality data (more detailed--wider range of socioeconomic and level-of-service information).
trip-interchange models	Trip-interchange models estimate mode split following trip distribution; this is the general sequence outlined in Figure 5-4. Pros: use mode "diversion curves," which can express transit use as a function of both socioeconomic status and cost of service/travel. Cons: require substantial data; are difficult to construct; are difficult to update over time; restrict mode choice to binary selection (e.g., auto versus transit).

continued

TABLE 4-6. continued

trip-end models	Trip-end models are sequentially applied after trip generation but before trip distribution; they assume transit ridership to be a function of socioeconomic status. **Pros:** particularly valid in areas with low transit service levels; models are simple to apply, require little data. **Cons:** especially important weakness with respect to TCM analysis is that model results are generally insensitive to policy changes.
Trip Assignment	
minimum path (all or nothing)	Computes ideal paths (assuming no congestion) for all O-D pairs, and loads the pairs on these ideal routes. **Pros:** simple, inexpensive; depicts routes most travelers would take assuming no congestion; results are easily interpreted. **Cons:** generates unrealistic traffic flows where systems are congested and strained beyond capacity.
equilibrium assignment	Models search for a user-equilibrium based on ideal traffic flow and cost penalties (e.g., costs due to congestion). **Pros:** more realistically represents peak-hour traffic flows; considers distributing trips for an O-D pair over a number of routes depending upon congestion. **Cons:** may be some question as to whether the simulated flows are actually the optimal solution from a user-equilibrium viewpoint.
alternative/supplemental approach	One alternative approach that can supplement traditional trip assignment techniques is the use of "select link analysis," which provides O-D patterns for specific links or groups of links. **Pros:** enhances ability of computer to clearly illustrate desired trips; allows for sensitivity studies involving several links with minimal cost or computer input changes (e.g., changing facility alignment or number of links). **Cons:** requires a select link analysis computer program that is compatible with programs already in use (e.g., UTPS); output needs to be cross-checked against base year traffic counts or O-D studies to establish reasonableness (relies on base year data availability); method does not normally recognize link capacity constraints--estimated volumes need to be compared to available capacity; may require more network specificity to properly represent freeway interchanges.

continued

89058 3

TABLE 4-6. concluded

Sources:

M. D. Meyer and E. J. Miller. Urban Transportation Planning, A Decision-Oriented Approach. McGraw-hill Book Company, New York. 1984; pp. 244-273.

N. J. Pedersen and D. R. Samdahl. Highway Traffic Data for Urbanized Area Project Planning and Design. National Cooperative Highway Research Program Report No. 255. Transportation Research Board, National Research Council. December 1982.

approach(es) are used by their system and understand how that system's limitations can affect TCM analyses.

Not surprisingly, once demand modeling is complete, there are substantial uncertainties built into resulting traffic forecasts. Transportation planners use a general rule of thumb that considers forecasted traffic assignments to be good if computer model assignments are within 20 percent of observed traffic volume statistics (Pedersen and Samdahl, 1982). TCM traffic analysis results should reflect the full range of potential effects given the variability built into the modeling systems.

Example Transportation Demand Modeling Tools

A number of computerized transportation demand modeling tools are available and in use throughout the United States. One of the most comprehensive tools is the Urban Transportation Planning System (UTPS), developed by the Urban Mass Transportation Administration and the Federal Highway Administration. UTPS (available for use with mainframe or microcomputers) is a network-based package of computer programs. UTPS and equivalent systems provide support to analyze long-range land development impacts, transportation system costs, travel demand, major facility and corridor travel volumes, energy use, air pollution and traffic accidents; these packages can also usually analyze problems on a street-by-street basis (PTI, 1986). Examples of transportation demand modeling tools similar to UTPS include TRANPLAN and MINUTP (PTI, 1986).*

Manual Methods to Conduct Transportation Demand Analyses

TCMs often affect very small areas of the metropolitan region, or induce small travel shifts. Traditional large-scale transportation model systems such as UTPS may be ill-suited to TCM applications. Designed for assessing regional and corridor-level impacts of major infrastructure investments, these model systems often represent the urban area and its transport systems at too aggregate a level to support TCM modeling. Similarly, the data sets collected to inform these models may be too sparse to permit detailed sub-area studies. In addition, exercising these model systems is costly and cumbersome.

* A recent survey of approximately 180 transportation agencies (both in and outside of the United States) identified six computerized transportation planning packages that these agencies use or planned to use most often: UTPS, TRANPLAN, MINUTP, QRS-II, TMODEL, EMME/II (UTPS Center, 1988).

Because of these concerns, many analysts recommend that TCM studies use less complicated tools. Analyses may involve individual applications of the components of the forecasting model system (e.g., using the mode choice model only, or the mode and destination models but not the network); or they may involve manual application of formulas or transfer of findings from cases well matched to the one under study. The estimated effects—reduced trip rates, shifts in travel patterns, mode shifts, and so on—can later be included, with no loss of accuracy, in the large-scale model system for analysis with large-scale project proposals.

Manual approaches to evaluate TCMs fall into two categories: methodologies that substitute for computerized approaches (otherwise known as sketch planning techniques), and methodologies that supplement computer approaches. Several documents describe sketch planning methodologies to analyze transportation control measure effectiveness (see Table 4-11 and Appendix B), including guidance specifically designed to assist air quality planners in their analysis of TCMs for SIP development (CSI, 1979). Sketch planning techniques offer less expensive and less data-intensive alternatives to computer modeling; they are best applied to evaluating TCMs that focus on smaller regions and involve few measures.

Supplemental manual approaches focus on correcting deficiencies in computerized travel demand modeling results. As discussed earlier in this section, substantial variability exists among the transportation demand modeling results produced by different agencies; supplemental approaches help "post-process" these computer outputs to insure their applicability to local conditions and to tailor system-wide analyses to the individual project level. Depending upon the computer tools utilized, these supplemental techniques can help forecast average daily traffic volumes and design hour traffic volumes by lin[illegible]ing movements for each intersection approach, levels of service, roadway capa[illegible]s, diurnal curve (time of day) data, vehicle classification data, speed and delay [illegible] and queuing data. A source book outlining these procedures has been prepare[illegible]y Pedersen and Samdahl (1982).

Characterizing TCMs for Analyses

Table 4-7 illustrates potential approaches to characterizing TCMs with transportation demand models. Table 4-8 provides an example of the approaches used by one area to simulate TCMs with a mode choice model.

Specialized Tools

A number of specialized transportation forecasting tools have been developed to service specific planning needs, such as specific project evaluations or applications to specific areas. Although this guidance preparation effort could not review all transportation forecasting options, it did identify several tools that may be of interest to

TABLE 4-7. Potential uses of transportation models to characterize TCMs.*

Area-wide Ridesharing

1. Represent increased time due to meeting pool members at a park and ride lot or picking them up by adding a time increment to the total travel time, or, if "access mode" is modeled, use that model to address this.

2. Represent reduced time due to HOV use in the input files for shared ride. Also reduce costs if ridesharing is given a preference (e.g., free parking or no tolls).

3. Reduce access time at the destination to represent preferential parking reserves.

4. Changes in auto occupancy may be modeled directly but often are simply handled by "off-line adjustments."

Bicycling Alternatives

1. Overall, it is difficult to model this measure; bicycling is generally not an alternative represented in a mode choice model, nor are bike facilities coded into a network. However, it is important to note that the VMT saved is in the cold-start mode, so emissions reductions are well targeted. One potential approach for estimating the impact of bicycling might be to reduce trip generation rates for shorter trips.

High Occupancy Vehicle Lanes

1. Network recoding can be done (new HOV links coded parallel to existing links; reversible lanes represented as a one-way link).

2. Adjust mode choice model inputs for shared ride vehicles: usually zone-to-zone travel times and possibly costs will be affected. Represent the time savings for HOV users by changing the input data file travel times between affected origins and destinations.

TABLE 4-7. Continued

Park and Ride Lots

1. Generally, these measures are difficult to model. Model systems that explicitly represent access to transit or ridesharing permit the analyst to represent park and ride lots as transfer points with associated wait times and costs.

Parking Management Programs

1. Increase parking costs in the mode choice input data file if the measure results in increased costs borne directly by the traveler.

2. If parking restraints result in increased roadway capacity and link speeds (e.g., by creating a new lane on arterials once curb parking is prohibited), then additional roadway capacity could be coded into the roadway network. A simpler way to model these changes is to represent them as reduced travel times and travel costs for nonscheduled road users.

3. If drivers can park on adjacent streets, increase the walk time (access) component of travel time for the auto modes affected by the parking restraint (drive alone and possibly shared ride).

Pricing Changes (e.g., Tolls)

1. These changes (auto costs, tolls, etc.) can be represented directly by modifying the input data file. Both mode choice and trip distribution modeling would use the revised price data.

Traffic Flow Improvements

1. Revise network coding to adjust travel times, turn penalties, parking, and capacities for individual links and nodes (for measures such as traffic operation improvements, signalization improvements, commercial vehicle prohibitions; also applies to parking management and transit operations), or simply revise the travel times and costs in the input file for the mode choice model.

2. Measures such as auto restricted zones can be handled by setting infinitely high traffic impedance values for specific links, or by deleting links from the network; however, these changes are on a limited scale and their impacts might be masked in the model output if the output is geared to a broad area or region.

TABLE 4-7 Continued

Transit Improvements

1. Region-wide improvements can be tested by changing the transit travel time or "wait time" in the modal split model (these changes produce an estimate of the percent of total trips diverted to transit as a result, and will produce a net decrease in the traffic to be modeled on the highway network).

2. In general, transit fare changes can be represented by changing transit passenger cost data in the input file. A potential problem with this approach is that the model may show an increase in transit riders, without changing transit capacity. If a fare change produced more riders than capacity, most network models will not recognize this since most transit network models are not capacity-constrained. In these cases, estimates should be made of the additional transit capacity needed.

3. Transit service improvements in specific areas can be tested by changing the transit network to reflect improvements (generally, this is a more time-consuming task than the regional analysis).

Work Schedule Changes

1. Few models have been developed to represent work schedule policies, and none are in regular use by public agencies. A trend-adjustment approach being considered by the Southern California Association of Governments includes the following steps (Hamerslough, 1989): (a) Run the travel demand model under base case conditions to get zone-to-zone pairs (this keeps trip generation rates at their base case level). (b) Estimate how many (what percent) of the work trips will be affected by a work schedule change program, for example, that 2 out of 10 riders will change their schedule. (c) Then, modify the trip distribution tables by factoring down the number of home-to-work trips, and factoring up (by a smaller percentage) the number of nonwork trips (e.g., in UTPS, the trip tables are part of the UMATRIX program). (A simpler way to test this policy is to reduce "peaking" factors in UTPS.)

No-Drive Days

1. An approach for modeling no-drive days or work-at-home policies would be to reduce work-trip generation rates. For areas that can target the trip reductions to specific types of work trips (e.g., to manufacturing facility workplaces), alter the attraction rates of specific work categories in the trip generation model.

TABLE 4-7 Concluded

* As a general caveat, there are limitations to the ability of transportation models to simulate short-range transportation control measures. Researchers emphasize that mode choice models require detailed origin-destination, travel time, and travel cost information. When used to evaluate TCMs, they are most effective for estimating region-wide changes (Levinson et al., 1987). In addition, it should be noted that Table 4-7 contains two distinctly different applications of travel models to evaluate TCMs. Some measures (e.g., parking cost changes, toll changes, HOV lanes) can be directly modeled; other measures (e.g., bicycle use, rideshare changes) often need to be represented by using surrogate modeling parameters (though some areas have models specifically designed for these measures).

Sources: Hamerslough, 1989; Purvis, 1988b; Pratt and Copple, 1981; CSI, 1979; DOT-EPA, 1979; Feldstein and Tranter, 1979.

TABLE 4-8. Example: approach taken by the San Diego Association of Governments (SANDAG) to simulate TCMs using a mode choice model.

Transportation Control Measure	Mode Choice Model[1] Simulation Approach
<u>Transit-Related</u>	
Increase service frequency	Reduce transit initial wait times
Extend light rail system or add new bus route	Reduce transit travel times Increase transit accessibility Reduce transit access time
Add light rail station	Increase light rail accessibility Reduce light rail access time Increase light rail travel times
Build park-and-ride lots	Reduce transit auto access times Reduce rideshare access times
Decrease fares	Decrease user's transit costs
Add express service	Reduce transit travel times
Construct transit center	Reduce transit transfer times
<u>Highway-Related</u>	
Build new freeway or arterial	Reduce highway travel times
Increase parking rates or gasoline prices	Increase highway costs
Build high occupancy vehicle (HOV) lanes	Reduce rideshare travel times
Expand ramp metering with HOV bypass lane	Reduce rideshare travel times Reduce transit travel times

[1] SANDAG runs a transportation modeling package called TRANPLAN, which is equivalent to UTPS.

Source: "Regional Transportation Models." San Diego Association of Governments. July 1988.

planners analyzing TCMs for state implementation plans, the most important of which involves intersection modeling tools. The remainder of this discussion highlights some of these alternative tools and references information sources.

Intersection Modeling

Intersection traffic modeling is an integral part of hot spot air quality evaluation. This discussion profiles one intersection model—TRANSYT-7F.

TRANSYT (Traffic Network Study Tool) is a popular signal timing model first developed in the late 1960s in England and updated frequently over the past 20 years. The most widely used version is TRANSYT-7F (over 1,000 United States users), developed under the sponsorship of the U.S. Federal Highway Administration (FHWA) by the University of Florida Transportation Research Center (Neffendorf, 1988). TRANSYT-7F operates in two stages; the first stage simulates traffic conditions for an arterial or a link with a set of traffic signals and then estimates degree of saturation, travel time, delays, stops, and fuel consumption; the second stage optimizes traffic signals to minimize delays and stops (Deakin and Skabardonis, 1985). FHWA-sponsored tests in 11 cities predicted that traffic signal optimization using TRANSYT-7F would annually save an average of over 15,000 vehicle hours of delay, 455,000 vehicle stops, and 10,000 gallons of fuel per intersection (Euler, 1983).

Inputs to TRANSYT-7F should include traffic volumes (including link-to-link volumes) (volumes can be prepared from UTPS or its equivalent), saturation flows, existing signal parameters, existing cruise speeds, and intersection geometry. The model outputs link-by-link and network summaries of total travel time, delay (maximum and average queue length), stops, and fuel consumption; it provides a range of supplemental information, including route summaries, plots of arrival and departure flow profiles (Neffendorf, 1988; Deakin and Skabardonis, 1985). TRANSYT-7F output can also be linked to emissions/air quality models such as CALINE3 (discussed under the air quality model section of the guidance) to estimate hot spot carbon monoxide concentrations. Guidance on TRANSYT-7F is available from the University of Florida (TRC, 1988).* Table 4-9 provides an example of how TRANSYT-7F has been integrated into TCM effectiveness analyses.

* Also available from the University of Florida is a software package to facilitate using TRANSYT-7F; the package is called EZ-TRANSYT PLUS.

TABLE 4-9. Example hot spot traffic modeling steps using TRANSYT-7F: Maricopa County, Arizona.

1. Grand Avenue/Thomas Road/27th Avenue intersection selection: Intersection (a) is one of the highest traffic volume intersections in the Maricopa County region, and (b) is in an area where initial carbon monoxide (CO) modeling indicated high CO background concentrations.

2. Fourteen traffic scenarios chosen for modeling: Five base case scenarios (for the years 1985, 1987, 1990, 1995, and 2005), and nine TCM scenarios. TCM scenarios were chosen if, in regional transportation demand model evaluations using UTPS, the TCMs had resulted in at least a 3 percent regional VMT change for each of the planning years.

3. Traffic volume estimation: (a) Base case volumes were estimated using traffic counts (taken between 1983 and 1985). Counts provided traffic volumes for through movements, left turns, and right turns for each approach; traffic volumes leaving each of the intersection's six legs; and turning movements for the hours of 6-8:00 a.m. and 4-6:00 p.m. (b) Scenario volumes were constructed by factoring base case volumes for future growth, and by using an overpass study to estimate volumes for a potential intersection overpass.

4. Signal parameters estimation: Used existing signal controller settings for guidance (cycle lengths are constant from 4-8:30 p.m.; vary with traffic demand otherwise).

5. Intersection geometry: Manually measured for existing conditions, calculations were taken from overpass study to create overpass scenario.

6. Intersection coding: Intersection was coded using TRANSYT-7F conventions.

7. TRANSYT-7F modeling: Used inputs for traffic volumes, signal parameters, and intersection geometry to forecast queue length at the end of the red cycle at the intersection under each of the scenarios. Modeling assumed that all signal intervals reached their maximum periods between 4-9:00 p.m. Starting with 9:00 p.m., TRANSYT-7F was used in its optimization mode to determine cycle length and phasing. For the scenario involving potential overpass, all time periods were modeled using optimization mode. TRANSYT-7F was run 172 times, once for each hour of each scenario.

8. Air quality modeling: TRANSYT-7F outputs (hourly information on traffic volumes, average queue length at end of the red interval, cycle length, and red time) are input to CALINE for hot spot CO modeling.*

Source: MAG, 1987.

* CALINE is discussed in the air quality modeling section of this guidance document.

Additional Tools

Numerous other tools can be used to analyze transportation problems. Some are relatively new and have not been widely tested; others apply to limited problem types and have not been widely circulated. Examples include:

System II: Subarea Analytical Software to Forecast Travel Demand. This tool is a region-wide modeling system with site, subareas, and corridor capabilities. It allows the analyst to address strategies that attempt to shift or reduce peak hour traffic--an area of weakness for UTPS. (UTPS is best applied for long-range forecasting over larger geographic areas, and tends to require a great deal of hand adjustments and postprocessing of output to analyze transportation system management (TSM) alternatives.) The model simulates intersection-related capacity constraints on subarea networks, produces detailed summaries of system performance, and addresses data manipulation and presentation requirements of air quality studies (Roden, 1988).

Freeway-Arterial Corridor Traffic Models. Many urban areas have to evaluate traffic management options for areas dominated by freeways and related arterials. Control strategies to be evaluated often involve routing, diversion, ramp metering, and other traffic management tactics. There are numerous corridor-level transportation models designed to help evaluate the effectiveness of potential management strategies. The Ontario, Canada Ministry of Transportation and Communications evaluated more than a dozen of these corridor-level models. The Ministry's review based its evaluation of models on five criteria: quality of traffic engineering theory; quality of program code; user friendliness and documentation; field validation and verification; and availability, implementation, cost and support. The Ministry has published its findings, and transportation planners may wish to review these to help consider the applicability of corridor-level models to their own urban area (see Van Aerde et al., 1987).

Quick Response HOV Lane Evaluations. One example of a measure-specific analytical tool is a model designed to evaluate the effects of high occupancy vehicle lanes (HOVs). The tool is a set of demand and supply models that predict peak-hour travel volumes for freeway HOVs. The demand models are based on empirical "before and after" data from several HOV facilities implemented around the United States. Supply models are based on speed/volume relationships; they estimate changes in running speeds and travel times on general purpose lanes for different volume levels and capacity configurations. The model is intended for quick-turn-around analyses; peak-hour volumes can be predicted by hand-held calculators and a set of worksheets (provided) that contain demand, supply, and equilibrium evaluation procedures (see Parody, 1984).

Sources of Information

Table 4-10 outlines sources of information for computerized and manual travel demand tools. In addition, the Urban Mass Transportation Administration recently updated a report that provides data inputs for transportation demand analyses (see CRA, 1988).

TABLE 4-10. Sources of information about computerized and manual transportation modeling tools.

COMPUTERIZED TRANSPORTATION MODELS

General Information Source	Description
The Center for Micro-computers in Transportation (McTrans), University of Florida, 512 Weil Hall, Gainesville, Florida 32611; (904) 392-0372.	The Center is the official software distributor and user support center for the Federal Highway Administration (FHWA). The Center publishes a newsletter ("McTrans"), distributes a catalog of services and software, and fields telephone requests for information, and distributes software.
Sources of Information on Transportation Planning Methods. FHWA/PL/85/005. U.S. Department of Transportation, Federal Highway Administration. Revised May 1986.	This is a guidebook to help transportation planners locate information concerning 17 topics, among them: transportation demand analysis, transportation demand modeling tools (particularly UTPS), and the opportunity to take instructional courses in transportation forecasting and planning in general. Materials referenced are not necessarily state-of-the art (the book is several years old), but many good background documents and other information sources are listed.
Software and Source Book. Published by The Center for Microcomputers in Transportation (McTrans) and the Transit Industry Microcomputer Exchange (TIME) Support Center (descriptions of both organizations are included in this table). June 1988.	This resource (published until 1988 by the U.S. Department of Transportation, Urban Mass Transportation Administration) is a valuable reference for those considering purchasing computerized transportation software. The book profiles some 200 software packages; each profile summarizes the software package's elements and applications, the computer hardware with which it is compatible, how many organizations have or are using the software, its availability, and a point of contact for further information.

continued

TABLE 4-10. Continued.

Information for Subareas	Description
A Comparison of Microcomputer Packages for Network-Based Highway Planning. Research Report 1110-3. D. M. Chang, V. G. Stover, and G. B. Dresser. Cooperative Research Program, Texas Transportation Institute, Texas A&M University; College Station, Texas. October 1988.	This document evaluates 11 software packages (5 in detail) and is a valuable resource for smaller areas. The book reviews the software programs' ability to analyze transportation problems in small geographic areas within an urban area. Though the research is specific to Texas--evaluation criteria included the ability of these software packages to accept data from the Texas Travel Demand Package--the general findings hold national relevance. Profiled are each package's hardware requirements, capabilities, structure and operations, and costs. Also, the reference discusses how each package treats highway network preparation and transportation demand modeling (i.e., trip generation, distribution, mode choice, and assignment). Appendices provide general descriptions for 5 packages (TRANPLAN, MicroTRIPS, MINUTP, MOTORS, and TransPro).
Quantification of Urban Freeway Congestion and Analysis of Remedial Measures. FHWA/RD-87/052. J. A. Lindley. Prepared for the Traffic System Division, Federal Highway Administration. October 1986.	This report describes a computerized methodology to quantify urban freeway congestion for a single freeway or urban area. The methodology estimates delay, excess fuel consumption, and user costs. The report demonstrates the methodology with data aggregated for the nation as a whole; the methodology is applicable, however, to local agencies because minimal data are required to run the model. The report also estimates the aggregate impacts of road widening, surveillance and control, low-cost roadway geometry changes, and demand reduction. Additional information on the methodology is also available (see Lindley, 1987a and 1987b).

continued

TABLE 4-10. Continued.

UTPS Information Source	Description
U.S. Federal Highway Administration Planning Support Branch (HPN-22) Washington, D.C. 20590 (202) 366-4065.	The U.S. Federal Highway Administration (FHWA) provides UTPS-user support. The FHWA distributes software and documentation, coordinates users' groups, and offers other services to help current and potential UTPS users.

MANUAL TRANSPORTATION MODELING TECHNIQUES

General Information Source	Description
Transportation Air Quality Analysis, Sketch Planning Methods (Volumes I and II). EPA 400/1-800-001a & b. Prepared by Cambridge Systematics, Inc. for U.S. Environmental Protection Agency. December 1979.	These documents offer analytical guidance for use by metropolitan planning organizations (MPOs) and other organizations that need to evaluate the traffic, emissions, and air quality effects of implementing transportation control measures. Though 10 years old, the guidance provides valuable insights and methodologies. Document users must update data used as inputs to the analyses outlined in the guidance. Volume I describes valuable methodologies to analyze travel demand and facility operations; the document's emissions estimation procedures have been updated (see the emissions estimation discussion in this section of the current guidance). The guidance also provides insights on designing analytical approaches. Volume II illustrates these tools through the use of case studies.
Transit Corridor Analysis, A Manual Sketch Planning Technique. UMTA-MD-06-0046-79-1. M. M. Carter, R. H. Watkins, J. D. O'Doherty, M. Iwabuchi, G. W. Schultz, and J. J. Hinkle. Prepared for the U.S. Department of Transportation. April 1979.	This document offers manual sketch planning techniques similar to those included in the computerized Urban Transportation Planning System (UTPS). The emphasis is on quick first evaluations of urban transportation planning proposals. Document users must update data used as inputs to the analyses outlined in the guidance.

continued

TABLE 4-10. Continued.

Quick Response Urban Travel Estimation Techniques and Transferable Parameters--User's Guide. National Cooperative Highway Research Program Report No. 187. Transportation Research Board, National Research Council. 1978.	This guide provides manual techniques to conduct trip generation, mode split, and traffic assignment analyses. The guide is complemented by NCHRP No. 255 (described below).
Highway Traffic Data for Urbanized Area Project Planning and Design. National Cooperative Highway Research Program Report No. 255. N. J. Pedersen and D. R. Samdahl. Transportation Research Board, National Research Council. December 1982	This report provides extensive guidance on conducting manual estimation procedures to complement transportation demand modeling (either manual modeling, as described in NCHRP No. 187, above, or computerized demand model techniques). The guidance describes and documents some of the best procedures used around the country to estimate traffic volumes. Relevant procedures discussed include refinement of computerized traffic volume forecasts; traffic data for alternative network assumptions, detailed networks, different forecast years; turning movement data; design hour volume and other time-of-day data; directional distribution data; vehicle classification data; and speed, delay, and queue length data. The resource provides valuable insights into the potential deficiencies of computerized transportation demand tools, and how to overcome these deficiencies.
Simplified Procedures for Evaluating Low-Cost TSM Projects. User's Manual NCHRP Report No. 263. J. H. Batchelder, M. Golenberg, J. A. Howard, and H. S. Levinson. Transportation Research Board, National Research Council, October 1983.	Discusses estimation techniques to evaluate how implementation of transportation system management (TSM) strategies affect performance characteristics of transportation systems and their components. The estimation techniques range from straightforward hand calculator approaches to more sophisticated computer modeling. The report (as mentioned elsewhere in this guidance document) also provides valuable descriptive information concerning 37 TCMs, their applicability to specific problems, and factors contributing to their successful implementation.

continued

TABLE 4-10. Concluded.

Information for Subareas	Description
Transportation Planning for Small and Medium-Sized Communities, Proceedings of a Workshop. Special Report 187. Transportation Research Board, National Research Council. 1980.	Though almost 10 years old, this reference provides insights to help planners in smaller urban areas manually forecast transit use and travel demand. To the extent that more up-to-date techniques are not readily available to planners, this document should provide some general guidance concerning transit operations planning, traffic operations and planning, surveillance and socioeconomic forecasting, system planning, and plan implementation.
Quick-Response Procedures to Forecast Rural Traffic. A. J. Neveu. In: Transportation Forecasting: Analysis and Quantitative Methods. Transportation Research Record 944. Transportation Research Board, National Research Council. 1983.	Reviews previous efforts to forecast rural traffic; identifies and discusses a recommended approach. Applications discussed include analyses of potential highway system improvements; aid in the selection of appropriate project designs; and use as a screening tool to identify rural towns and counties where the greatest traffic growth may occur. The study also reviews the approach's limitations.

89058r1 5

STEP 3: EVALUATING EMISSIONS CHANGES

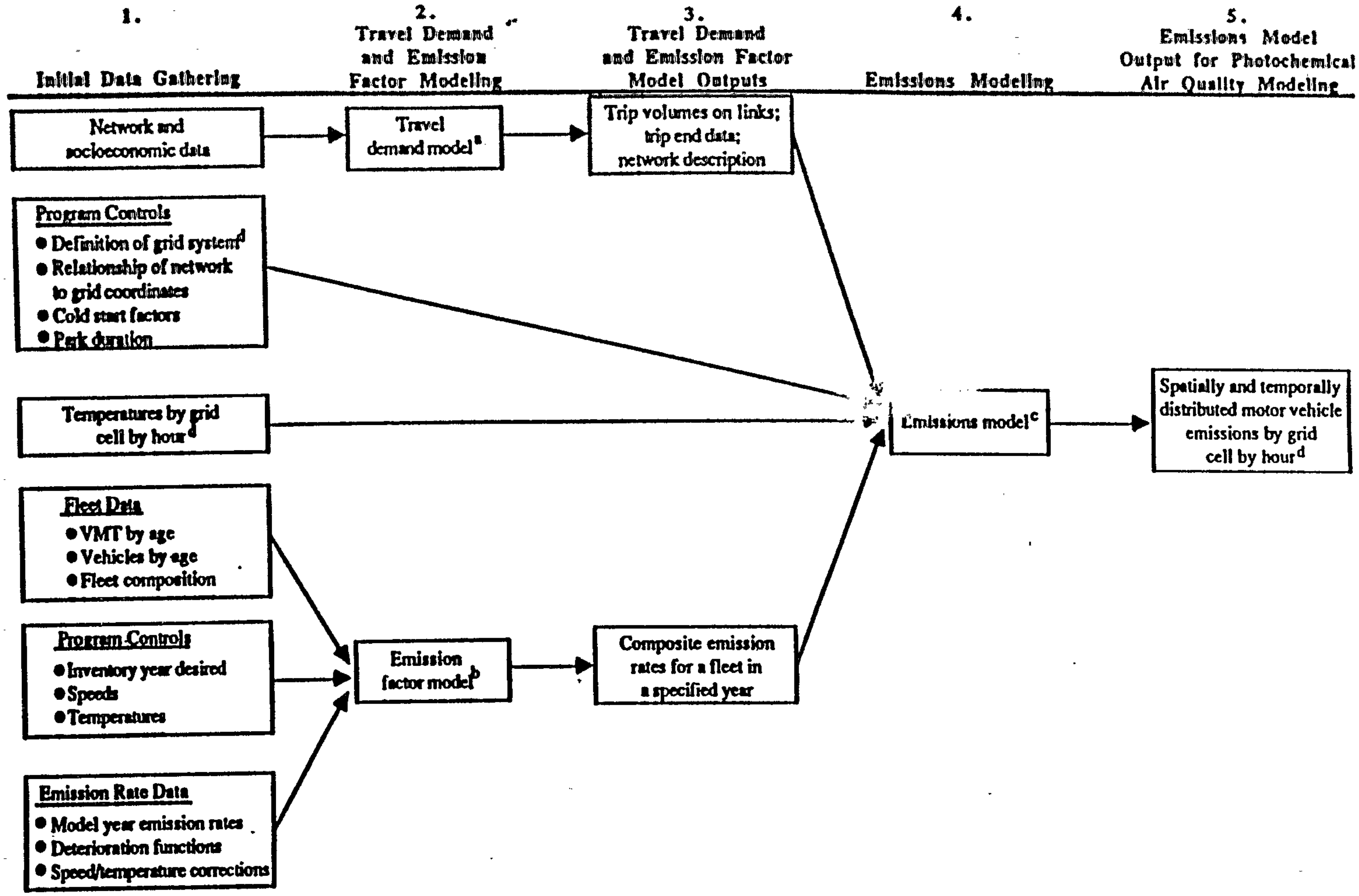
Transportation demand modeling (or sketch planning analyses) of TCMs will yield expected changes in temporally (i.e., hourly or peak/off-peak) and spatially disaggregated traffic volumes and speeds. For emissions analyses, one of the most important transportation demand outputs are a trip table estimating the number of trips originating and ending in each traffic analysis zone (TAZ) in the urban area, and a coded highway network with traffic volume and average speed estimates for each highway segment in the region's transportation system. Other EPA guidance documents address mobile source emissions inventory preparation (see documents listed under "Technical Analyses" in Appendix B). This discussion highlights important emissions analysis steps, identifies tools to complete these analyses, and references information to use for additional guidance.

Emissions Analyses: Overview of the Process

Steps to complete the emissions analyses differ depending upon whether the analyses are to forecast emissions at the regional or intersection ("hot spot") scale. At the regional scale, emissions analyses are driven by the output from transportation demand estimates (and resulting spatial and temporal traffic volume and speed estimates), emissions factors for each vehicle, and the composite emissions rates for a given year's vehicle fleet. Typical approaches used to evaluate mobile source emissions for SIP submittals include several steps such as (1) definition of a road network for a given year; (2) network subdivision into traffic analysis zones (TAZs); (3) transportation demand model forecasts of inter- and intrazonal trips; (4) assignment of trips to links in the network; (5) validation of model results (travel patterns verified against traffic counts and known link capacities); (6) transportation demand model output of vehicle trips on each link ("loadings"); and (7) use of emissions model(s) to calculate emissions by link (stabilized, running emissions from warmed-up vehicles; plus trip end emissions including cold and hot starts and hot soak) (Perardi et al., 1979). Figure 4-5 illustrates the steps necessary to complete a regional analysis.

Intersection emissions analyses integrate intersection traffic model outputs with data on intersection geometry, meteorology, background carbon monoxide levels, and other factors to estimate "hot spot" emissions. Some tools combine intersection traffic modeling and emissions estimation. Figure 4-6 illustrates the intersection analysis process.

EPA recently updated its mobile source emissions inventory preparation guidance (EPA, 1989b), and the agency has published its emissions inventory requirements for post-1987 carbon monoxide and ozone state implementation plans (see Appendix B). (Readers are encouraged to contact their regional EPA office to determine the latest guidance available.) The major steps required to complete mobile source emissions inventories included in the updated inventory preparation guidance are as follows:



[a] Examples include UTPS, LARTS, TRANPLAN, MINUTP (see discussion on travel demand modeling in text).

[b] This is EMFAC in California and MOBILE4 everywhere else.

[c] In California, DTIM provides gridded emissions model output appropriate for use with photochemical grid models (i.e., Urban Airshed Model); BURDEN provides county-level emissions suitable for use with EKMA (EKMA modeling should not utilize emissions data geographically distributed in grid cells smaller than 10 km). For non-California applications, MOBILE4 serves both the "emission factor" and "emission" modeling roles (see text for a more complete discussion).

[d] Gridded data applies to gridded photochemical modeling (i.e., Urban Airshed Model); EKMA modeling does not require a level of detail below county-wide data. Gridded data would also apply to gridded CO modeling with the Urban Airshed Model or RAM model.

FIGURE 4-5. Developing motor vehicle emissions inventories for ozone air quality modeling.

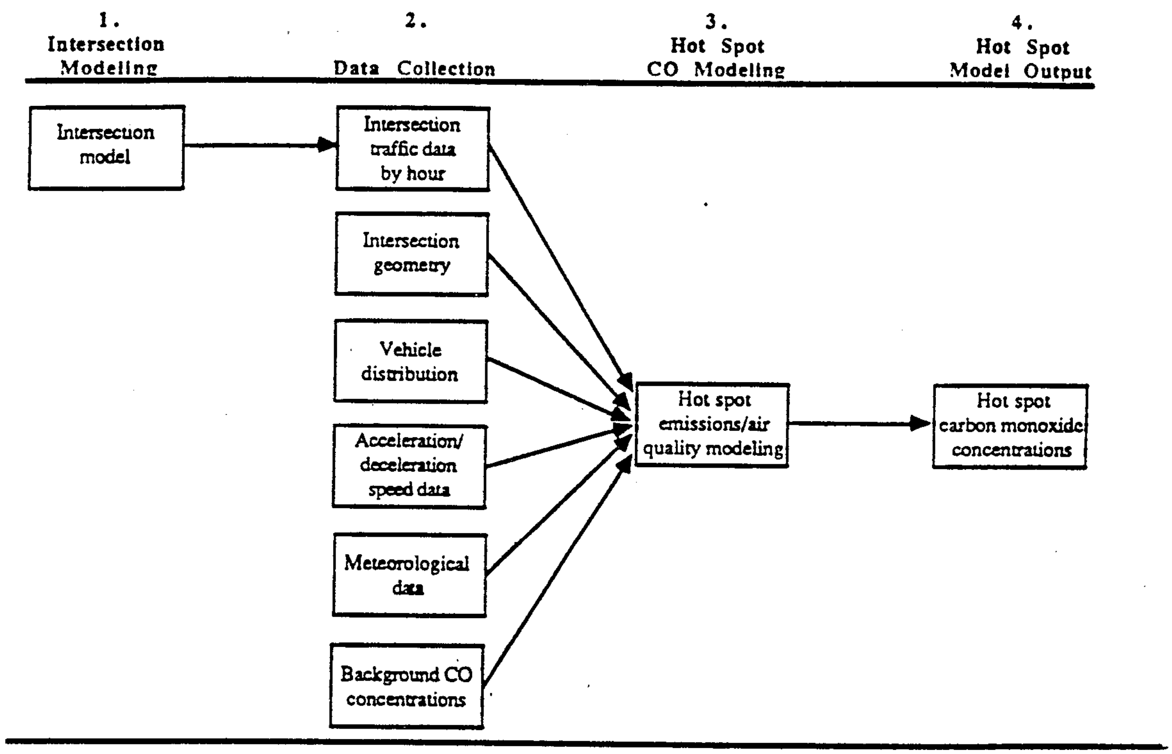


FIGURE 4-6. Sample mobile source hot spot analysis process for CO: intersection traffic, emissions, and air quality analyses.

1. Include local traffic emissions, as well as major highway emissions, in the highway vehicle emissions inventory; include such off-highway vehicles as aircraft, railroads, vessels, industrial equipment, construction equipment, and other sources unique to an area (e.g., snowmobiles); guidance to develop the off-highway inventory is contained in EPA (1981).

2. Derive highway emissions by multiplying VMT by MOBILE4 emission factors;

3. Obtain MOBILE4 emissions factors by running the MOBILE4 model;

4. Derive VMT (procedures in EPA, 1989b and EPA, 1988c) using VMT base year of 1987 or 1988 and transportation model;

5. Identify transportation model used, transportation agency that developed model, travel information used to estimate inventory, and contact (name and phone number) at the transportation agency;

6. Comply with various other requirements pertaining to year run was generated, data used to "grow" VMT to 1987-1988, road classifications, etc. (see EPA, 1988d and e).

Tools to Conduct Regional Emissions Analyses

Development of Emissions Factors

For all non-California applications, MOBILE4 is the EPA-required tool to be used to estimate mobile source emissions factors. MOBILE4 estimates carbon monoxide (CO), hydrocarbon (HC), and nitrogen oxide (NOx) emissions factors for all motor vehicle types and for a wide range of vehicle operating conditions. EPA has prepared guidance on MOBILE4 and on procedures for mobile source emissions inventory preparation (see EPA, 1989a; EPA, 1989b).

In California, EMFAC (as of this date EMFAC-7E is latest available) should be used as the emission factor model. Unlike MOBILE4, EMFAC does not have a wide range of default values built into the program, and users must supply substantial data to run the model. Guidance on EMFAC is available from the California Air Resources Board (CARB, 1990).

Preparing Mobile Source Emissions as Air Quality Model Inputs

Two types of emissions analysis tools are available to translate emissions factors and activities into air quality modeling inventories: tools that "grid" emissions (grid cells usually range from 1 to 5 kilometers) or tools that provide emissions at the county or regional scale. Air quality model requirements dictate the input format (e.g., EKMA ozone modeling usually relies on county emissions data; Urban Airshed Model ozone and CO modeling relies on gridded emissions data. The modeling section discusses this topic in greater detail).

Regional or County-Level Inventories. For non-California applications, MOBILE4 will estimate motor vehicle emission factors for inputs ranging from national average defaults to very city-specific. Parameters that can be specified include local Reid vapor pressure (RVP), minimum and maximum temperatures, I&M programs, vehicle type and age distributions, and fractions of hot and cold starts. There are no standard programs to merge MOBILE4 emission factors with traffic activity data (gridded or not) to produce motor vehicle emission inventories.

In California, EMFAC emissions factors are linked to an emissions model called BURDEN to provide county-level mobile source emissions inventories. Technical assistance to use BURDEN is available from the California Air Resources Board.*

Gridded Inventories. In California, EMFAC emissions factors and California Department of Transportation roadway data are linked to the Direct Travel Impact Model (DTIM) to produce gridded emissions inventories. Information on DTIM is provided in Seitz and Baishiki (1988). No one tool has emerged as the standard gridding device for non-California applications; various agencies have developed a number of tools to facilitate emissions gridding. In addition to DTIM,‡ TRFCONV and IMPACT can be used (as described below).

TRFCONV was originally developed by the Arizona Department of Health Services to estimate on-road mobile source emissions for the Phoenix metropolitan area, based on UTPS outputs. The model produces gridded mobile source emissions for use with the Urban Airshed Model and has been generalized for applications to other areas. It has the ability to (1) treat traffic on a link-by-link basis, allowing detailed spatial resolution of emissions, (2) address diurnal traffic volume patterns, allowing temporal resolution of emissions, and (3) remain sensitive to the effects of volume and capacity on vehicle speed (and hence emissions factors) (Ireson and Dudik, 1987).

---

* Contact the Projects, Gridding, and Motor Vehicle Section of the Emission Inventory Branch, Technical Support Division, California Air Resources Board, Sacramento, California (Wade, 1989).

‡ The California Department of Transportation has plans to modify DTIM for use with UTPS-formatted data (Seitz, 1989).

IMPACT, developed by the Texas Transportation Institute, is a highway pollutant emissions model that uses a loaded highway network (in UTPS format) and MOBILE emissions factors to estimate mobile source emissions. IMPACT computes HC, CO, and NOx emissions on a gridded or traffic analysis zone (TAZ) scale. Model outputs include (1) vehicle hours traveled (VHT) emissions factors for HC, CO, and NOx in pounds per minute or grams per minute for each speed specified, (2) start-up emissions factors for vehicles parked more or less than four hours, (3) hot soak emission factors for HC, (4) diurnal emissions factors for HC in pounds per vehicle per degree temperature change, by vehicle type, (5) total emissions for the study area for each emission element (e.g., running emissions, hot soak emissions), and (6) total emissions by TAZ or grid square (Dresser and Bell, 1986).

Tools to Conduct Intersection Emissions Analysis for Hot Spot Air Quality Modeling

MOBILE4 is the EPA-required model to produce vehicle emissions since it incorporates the latest EPA-approved emissions factors and also considers new findings concerning running losses. There are, however, a number of additional tools specific to intersection analyses. Most are traffic models that have been adapted to produce emissions estimates. One of these models, TRANSYT-7F, was profiled in the transportation modeling discussion presented earlier in this section.

STEP 4: EVALUATING AIR QUALITY CHANGES

EPA requires states to use EPA-approved models to evaluate air quality control plans. For ozone, states can use either the Empirical Kinetics Modeling Approach (EKMA) or the Urban Airshed Model (UAM) although use of the UAM is the preferred approach. Urban-scale CO problems can be addressed by using the UAM or RAM model; "hot spot" CO problems can be addressed by using roadway dispersion models approved by EPA (CALINE3 is preferred) (EPA, 1986a). The focus of this discussion is to help analysts decide which ozone air quality model is most appropriate for their application—deciding whether to choose EKMA or UAM will likely be the most difficult of the tool selection tasks; this part of the guidance highlights the key strengths and weaknesses of EKMA and the UAM for ozone modeling and TCM analyses. First, a short discussion of CO models is given.

CARBON MONOXIDE ANALYSES

"Hot Spot" Carbon Monoxide Analyses

EPA identifies two screening approaches to determine problem hot spot carbon monoxide areas (see EPA, 1986a). Once problem areas have been identified, the EPA recommends CALINE3 (the California Line Source Model) as the preferred model for hot spot or intersection air quality analyses. Because CALINE3 is a Gaussian model (i.e., it models inert pollutants such as CO) applicable to highway segments, it is useful for analyzing TCMs such as high occupancy vehicle (HOV) lanes. A user's manual is available (Benson, 1979). "Hot spot" problems are likely to involve major intersections or interchanges that are operating at or above nominal vehicle-handling capacity during peak traffic hours. When vehicle queues are too long to "clear" the intersection during each traffic light cycle, emissions from idling and acceleration become an increasingly significant factor in near-field concentrations. It is particularly important that overly simplistic modeling approaches be avoided, since CO emission rates (in grams per mile per vehicle) increase dramatically as speeds drop, especially below 15 miles per hour. EPA is updating its hot spot CO guidance; consult with EPA regional office staff for the most current CO guidance.

Urban-Scale Carbon Monoxide Analyses

The UAM and RAM models are acceptable for urban-scale CO analyses (EPA, 1987a). Guidance on RAM is available from the National Technical Information Service ("User's Guide for RAM—Second Edition," 1987). Guidance on UAM is listed in Appendix B.

A principal criterion for selecting urban-scale modeling approaches is the ability to describe extended periods of CO buildup with progressively worsening dispersion conditions. This is particularly important if TCMs are expected to significantly alter the temporal distribution of emissions since simple models (e.g., rollback) assume that spatial and temporal emission patterns are invariant. If there are a large number of "saturated" major intersections in an urban center during traffic peaks, it is possible that fairly detailed traffic modeling and emission estimation procedures will be needed to accurately describe diurnal variation in emissions. This is particularly true for growing areas in which congestion is expected to worsen in future years (with the concomitant increases in per-mile emissions due to decreasing speeds). Simple emission calculations based on a single composite emission factor and regional VMT are not appropriate for such situations.

OZONE ANALYSES

The post-1987 policy for demonstrating attainment of the ozone National Ambient Air Quality Standard (NAAQS) lists two possible photochemical modeling approaches for use in State Implementation Plan (SIP) development: the UAM and EKMA. The recommended approach is to use the UAM; however, the choice of these modeling approaches depends on the severity of the ozone attainment problem, the complexity of the meteorology and topography, the resources available for modeling, and the recommendations of the relevant federal and state offices. These two modeling approaches differ primarily in (1) basic model formulation, (2) model application methods for a SIP, and (3) the amount of information provided as output. The following paragraphs discuss these differences and summarize the advantages and disadvantages of each approach for TCM analysis. (Because of pending Clean Air Act amendments, readers should consult with their regional EPA staff to determine current modeling requirements.)

It is important to note that with any ozone modeling approach, TCMs should be modeled as a package. The emission changes resulting from individual measures will have limited effects on an urban area's ozone levels.

The Empirical Kinetics Modeling Approach (EKMA)

Overview

EKMA involves a simplified approach that considers the entire urban area's emissions as a single pollutant emissions source and calculates a single ozone concentration for each episode simulated. EKMA modeling simulates a single air parcel, or "box" of air, as it moves from the center of an urban area to the location of the observed high ozone event. The model simulates a column of air (the box) containing ozone and ozone precursors as it is transported along an assumed straightline trajectory. The trajectory is defined so that the box begins to move at 8:00 a.m. (local time) and travels over the city or air basin to arrive at the location and time of the observed maximum ozone concentration.

Technical Discussion

EKMA is based on a Lagrangian (moving air parcel) box model (the computer code associated with EKMA is known as the "Ozone Isopleth Plotting with Optional Mechanisms 4," or OZIPM4). The Lagrangian box contains initial nonmethane hydrocarbon (NMOC), NO_x, and CO concentrations corresponding to 6:00 to 9:00 a.m. measurements. EKMA can also consider transport of precursors before 8:00 a.m. and precursors transported aloft. As the box moves over a city, fresh volatile organic compounds (VOCs), NO_x, and CO are emitted into the box; the concentrations are diluted due to mixing height rise; and entrainment of precursors aloft occurs. Chemical reactions occur with the resulting concentration mix (the current chemical mechanism in OZIPM4 is the "Carbon Bond IV" chemical mechanism).

Region-wide (county, MSA, CMSA) average VOC, NO_x, and carbon monoxide (CO) emissions are used in the EKMA calculations. Morning minimum (at least 250 meters) and afternoon maximum mixing heights are required as input, with hourly variations provided through interpolation. Some consideration is given to including emissions from large (over 5 percent of the inventory) NO_x point sources during the morning hours when the plume rise may exceed the mixing height. There is no consideration of the emissions' spatial (both horizontal and vertical) variability within the resolution of a county, MSA, or CMSA. EPA guidelines recommend that VOC emissions be allocated into Carbon Bond IV (CB-IV) species by using a set of default speciation profiles (EPA, 1987b), although the actual speciation (reactivity) of the VOC emissions can be input into EKMA.

EKMA Application Guidance

The EPA has tentatively defined a set of procedures for applying EKMA for a post-1987 SIP (EPA, 1987b). Days for simulation are selected by analyzing daily maximum ozone concentrations at all ozone monitors in the vicinity of the urban area. Days selected are those on which the five highest daily maximum ozone concentrations at each site occur within or downwind of the urban area and are not overly influenced by transported ozone or ozone precursors from outside of the urban area in question.

The Urban Airshed Model (UAM)

Overview

The Urban Airshed Model (UAM) is a three-dimensional grid model designed to calculate the concentrations of both inert and chemically reactive pollutants by simulating the various physical and chemical processes that take place in the atmosphere. The UAM is based on the atmospheric diffusion, or species continuity equation, which represents a mass balance in which each of the relevant emissions, transport, chemical reaction, and removal processes is expressed in mathematical terms. Based on the grid concept, the model is generally employed to simulate a 24-hr to 72-hr period during which episodic meteorological conditions persist.

Because the model can resolve both spatial and temporal features of the concentration field, it is well suited to analysis of spatially and/or temporally differentiated future control strategies and their effect on air quality in various parts of the modeling region. This analysis is accomplished by first replicating a historical ozone episode. Model inputs are prepared with observed meteorological, emission, and air-quality data for a particular day or days. The model is then evaluated by using observed data to determine its "performance." Evaluation of the model is necessary before the modeled episode can be used as the basis for future air quality predictions. Once the model inputs have been evaluated and the model has been determined to perform within prescribed levels, the emissions inventory can be modified to replicate possible future emissions scenarios. The model simulation is then re-run with the forecast emissions, producing hourly pollutant concentration patterns that would be likely to occur under similar future meteorological conditions.

Technical Discussion

Selection of a modeling episode is usually based on the occurrence of an observed widespread exceedance of the ozone NAAQS and fairly typical meteorological conditions for ozone exceedances in the region. The modeling domain is then selected to encompass the ozone monitors that reported the exceedances and all major source regions within and around the urban area. The UAM is usually exercised with at least four vertical levels so that vertical variations in emissions distribution can be treated. The gridded UAM inputs are prepared through objective interpolation of observations. Hourly gridded inputs are prepared for the day(s) in question; model runs, performance evaluations, and control strategy analyses follow.

UAM Application Guidance

The EPA has not yet released formal guidelines for implementing the UAM for a SIP; however, UAM user guides and systems manuals are available (see Appendix B, Technical Analyses, Evaluating Air Quality Effects). Inputs are usually prepared by using objective techniques that are mutually agreed upon with approval from the EPA. It has become standard practice in applications of the UAM to compile all of the model application methodologies in a modeling protocol document. This document sets forth the procedures to be followed in an application of the UAM for the following: (1) modeling domain selection, (2) episode selection, (3) model input preparation, (4) model performance evaluation, and (5) model application. The protocol document is reviewed and approved by all participants before the bulk of the work is initiated.

Comparison of EKMA and UAM Model Formulations

The primary differences between EKMA (OZIPM4) and UAM stem from the trajectory nature of EKMA versus the grid nature of the UAM. The EKMA/OZIPM4 simulates the trajectory of a single air parcel from the urban core to the location of the observed maximum daily ozone concentration. Emissions are assumed to be instantaneously mixed within the Lagrangian box, winds are assumed to be uniform, and there is no treatment of diffusion. As the mixing height rises, specified concentrations are entrained (i.e., diluted) from aloft. EKMA attempts to replicate the observed maximum daily ozone concentration in terms of initial conditions, emissions, chemistry, and dilution. EKMA predicts the maximum daily ozone concentration, and the NMOC emissions reduction required to reduce the maximum daily ozone concentration to the ozone NAAQS of 0.12 ppm. EKMA also predicts the effects on maximum ozone of reducing NMOC and/or NO_x by specified amounts.

In contrast, the UAM simulates a number of grid cells that make up a three-dimensional volume encompassing the entire urban area rather than one air parcel. Unlike EKMA, variations in wind fields, wind shear, vertical transport, and diffusion, as well as variations in emissions distributions and emissions reactivity, are explicitly treated. Elevated point source emissions are injected into the upper layers of the UAM and entrained into the lower layers as the mixing height rises. The UAM calculates hourly ozone and ozone precursor concentrations across the entire urban area. To determine the amount of VOC emissions reduction required to achieve the ozone NAAQS, a series of UAM simulations must be made with different emissions inventories. Because of the spatial and temporal resolution of the UAM, the model may provide a number of VOC reduction estimates to meet the standards that can be evaluated with a cost-benefit analysis.

EKMA estimates the VOC control required to achieve the ozone NAAQS, whereas the UAM predicts the ozone concentrations from a given emissions scenario. The UAM replicates atmospheric processes better and is technically superior to EKMA; however, it is also more costly and complex to use.

Use of EKMA in Preparing a SIP

EKMA inputs are prepared for the modeling day(s) according to the guidelines (EPA, 1987b), and the model is exercised to calculate a maximum daily ozone concentration. If the EKMA-predicted maximum daily ozone concentration is within 30 percent of the observed value, then the EKMA inputs are considered to be adequate for calculating control requirements. If the predicted maximum daily ozone concentration deviates more than 30 percent from the observed ozone, then the inputs are reviewed and a series of adjustments are made according to the procedures given in the guidelines.

Once EKMA inputs are deemed to be adequate, the VOC emissions control requirement can then be calculated. This calculated emissions control requirement is based on the observed maximum daily ozone concentrations, not the predicted value. EKMA obtains this emissions control requirement by adjusting the VOC and NO_x emissions (but not VOC-to-NO_x emission ratio) up or down until the predicted maximum ozone concentration matches the observed value. Then EKMA performs a series of simulations lowering the VOC emission rates until the predicted maximum daily ozone concentration is less than the ozone NAAQS. The resultant output is the percent reduction of VOC emissions required to meet attainment of the ozone NAAQS.

Use of UAM in Preparing a SIP

Three main tasks must be completed to apply the UAM for SIP development: model input preparation, performance evaluation, and model application for future year scenarios.

Input Preparation

Hourly, gridded inputs of emissions, meteorology, and air quality data for the high ozone event-day(s) being modeled include more than a dozen variables. Wind measurements are interpolated or used as input into a wind model to create three-dimensional, hourly wind fields. Mixing heights are estimated from data obtained at upper-air observation sites (and from any other special observations), and interpolated onto the modeling grid at hourly intervals. Hourly temperatures are input for each grid cell. Water vapor concentrations and photolysis rates are assumed to be constant across the entire modeling domain. Initial and boundary concentration specifications are based on day-specific measurements and historical observations of background concentrations in and around urban areas. The UAM also requires both low-level (area) and elevated (point) source emissions data. The low-level emissions consist of emissions of hourly emission rates for each source in the modeling domain. The elevated emissions file consists of emission rates and stack parameters so that plume rise calculations can be made and emissions can be released into the proper vertical layer for each hour of the simulation.

Performance Evaluation

After all of the inputs for the UAM have been prepared, the base year emissions inventory is used to exercise the model, and the hourly ozone predictions are compared to the observations. The ability of the model to replicate the observed ozone is evaluated by calculating model performance statistics (e.g., bias and error). For most UAM applications, model performance criteria defining acceptable model performance are stipulated ahead of time. In past applications, a UAM performance goal of calculating ozone concentrations within 30 percent of observed values has been used as acceptance criteria (the specific acceptance criteria should be included in the modeling protocol document). Also, model performance has been considered adequate if the calculated peak values are within 15 percent of the observed peak values. The ability of the UAM to simulate the spatial and diurnal variations of the hourly ozone observations is also examined to ensure that the model is providing the right answers for the right reasons. Diagnostic simulations can be performed that examine the effects on ozone concentrations of varying important inputs such as boundary conditions and mixing heights. If the model performance is not deemed to be acceptable, then uncertain inputs, such as the wind fields or mixing depths, are reexamined and may be adjusted within their known range of uncertainty, before the model is rerun. Because of uncertainties in obtaining model inputs, it is common to conduct several diagnostic simulations before UAM model performance is deemed to be satisfactory.

Model Application

Once all parties involved have accepted the base case model simulation, adjustments to the emissions inventory can be made reflecting future year emissions and differing emissions control requirements. Emissions inventories are constructed reflecting possible emissions controls, and the model is rerun. A general goal is to find the lowest-cost emissions control scenario that will produce predicted peak ozone concentrations less than the ozone NAAQS. Note that there is no one unique emissions inventory that will achieve attainment. In fact, since the UAM explicitly treats the reactivity and distribution of the emissions, there may be several different percentages of VOC controls that will achieve attainment. Changes in ozone concentrations from the base case simulation are obtained by comparing the maximum concentrations calculated for the day, hour-by-hour concentrations at specific locations, and the spatial differences in ozone throughout the modeling domain for each hour. Time series graphs and ozone difference isopleth figures are used to show ozone response to changes in emissions.

Advantages and Disadvantages of EKMA and UAM Modeling Approaches

Table 4-11 outlines some of the advantages and disadvantages of the two modeling approaches and summarizes information presented in this discussion. In the past it has been thought that intensive measurement studies were needed to develop UAM inputs. However, when the input requirements of the EKMA and UAM are examined side by side, the principal difference is that the UAM requires gridded inputs. The U.S. Environmental Protection Agency (EPA) is currently sponsoring a study to examine the feasibility of a low-cost procedure to use the UAM in five cities (the EPA Five Cities Project) (Morris et al., 1989). The lower-cost methodology, referred to as the Procedure for Low-cost Airshed-application in Nonattainment Regions (PLANR), applies the UAM using only routinely available data while relaxing the usually strict model performance standards. Relaxation of model performance standards is necessary since most of the cost of UAM application is associated with the many diagnostic simulations required to meet the traditionally strict UAM model performance criteria. If shown to be feasible, PLANR use of the UAM appears to offer an ozone attainment approach that is more robust and reliable, though still more expensive, than EKMA. However, the potential information provided by a PLANR UAM application may outweigh the added cost of applying the model compared to EKMA.

Factors to Consider in Choosing EKMA or UAM for Application to TCM Analyses

The UAM is preferred to EKMA as an analytical tool to be applied to transportation control measure analyses. EKMA aggregates an entire region's emissions into one air parcel; UAM facilitates investigations of corridor or small area-specific emissions changes. The UAM, through its use of spatially resolved (gridded) emissions, can simulate the downwind ozone concentration effects resulting from implementation of geographically specific TCMs. The model can also simulate ozone effects from changes in the spatial distribution of emissions due to growth, development, and congestion. Given the small emissions changes (in relation to an airshed's entire emissions) that are likely to result from implementing individual TCMs, obtaining meaningful predictions of air quality changes from either UAM or EKMA modeling requires that a variety of TCMs be evaluated as a complete package.

TABLE 4-11. Comparison of the EKMA and UAM models.

Model Feature	EKMA	UAM
Model Type	Lagrangian (air parcel trajectory)	Eulerian (grid model)
Model Formulation		
Transport	Single trajectory from urban core to location of maximum observed ozone concentration. Vertical transport is treated as a linear dilution	Hourly and spatially varying wind field at several vertical levels for entire urban region. Wind shear and vertical transport treated
Dispersion	Horizontal dispersion not treated. Vertical entrainment of concen-rations aloft as the mixing height rises	Horizontal diffusion based on Fickian diffusion approach. Vertical diffusion through mixed layer and entrainment/detrainment between layers as mixing height rises and falls
Dry deposition	Not treated	Spatially and temporally varying dry deposition rates as a function of meteorology (stability), surface type, and species
Wet deposition	Not treated	Not treated
Chemistry	Any chemical mechanism can be input; Carbon-Bond IV (CB-IV) Mechanism is default	Carbon Bond IV (CB-IV) Mechanism

Continued

89058Ø1 7

TABLE 4-11. Continued.

Model Feature	EKMA	UAM
Model Inputs		
Chemistry	Chemical kinetic mechanism and rate constants (CB-IV is default)	CB-IV chemical rate constants and species surface resistances
Location	Latitude, longitude, and time zone	Gridded terrain heights, surface roughness, and vegetation factors
Modeling period	8:00 a.m. to 6:00 p.m.	Recommended multiple day to minimize initial condition effects
Winds	Used to screen trajectory to location of peak observed ozone from 8:00 a.m. to 6:00 p.m.	Hourly gridded three-dimensional wind fields
Mixing height	Morning (0800) and afternoon mixing heights	Spatially and temporally (hourly) varying
Temperature	Hourly varying surface measurements	Spatially and temporally (hourly) varying surface temperature; temperature lapse rate above and below the mixing height
Water vapor	Constant default value (20,000 ppm)	Hourly varying

Continued

89058r1 7

TABLE 4-11. Continued.

Model Feature	EKMA	UAM
Emissions	Region-wide VOC, NO_x and CO emissions, with large NO_x point sources screened to determine if emissions will be in mixed layer. VOC emissions generally split into CB-IV species using default reactivity	Spatially and hourly varying gridded area source emissions and point source emissions and stack parameters. Individual mixed layer. Speciated appropriately depending upon chemical mechanism
Initial concentrations	Based on day-specific 6-9 a.m. urban core measurements (can be median values)	Based on day-specific measurements and historical observations interpolated onto the modeling grid
Boundary conditions	Concentrations transported in surface layer above the mixed layer specified according to procedures in the guidelines	Concentrations above the top of the modeling region and along the lateral boundaries based on measurements and historical observations
<u>Model Output</u>	Maximum hourly ozone concentration and percent VOC emissions reduction required to meet the ozone NAAQS	Hourly ozone and ozone precursor concentrations at each location within the modeling domain
<u>Advantages</u>	Explicit treatment of chemistry	Explicit treatment of chemistry
	Ease of use, simple inputs	Explicit treatment of transport
	Low computer costs	Explicit treatment of diffusion
		Explict treatment of emissions distributions and reactivity

Continued

TABLE 4-11. Concluded.

Model Feature	EKMA	UAM
		Treatment of transport from outside of urban domain
Disadvantages	Cannot treat variable winds, wind shear, vertical transport, and diffusion	Requires more extensive computer time
	Does not account for variations in emissions distributions or emissions reactivity	Requires more detailed inputs
	Modeling result is single point estimate	
	Cannot be evaluated; reduced certainty of obtaining "right answer for right reason"	
Applicability to TCMs	Useful for evaluating TCMs' region-wide air quality effects; cannot distinguish corridor-specific effects; significant emissions changes are necessary to observe meaningful model results	Useful for regional or corridor-specific analyses, and accounting for changes in population distribution, traffic patterns, etc.; however, TCMs must result in significant emissions reductions individually or in packages to obtain meaningful model results

8905882 7

5 ORGANIZATIONAL/ADMINISTRATIVE GUIDANCE

INTRODUCTION

This review of issues arising in TCM program administration is designed to help government officials monitor and enforce adopted TCMs. Since monitoring TCMs can be especially complex, this topic is discussed in some detail; methods for monitoring background conditions and growth trends, for tracking implementation, and for assessing in-place performance and making adjustments as needed are reviewed. Enforcement issues are then considered, along with alternative approaches such as in-lieu fees and assessments. The concluding section presents a discussion of issues to consider in setting up the administration of TCM programs.

The success of transportation control measures (TCMs) depends in large part on the quality of their implementation. For some measures, primarily those that can be classified as capital improvement projects, the implementation question may seem straightforward: Were the projects implemented (built or installed) as proposed? The establishment of park-and-ride lots, installation of traffic signals, and construction of high-occupancy vehicle (HOV) lanes are examples. However, such projects should be examined to determine whether they are performing as expected; adjustments may be in order. Park-and-ride lots may need better marketing, signage, and lighting; traffic signals' timing plans may need adjustments; HOV lanes may need stricter enforcement.

Many other TCMs involve day-to-day operations and therefore must be periodically reviewed and adjusted to reflect the problems and opportunities of the time. Demand management programs promoting commute alternatives, parking restrictions, and work schedule changes provide good examples. For instance, experience may show that shuttle services are carrying few passengers, but subsidized subscription buses are in heavy demand. A sound TCM program will have the information and the flexibility to transfer resources from the shuttles to the buses in such a case.

Occasionally, TCMs will not be implemented as expected (perhaps, despite commitments to the contrary, some will not be implemented at all). In these cases decisions will need to be made on what to do next—adjust the requirements, require substitute measures, take enforcement actions. Whichever strategy is chosen, good monitoring data, sound record-keeping, and creative organizational and administrative approaches will be critical.

MONITORING

"Monitoring" as the term is used here is the tracking and evaluation of transportation projects and programs, and their interplay with changes in land use and development patterns, demographic and employment trends, economic conditions, and related elements of the broader urban system. The purposes of monitoring are to provide transportation managers and oversight agencies with the information they need to assess the performance of transportation programs, and to make any adjustments or improvements that are needed to achieve program goals. TCM monitoring should also be designed to provide direct input to help air quality officials track percentage emissions reductions achieved and to prepare "Reasonable Further Progress" (RFP) reports. (Consult with regional EPA staff on how to appropriately include TCM effectiveness in RFP reports.)

Transportation monitoring can take several forms:

- Monitoring trends for input to planning and to provide a "background" or "base case" for analysis of TCM effectiveness;
- Monitoring planning activities to assess consistency and progress toward implementation; and
- Monitoring implemented projects and programs to assess their efficiency and effectiveness.

Although much of the effort of TCM program administration goes into the monitoring of projects (progress toward implementation and as-implemented performance), all three types of transportation monitoring are usually needed in order to fully evaluate a TCM program. Monitoring trends allows the analyst to assess their effects and to distinguish these effects from the results of TCM activities, so that the transportation management program can take credit (or blame) only for the consequences of its own actions. Monitoring planning activities allows the TCM effort to evaluate the effects of such things as proposed or actual land use and transportation projects, assess how much progress is being made toward effective TCM action, and present cohesive policy arguments to the decision makers in the responsible organizations. With these two sources of information in hand, the TCM program's own efforts can be better assessed and adjusted as appropriate.

Table 5-1 lists common sources of data for each of the three categories of monitoring discussed here. It should be noted that trends monitoring, which is potentially the most resource-intensive of the three, is routinely carried out by state and regional planning agencies, departments of finance, and metropolitan planning organizations. TCM planners rarely would need to carry out these forms of monitoring themselves; using the available resources is adequate if the sources of data and their strengths and limitations are clearly understood.

TABLE 5-1 Monitoring strategies.

1.	Analyze growth trends, travel data (to establish baseline and provide accurate assessment of TCM performance)
	data on population, employment, incomes (Census, Finance Depts.) land use changes (local, regional agencies) traffic counts (local, regional, state) employee surveys home interview surveys (regional)
2.	Track planning activities, policies, finance (to assess progress toward implementation of plans and programs, consistency of other actions that could support or interfere)
	state, regional, local plans legislation; regulations and guidelines work programs budgets; capital improvement programs
3.	Assess implementation of projects, programs
	employee travel surveys annual reports and work programs (employers, developers, building managers) employer surveys reviews of state, regional, local plans, work programs, budgets traffic counts, parking surveys, vehicle occupancy studies

Monitoring Trends

The monitoring of trends includes keeping track of development--"growth tracking"--and travel monitoring. These types of monitoring usually involve review of census data, economic reports, land use inventories and building permit files, regional and local transportation studies, and the like; sometimes data collection is also undertaken expressly to support trends monitoring. They are undertaken because changes in social and economic factors and in the natural and built environments all can have decided effects on the feasibility and performance of transportation control measures. Unless trends are monitored, meaningful statements about the performance of TCMs cannot be made.

Growth tracking is carried out to establish a (moving) baseline for purposes of evaluation. It usually covers such factors as population size and demographics, household size and composition, housing choices, employment characteristics, and income levels, as well as changes in the magnitude, distribution, and characteristics of commercial development and housing stock and in the availability of land and infrastructure for future development.

Travel monitoring is carried out to provide an understanding of trends in travel behavior, traffic levels, and transport systems' operations and performance; it also provides a baseline against which to assess transportation programs and projects. It involves reviewing and/or gathering data on such indicators as home-based and non-home-based trip generation rates, by purpose of trip and time of day; mode of travel; trip length and distribution (origin-destination patterns); and traffic volumes. When these data are not available, judicious use of gasoline tax receipts and counts at key locations can provide rough indicators.

Other variables that influence travel choices, such as gasoline prices and transit fares, should be monitored as well.

Monitoring Planning Activities

The monitoring of planning activities is carried out to track TCMs' progress toward implementation as well as to ensure that the TCMs will be effective when implemented and will not be offset or "cancelled out" by factors and actions not fully accounted for. Specific activities in this category include:

- Review of planning and implementation status, to assess whether particular policies, projects, and programs are progressing toward funding and implementation;
- Consistency assessment, to ensure that compatible assumptions and data are being used in different planning efforts that may affect one another;

- Tracking of legislative actions that could substantially affect transportation programs.

These types of monitoring usually involve review of legislative actions, budgets, planning reports, and transportation improvement programs.

Monitoring Projects and Programs

Monitoring of transportation projects and programs includes:

- Determining whether projects and programs were in fact implemented as planned;
- Monitoring as-implemented performance to assess whether the TCM is operating efficiently and producing positive results (and to check whether it is performing as assumed in the emissions projections estimates); and, where necessary,
- Monitoring any changes and modifications undertaken to correct deficiencies or enhance performance.

Tracking implementation of TCMs can be complicated if there is a heavy programmatic emphasis on employer-based programs, development mitigation, and small-scale, operations-oriented localized activities. In these cases, careful record-keeping is critical. Record-keeping strikes many as a trivial task, but too often it has proven to be the Achilles heel of implementation: experiences show that a lack of clear records can even lead to a measure literally being "forgotten"! (This is especially a problem with requirements imposed, on a case-by-case, basis, on new developments.) Later, lack of records can make it hard to measure performance accurately, and can undermine enforcement.

Today's microcomputers and data base management software can help keep records straight, and can be set up to provide reminders that a review is called for or a submittal is due. Simpler methods such as calendar displays can also be helpful.

Evaluating performance of TCMs is also greatly helped by good record-keeping. Ideally, program and project impacts are forecasted or estimated as part of the initial program/project design; evaluations are then carried out as a means of assessing the extent to which the predicted results have been realized. Other evaluations may be conducted to assess cost-effectiveness and efficiency, or to identify possible modifications to respond to changed conditions.

Review of in-place performance can entail a variety of actions. Few TCMs can be meaningfully evaluated by simply determining whether they were deployed as proposed. Performance depends, as well, on market acceptance, changes in exogenous factors, etc., and may vary with the amount of elapsed time since implementation. For example, consider a traffic signal timing project. Initially, the review of in-place performance may merely involve ensuring that the new timings were in fact installed, and are performing as expected. In later years, however, it would be appropriate to check whether traffic volumes and/or patterns may have changed substantially. If so, retiming may be warranted. Similar kinds of monitoring are warranted for other capital investment projects whose operations may affect how well they work.

Pricing strategies also should be reviewed periodically. For example, tolls or parking fees may be set to capture the externality costs of congestion, pollution, and noise, to discourage commuting by single occupancy vehicle, or to put out-of-pocket auto travel costs on par with costs of vanpooling or using transit. Unless such tolls and fees are reviewed periodically, their effect may be lost as real costs change due to inflation, changed vehicle characteristics, or other factors.

Probably the most complex strategies to monitor are those that involve employer-based transport management, which itself may encompass ridesharing, parking management, transit improvements, work schedule changes, and voluntary no-drive days. As implemented under trip reduction ordinances, these programs may set employee participation rate targets and specific actions to be taken by employers which vary in scope and extent with employer or complex size and location. Monitoring often includes review of employee travel surveys as well as evaluation of trip reduction plans and programs. In addition, complementary government actions such as park-and-ride facilities, higher downtown parking rates, reduced parking requirements for new developments, and additional transit and paratransit service may be committed to by local government in a trip reduction ordinance (or otherwise), and these commitments also should be monitored.

Examples of common monitoring tasks and the issues they raise are discussed next.

Monitoring Employee Travel: Surveys

The most critical element of monitoring efforts for employer-based TCM programs is employee travel surveys. In a typical application, an initial survey, together with information on general transportation conditions, is the basis for the design of the initial TCM efforts to be undertaken by employers. Later surveys, usually administered one to two years after the commencement of program activities and annually or biennially thereafter, aim at assessing performance of the TCM programs and would form the basis for potentially significant program revisions and redirection of effort. In some applications employee surveys (interpreted in light of exogenous trends and supplemented by evidence from traffic counts or parking lot surveys, e.g.)

also would be used by agency officials to decide whether to permit employer programs to continue as voluntary undertakings or shift to mandatory requirements.

Employee travel surveys have been successfully utilized in many jurisdictions, but there are usually a number of complications to contend with. One issue is when to conduct the first evaluation survey. If it is scheduled for a year after the baseline survey, certain program activities might not yet be implemented or might be just getting started (since many would require some preparation time and review before implementation, and some may have necessitated certain refinements during the early start-up phase.) However, a longer wait may unduly delay needed evaluation and program adjustments.

Another issue is how to account for exogenous changes. If at all possible, the evaluation surveys should be accompanied by a round of collecting and assessing information on changes in the transportation system, land use changes, population and employment shifts, etc., in order to give context to the survey results. For example, if gasoline pr:ces should increase substantially, or if transit services are added or dropped, an attempt should be made to estimate the effect the changes have had on travel behavior, in order to avoid attributing too much or too little to the TCM program itself.

In practice, a number of changes are likely to have occurred since the initial survey, and these changes may make interpretation of the evaluation survey difficult. For example, some employers will have expanded; others will have reduced their work force or moved. Changes in markets or in business practices or emphases may have substantially altered the employment composition of some employers. Management changes may have resulted in major shifts in parking policies, or in the availability of commute subsidies. While many of these changes will be known to staff, it nevertheless will be a challenge to account for them in survey interpretation. These matters will require careful consideration and discussion, and sufficient time and resources should be allotted to the evaluation process to accommodate this.

A major set of decisions has to be made concerning the administration of employee surveys (both the initial one and those that follow). A review of practices reveals a wide range of options. For example, nearly all jurisdictions require the use of a standard survey form, but some require administration to 100 percent of employees with a 75 to 80 percent return; some permit a random sampling of employees subject to sample reliability constraints, and others have no set standard for survey administration. While there is no hard and fast rule on survey design issues of this sort, steps should be taken to ensure that the response rate is representative and large enough to support needed cross-tabulations. Assistance in sample design often can be obtained from regional planning agencies, state agencies, or local universities.

Analysis of the survey data is another area where there is a wide variation in practice. Some jurisdictions require each employer or employment complex to tabulate the data, while others carry out the analysis of raw data as a service of the

89058r2 23

staff, and still others rely on a third-party contractor. In general, employer-reported summaries are considered inferior to the other options (both because employers usually lack the requisite expertise for the job, and out of fear that the results may be misreported). Some believe that self-reporting is acceptable as long as the right to audit is preserved and a stiff fine provided in case of irregularities. Staff analysis of the raw data is feasible but also can be problematic because of the heavy time and skill requirements; therefore a third-party contract for data preparation and initial analysis seems to be the preferred approach in a number of jurisdictions (e.g., Pleasanton and Santa Barbara, California). Contractors typically turn over the data files and allow the staff to carry out additional analyses as deemed appropriate.

Another issue is whether and how to aggregate the survey data. Ideally, the survey data should help all those involved in the program—employers, cities, air agencies—decide what actions to take next. In order for employers to benefit from the survey results, it would be useful to tabulate the data by employer or employment complex, to the extent that the sample sizes are large enough to produce statistically interpretable results. On the other hand, individual employers may worry about confidentiality and prefer not to have disaggregate data made public. This issue should be discussed thoroughly before an analysis strategy is selected. In addition, local jurisdictions may wish to have tabulations prepared for the employees within their boundaries, or even within specific areas, e.g., downtown or an office park, so that the information can be used to guide local policies and projects.

Most important, however, is the interpretation of the data—judging whether the program is working adequately or not. Performance targets adopted at the initiation of the program are certainly one basis for this decision. The experimentation and learning that occurs as the program is carried out, however, may suggest revision of the performance targets, or perhaps substitution of different goals and targets. If such changes are made on the basis of thoughtful review of experience, they should not be cause for concern—indeed, such an event would be evidence of the success of the monitoring program.

Monitoring Program Activities: Plans and Work Programs

While the employee surveys would be a major source of performance data, plans and work programs developed by individual employers, transportation management organizations or associations (TMOs/TMAs), or other TCM coordinators also will provide valuable feedback on performance, and most important, will provide a tool for managing those activities.

In most cases a TCM plan is developed for each employer, employment complex, or transportation management association; it may or may not be reviewed and approved by the local government. A work program implementing the plan for the next period then serves as the basic management tool for the TCM activities. The work program would spell out the planned activities under each program element and would specify the schedule, staff assignments, and budgetary commitments for each activity.

Progress reports discussing activities under each program element during the reporting period and presenting statistics on accomplishments are usually prepared monthly or quarterly. These reports are referenced to the work program and review accomplishments on each element (percent complete, problems encountered and changes made, if any.) Planned activities for the next period also are outlined, and sometimes expenditure data are included as well. The progress report thus serves as the basis for management of the program, as well as documenting work performed. It can be invaluable to state or regional agencies who are technically responsible for a measure, the actual implementation of which is being carried out by a local jurisdiction or private organization; in many cases, progress payments or other monies can be made contingent on adequate progress as documented in the progress reports; this helps reduce the need for field surveillance.

Monitoring Employers' TCM Activities

Employers are often asked to implement different levels and types of TSM activity, depending on their size. Monitoring activities also might differ by employer size. For example, large employers could be required to submit a TCM plan for review and approval, with annual reports to document performance. Medium-sized employers might be expected to offer ridesharing services and transit pass sales, but a plan might be optional. For small employers TCM activity might be optional.

A proposal for a suburban California county's TSM program illustrates a similar approach using surveys rather than plan submittals. For small employers, an annual survey would be administered and tabulated by the staff of the oversight agency. The survey would request information on any TCMs the employers may have implemented. For medium-sized employers, both a survey and a request for information on planned activities for the coming year would be used. These employers also would be asked to report on such items as the number of subsidized transit passes sold, the number of vanpools assisted, etc. Large employers would be asked to provide the most detailed data on accomplishments under each relevant program element; an annual progress report and work program for the next year would be required and would be reviewed and approved or disapproved (in which case revisions would be mandatory).

Surveys of Developers or Building Managers

Most of the TCMs for which developers or building managers would be responsible are capital projects; a few are services and operations such as shuttle buses, which, if implemented, probably would undergo significant modification only occasionally.

Therefore, developers and building managers might be asked to provide an initial status report, and thereafter, report only on any changes that have occurred.

At small and medium-sized developments, this might be accomplished via a survey conducted annually (or perhaps biannually). At large developments, an annual report documenting the details of parking supply and pricing policies, preferential parking utilization, etc., and setting forth planned actions for the coming year might be requested.

Monitoring City and County Activities

Cities and counties often have primary responsibility for implementing traffic engineering and operations improvements and land use plan and zoning changes, and for monitoring traffic levels and calculating levels of service. General plans, capital improvement programs, and other planning and budgeting tools often set forth current rules and outline proposed activities. Annual work programs, by department, also may provide important monitoring data. However, review of local governments' plans, zoning ordinances, work programs, etc. could be a massive undertaking, and may be justified only for major cities and communities undergoing massive change.

In other cases cities and counties will make commitments to implement TCMs, which become part of the SIP. Monitoring implementation on a regular basis then becomes a regional responsibility. One way to handle the monitoring of TCM-relevant activities of smaller jurisdictions would be to send out an annual survey to these jurisdictions, in which they would report any engineering and planning TCM actions accomplished during the preceding year and report available data on such items as parking supply, regulation, and prices; traffic levels (ADT, LOS) on major streets and at critical intersections, and so on. The progress report approach discussed earlier also can be used and is particularly appropriate when funding is provided [illegible] state or regional sources.

Monitoring the Activities of State and Regional Agencies

State departments of transportation and metropolitan planning agencies together are responsible for planning, budgeting, and programming major highway improvements (and often, ridesharing programs and amenities); the MPOs and transit agencies perform the parallel function for capital investments in urban and suburban rail, bus, and paratransit systems. In many cases there are additional county, regional, and state commissions and committees who also have important review and decision responsibilities for major transport programs.

Monitoring the activities of these agencies will involve review of planning documents, work programs, and numerous special studies. However, in view of the importance of many of the projects considered by these agencies, it is well worthwhile for agencies with TCM responsibilities to attend the meetings of these organizations in order to stay on top of the issues. Being on the mailing list of important committees is critical.

Other Monitoring Activities

Numerous other monitoring strategies can be utilized to assess the performance of various TCMs. They include spot traffic counts (total traffic, turning movements), origin-destination studies (surveys and license plate studies), travel time and delay studies, on- and off-street parking surveys, vehicle occupancy studies, home-based travel surveys, on-board transit passenger counts and surveys. Such data can provide a useful picture of overall system performance and, together with TCM-specific monitoring data and data on broader trends (in fuel prices, income, population and employment, etc.), can be helpful in developing a deeper understanding of TCM performance. These data also can provide independent evidence of TCM performance (e.g., driveway counts or parking occupancy data are indicators of commute patterns that can be compared to survey results). Discrepancies are commonly found, however, and reflect methodological differences as well as actual under- or over-reporting biases. Therefore, caution should be used in drawing conclusions from two separate measures of the same phenomenon.

Standard traffic engineering handbooks provide much useful information on traffic and travel monitoring techniques. Survey research centers at many universities offer public advisory help, as well.

ENFORCEMENT

Implementation failures are an eventuality for which agencies charged with administering a TCM program must be prepared. Such failures can result from a total refusal to act, continued delays, or implementation of only some aspects of the TCM project or program. Also, monitoring results may indicate that a particular TCM has performed poorly because implementation has been poorly carried out. Whatever the circumstances, oversight agencies must decide how to proceed. A number of alternatives are available, so that enforcement actions can be tailored to the situation at hand.

One option is to utilize conventional enforcement procedures. In broad terms this would involve sending a notification or citation to the offending party, providing for a hearing and/or appeals process with adequate due process protections, and then imposing sanctions for failure to comply. For this approach to be effective, there must be (1) an ability to determine whether a failure has, in fact, occurred, and (2) some consequence (a fine, loss of operating permit, loss of funding, restriction on permissible uses of funds, etc.) for continued failure to comply. Equity considerations suggest that failure to comply should be due to wrongful actions or refusal to act, rather than impossibility or noncompliance despite good faith efforts.

Many trip reduction ordinances and similar regulatory programs impose fines or other penalties in cases of failure to submit plans, make required revisions, or implement programs. On the other hand, few impose conventional penalties for failure to achieve established performance targets. Probably the most important reason is that for many TCMs, good faith implementation is no assurance of success. For example, transit service can be deployed but may not attract riders; high-quality bike lanes may not be used by commuters; land use plans designed to maintain acceptable levels of service on adjacent streets can lead to gridlock if transit services are cut. While a few programs, including Pleasanton, CA's trip reduction ordinance and the Los Angeles area's South Coast Air District's Regulation XV, require plan revision when established goals are not met, they do not attach further penalties in cases of poor consumer acceptance.

Required plan revision is one form of a broader strategy in which failed implementation triggers a review of the requirement, with modification or substitution of another, equally effective, measure. This approach is most often used when performance is below expectations, but it also seems to be applicable to cases in which failure to implement is for good cause. For example, a lack of financial capacity may make it impossible for a transit agency to carry out commitments made in more optimistic times; a parking agency may lack legal authority to provide free parking to carpools; an employer may have union agreements setting forth precise hours of work and preventing alterations. Sometimes an extension of time will suffice, but in other instances a renegotiation of the requirement may be in order.

One difficulty with fines is that they can be hard to collect. Another consideration is that, because they are associated with "wrong-doing," there often is reluctance to apply them to such matters as TCM implementation quality or success. As an alternative to fines, a few jurisdictions have created in-lieu assessments, which are then used to fund other TCMs (e.g., to subsidize shared ride services or improve bike parking). Traffic impact fees are charged on a per-trip basis, with a substantially higher rate for those trips in excess of TSM goals. (An approach that gives credits for trips reduced via TSM programs achieves a substantially similar result.) The advantage is that there is no need to show bad faith, to revise plans, or even to take action; nonperformance for any reason triggers the fee. The disadvantage is that accurate monitoring is needed to provide the trip-count basis for the fee.

A variation on the in-lieu fee concept is to have a third party implement services for those who fail to do so, or who simply prefer to leave the responsibility to someone else. For example, an employer might choose to have the regional ridesharing agency act as its transportation coordinator rather than appointing an in-house person to do so. The employer would be billed for the costs of the ridesharing agency's services. Employers who fail to offer an adequate commute alternatives program could be required to use the services of the ridesharing agency. Table 5-2 summarizes available enforcement options.

TABLE 5-2. Enforcement approaches.

- Conventional enforcement: notice, hearing, fines or other penalties
- Required plan revision to achieve required performance
- In-lieu fees for failure to achieve required performance
- Third-party implementation of required measures; assessment of costs

ADMINISTRATIVE CONSIDERATIONS

TCM program administration generally involves a number of organizations and actors. Responsibility for TCMs may fall to state transportation departments (HOV lanes, park-and-ride lots, ramp metering, tolls, and other projects on and along state highways); area-wide ridesharing agencies (carpool and vanpool programs, promotion of "no drive" days); area-wide transit districts (route restructuring, special fare programs); city and county traffic engineers (intersection improvements, on-street parking management, traffic signals); local planners (off-street parking requirements, traffic mitigation for new development, land use-transportation coordination); land developers (bike facilities, shuttle services, parking supply and price); and employers (work schedule changes, transportation benefits, parking charges.) Furthermore, TCMs may be developed by one group, approved by a second, implemented by a third, and monitored by still another agency. This complex institutional setting means that program management and administration itself requires careful planning. As the TCMs being utilized will vary from place to place, so will program administration.

A TCM oversight agency (whether an air district, a COG, or a local government department) will need to devise administrative procedures that reflect not only the particulars of the program but also the resources available for administration. Since organizational arrangements, assignments of responsibility for particular kinds of measures, and internal staff capabilities vary widely, it's likely that no two TCM programs can or should be administered in exactly the same way, even if they involve similar measures. Indeed, what works well in San Francisco, with a planning staff of 90, may not work at all well in Sacramento, where staff size is considerably more modest.

A first step may well be to identify all the important players, put them on an air quality planning committee, and call periodic meetings to discuss implementation and enforcement. The committee can serve an important educative function as well as providing a forum for negotiation and decision making.

Factors to consider in designing the administrative program include staff skills, funds available, and questions of timing. With regard to staff skills, it should be noted that many TCMs are based in traffic engineering know-how, others require planning skills, and still others rely on knowledge of economics and pricing. In addition, skills in traffic data collection, data analysis and modeling, and survey research may be needed to evaluate performance of the measures. Depending on the kinds of TCMs being pursued and staff already available to the oversight agency, it may be possible to conduct an adequate in-house program of administration and assessment. Alternatively, the following approaches might be used to carry out the work:

- Add staff positions (e.g., hire a traffic engineer to administer programs involving signals and HOV lanes, or a marketing specialist for the demand management programs); match skills to the requirements of priority TCMs;

- Hire consultants to assist with specific tasks (e.g., to conduct employee surveys or review all traffic signal projects) or to handle special, one-time projects;

- Design an implementation and assessment strategy that relies on self-reporting (e.g., employers must survey their own employees' travel behavior, and cities must report on parking price, supply, and utilization);

- Some combination of the above (e.g., use self-reporting but audit every Nth report using in-house staff or consultants).

The approach that works best will depend on the agency's funding levels, the ability to pass program costs on to those being regulated, and the "fit" with the way things are done in the area in question.

Timing questions include staff's ability to spend time out of the office; size of the program versus time available to carry out tasks; and acceptable frequency of reviews and turn-around times. Even if staff have the skills to carry out the administrative and implementation tasks, it may not be practical for them to do so if that would require considerable amounts of field work and absence from the office would disrupt other important agency functions. Similarly, staff may be able to perform certain tasks (analysis of travel surveys, e.g.) but might not be able to do it as fast as a consultant, who could put large numbers of analysts to work on it at once. If the program design permits biennial evaluations with a six-month turn-around, staff may be able to do the work; if an annual survey is desired with 60-day response times, either self-reporting or use of a consultant may be a preferable choice.

Monitoring for each TCM or package of TCMs will be most effective, and most likely to feed back into subsequent programmatic improvements, if it is designed to be carried out by (or at least with the active participation of) those to which implementation responsibilities are assigned. The monitoring products also should be designed for use in program management; they should be used as the basis for decisions or subsequent activities.

Program administration, particularly monitoring, unavoidably involves a substantial amount of data gathering and analysis. Its objective, however, is to provide useful information for planning and decision making, and not simply to amass statistics. It is critical that monitoring activities be designed to respond to programmatic information needs, as reflected in the goals of the programs being evaluated. Care must be taken not to lose sight of the ultimate program goals in a quest for better numbers or to let monitoring activities become an end in themselves. In addition, because monitoring can be time consuming and expensive, it must be designed to be efficient in its use of resources and to utilize and complement, not duplicate, the work of other agencies.

DEFINITIONS OF ABBREVIATIONS

ADT:	Average daily traffic
ARZ:	Automobile restricted zone
CAA:	United States Clean Air Act of 1970 and the Clean Air Act Amendments of 1977
CALINE:	EPA-preferred roadway model for PM-10 analyses and for CO hot spot analyses; CALINE3 is the EPA-approved current available version
CBD:	Central business district
CB-IV:	Carbon-Bond IV Chemical Mechanism for ozone formation; the current version of the chemical mechanism for use with the Urban Airshed Model and EKMA
CMB:	Chemical mass balance receptor model; used to model PM-10 concentrations
CMSA:	Consolidated metropolitan statistical area
CO:	Carbon monoxide
DOT:	U.S. Department of Transportation
DTIM:	Direct Travel Impact Model; used in California to produce gridded mobile source emission inventories.
EKMA:	Empirical Kinetics Modeling Approach; simplified computer modeling approach for urban-scale ozone air quality modeling
EMFAC:	The motor vehicle emission factor model for use in California; EMFAC7E is the current version
EPA:	U.S. Environmental Protection Agency
FHWA:	U.S. Federal Highway Administration; part of the U.S. Department of Transportation
HC:	Hydrocarbon
HOV:	High occupancy vehicle
I/M:	Inspection and maintenance program for motor vehicles
MOBILE4:	The current version of the U.S. EPA motor vehicle emission factor program
MOBPART:	A computer model to calculate motor vehicle exhaust, tire wear, and brake wear particulate emission factors; available from the U.S. EPA
MPO:	Metropolitan planning organizations
MSA:	Metropolitan statistical area
NAAQS:	National Ambient Air Quality Standards
NCHRP:	National Cooperative Highway Research Program
NOx:	Nitrogen oxides

O-D: Origin-destination
OSHA: U.S. Occupational Safety and Health Administration
OZIPM4: Ozone isopleth plotting with optional mechanisms 4; the computer code used with the EKMA ozone model
PLANR: Procedure for low-cost airshed application in nonattainment regions; lower-cost procedure to use the Urban Airshed Model with routinely available data while relaxing usually strict model performance standards
PM-10: Particulate matter having an aerodynamic diameter of approximately 10 microns or less
RAM: Air quality dispersion model that can be used for urban-scale CO and PM-10 modeling
RFDAs: Rural fugitive dust areas; sparsely populated areas with non-anthropogenic emission sources of PM-10
RVP: Reid vapor pressure of gasoline
SIP: State implementation plan
SOV: Single occupant vehicle
TAZ: Traffic analysis zone
TCM: Transportation control measure
TDM: Transportation demand management
TMA: Transportation management association (same as TMO)
TMO: Transportation management organization (same as TMA)
TRANSYT: Traffic network study tool used as a computerized signal timing model; U.S. versions developed by the U.S. Federal Highway Administration and the University of Florida Transportation Research Center; TRANSYT7F is the current version
TRO: Trip reduction ordinance
TSM: Transportation system management
UAM: Urban Airshed Model; three-dimensional computerized air quality grid model; designed to calculate concentrations of both inert and chemically reactive pollutants (e.g., ozone)
UMTA: Urban Mass Transportation Administration (part of the U.S. Department of Transportation)
UTPS: Urban Transportation Planning System; a transportation computer modeling system developed by the Urban Mass Transportation Administration and the U.S. Federal Highway Administration
VMT: Vehicle miles traveled
VOC: Volatile organic compound

Appendix A

GUIDANCE FOR ESTIMATING EFFECTS OF TRANSPORTATION MEASURES ON PM-10 EMISSIONS

89058r2 9

Appendix A

GUIDANCE FOR ESTIMATING EFFECTS OF TRANSPORTATION MEASURES ON PM-10* EMISSIONS

1. INTRODUCTION

Scope and Purpose

The promulgation of the PM-10 National Ambient Air Quality Standards and PM-10 SIP requirements (EPA, 1987d) has imposed new requirements for qualitatively assessing primary particulate emissions and ambient concentrations. Re-entrained road dust and motor vehicle exhaust and tire wear are among the most significant contributors to primary and secondary PM-10 emissions in urban (and some rural) areas.

The purpose of this appendix is to provide conceptual background and technical guidance to assist local agencies in estimating the impacts of transportation control measures (TCMs) on PM-10 emissions and ambient concentrations. Controls on non-vehicle-related PM-10 sources, and controls that affect the PM-10 emission factors for vehicle-related sources are outside the scope of this guidance, which is directed at controls that affect motor vehicle use.

To make this guidance as general as possible, we have refrained from quantifying the decreases (or increases) in trip generation and vehicle miles traveled (VMT) that might be expected from any particular type of control measure. Such figures are city-specific since they are dependent on local urban traffic conditions and roadway network layout. The main guidance document offers information to help estimate the effectiveness of specific TCMs.

In general, TCM effectiveness in reducing PM-10 concentrations will result primarily from reductions in road dust emissions.

* PM-10 is an acronym for particulate matter having an aerodynamic diameter of approximately 10 microns or less.

This appendix first briefly discusses general background information, including the regulatory requirements that are pertinent to motor vehicle PM-10 issues (Section 2). Section 3 presents the technical procedures and concepts on which baseline (pre-control) PM-10 inventories should be based. This discussion focuses on motor-vehicle-related emissions and, particularly, on those parameters that can be changed by TCMs. Following that, Section 4 discusses methods for determining the effectiveness of TCMs in reducing PM-10 emissions. Sources of emission factors and related information are listed in Section 5. Finally, Section 6 discusses air quality receptor and dispersion models that can be used to model PM-10 baseline and TCM impacts.

2. BACKGROUND

General Background: Motor Vehicle-Related PM-10 Emissions

Representing one of the most significant source categories of PM-10 emissions, motor vehicles contribute both primary and secondary PM-10 emissions to an area's total PM-10 inventory. Primary emissions are those emitted directly from the vehicle or that result directly from the vehicle's use. Primary motor vehicle PM-10 emissions consist mostly of dust that is re-entrained from paved and unpaved roadways. Vehicle exhaust, tire wear, and brake wear also contribute. Secondary PM-10 results when motor vehicle emissions chemically react in the atmosphere to form PM-10. Vehicle exhaust emissions of nitrogen oxides (NOx), sulfur dioxide (SO_2), and volatile organic compounds (VOCs) contribute to secondary PM-10 formation. NOx reacts in the atmosphere to form particulate nitrate; SO_2 reacts to form particulate sulfate; and VOCs react to convert to organic secondary particulates (VOCs also affect nitrate and sulfate reactions).

Two brief examples demonstrate the significance of motor-vehicle-related PM-10 (and PM-10 precursor) emissions:

> Mobile exhaust sources were estimated to contribute 29 to 38 percent of the PM-10 mass in 1985 ambient PM-10 concentrations in California, when secondary as well as primary contributions were considered. Re-entrained dust from paved roads made up 40 percent of the California PM-10 inventory (Wendt and Garza, 1988).
>
> Vehicle-related exhaust and dust emissions accounted for 30 percent of 1985 Denver PM-10 primary and secondary emissions (Huhn et al., 1988).

Regulatory Background

The 1987 EPA promulgation of NAAQS and SIP requirements for PM-10 was based on the health effects of fine particulate matter. The health effects of individual chemical constituents of PM-10, such as sulfates and certain potentially toxic organic substances, were not neglected but were considered to be covered by the overall PM-10 standards (Emison, 1988). Thus, PM-10 composition is not directly a regulatory issue.

The previous total suspended particulates (TSP) NAAQS were replaced with a 24-hour-average ambient PM-10 standard of 150 $\mu g/m^3$ and an annual average PM-10 standard of 50 $\mu g/m^3$ (EPA, 1987d). Areas are classified as Group I, II, or III, in increasing order of the probability of meeting the NAAQS and decreasing order of difficulty in reaching attainment. A few sparsely populated rural areas have also been classified as rural fugitive dust areas (RFDAs) on the basis that PM-10 emissions are primarily from non-anthropogenic sources.

This regulatory structure implies certain constraints on modeling of PM-10 emissions and ambient concentrations, as follows:

> SIP modeling must demonstrate attainment of both the 24-hour and annual average standards. Different assumptions and modeling techniques are needed for the two averaging periods. This is important because vehicular activity contributes varying proportions of the total PM-10 impact during the year. This time variation must be accounted for in both the peak-day inventories used for 24-hour-average modeling and the annual average inventories.
>
> A PM-10 inventory and receptor modeling may be used as partial evidence that an area does or does not qualify as an RFDA, which may result in a change in its group classification. Road dust emissions may very well be a large part of the inventory of an area potentially classifiable as an RFDA.

3. BASELINE INVENTORY DEVELOPMENT

Introduction

The first step in estimating TCM effectiveness in PM-10 control is the development of a baseline PM-10 inventory (and of a precursor inventory if secondary PM-10 is a significant part of ambient PM-10 concentrations—a secondary inventory will usually be available, however, with the possible exception of SO_x). A baseline PM-10 inventory may be generated either for a historical year or for a future year. This section of the appendix concentrates on the procedures to follow and the information required to compile baseline inventories of vehicle-related PM-10 sources.

Factors Affecting the PM-10 Emissions Inventory

Paved and unpaved road dust is typically the largest source of primary PM-10 emissions in the vehicle-related inventory. The quantity of road dust emissions, whether from paved or unpaved roads, depends on traffic activity (typically expressed in VMT); average vehicle weight is also important, particularly for unpaved roads. Paved road dust emissions also depend on the silt loading of the pavement (the amount of material of under 75 microns that is lying loose on the pavement). The silt loading tends to decrease as traffic volume increases. The quantity of emissions also depends on the local soil, local industries (if the road is industrial rather than public), truck load spills, nearby erosion, pavement condition, and whether the pavement has been sanded or salted over the past season. Unpaved road dust emissions depend on the silt content of the road soil as well as certain vehicle parameters that do not affect paved road dust but do affect unpaved road dust—e.g., the average vehicle speed and the average number of wheels per vehicle. Again, the kind of industry associated with an unpaved industrial road may also have an effect on the quantity of emissions (Cowherd et al., 1988).

Road dust emissions are also subject to meteorological conditions. Road dust emissions are usually assumed to occur only on days when no precipitation has occurred. Wind speed, however, is not a factor in road dust emissions since, by definition, dust raised by the wind is the result of wind erosion rather than of re-entrainment by vehicle activity.

Tire and brake wear contribute relatively small amounts of PM-10 emissions. The emission rates depend only on VMT; there is no current information to characterize the effect of vehicle age, type, weight, or speed on tire or brake wear emission factors (EEA, 1985). Since radial tires last about 50 percent longer than bias-ply tires, and emit one-third less PM, tire wear PM-10 emission factors for a vehicle fleet depend on the fraction of vehicles that use radial tires (SCAQMD, 1988).

Vehicle exhaust emissions of primary PM-10 and precursors (NO_x, SO_2, and VOC) require characterization of the quantity of traffic, the average vehicle speed, the vehicle operating mode, the types and ages of the vehicles in the fleet, and (for precursors) the ambient temperature. Vehicle exhaust emissions of PM-10 and SO_2 do not depend on temperature; the variation of these exhaust emissions throughout the year or throughout the day therefore reflects traffic conditions only, not the effects of seasonal or diurnal meteorological changes. On the other hand, exhaust emissions of NO_x and exhaust and evaporative emissions of VOC vary strongly with temperature. Exhaust emissions of NO_x and VOC decrease with increasing temperature, while evaporative emissions of VOC increase with increasing temperature. Another distinction between the exhaust pollutants is their dependence on vehicle operating mode. Exhaust PM-10 and SO_2 do not depend on whether the vehicle is in hot start, cold start, or hot stabilized mode. Exhaust NO_x and VOC do exhibit such a dependence. Finally, PM-10 emissions from diesel-fueled vehicles are considerably greater than those from comparable gasoline-fueled vehicles. PM-10 exhaust emission factors are about 10 times as high for heavy-duty diesel vehicles as for autos; because of these high emission factors, heavy-duty diesel vehicles contribute well over half of the on-road exhaust PM-10 emissions (EEA, 1985; EPA, 1985).

Relative Importance of Factors Affecting the Emissions Inventory

In most areas the most important vehicle-related source of PM-10 is road dust. The relative importance of unpaved and paved road dust depends on the relative amounts of traffic on paved and unpaved roads. Exhaust PM-10 and tire and brake wear are next, and roughly equal, in order of importance among primary PM-10 vehicle emissions. Table A-1 summarizes these points.

The exact importance of vehicle emissions of secondary PM-10 precursors is difficult to establish. In some regions, such as Phoenix, Arizona, nitrates and sulfates constitute a small part of ambient PM-10, partly because of the dry climate (Bird, 1989). In other regions, such as the Los Angeles area, secondary PM-10 is a major contributor (Gray et al., 1989). Since there are no established methods of calculating the effect of TCMs on secondary PM-10 concentrations, and since these concentrations depend on local humidity, ammonia concentrations, and other locally specific factors, the importance of improving precursor emission data cannot be ranked in the same way as for primary emissions.

Estimating the Baseline Inventory

A reasonable estimate of the baseline quantity of paved and unpaved road dust requires three basic kinds of information: (1) soil (or surface dust) characterization, (2) traffic characterization, and (3) exhaust characterization.

Soil/Dust Characterization

Soil or dust characterization should be carried out for roads or parking areas that represent

- Paved and unpaved roads and parking lots;
- Road surfaces in areas with typical and atypical soil;
- Low and high traffic volumes; and
- Public and industrial roads

The current equations for estimating road dust show less dependence of emissions on silt content for industrial paved roads than for public paved roads (Cowherd et al., 1988; this reference includes an appendix with a methodology to estimate silt loading on paved roads; default values are listed in EPA's AP-42). This implies that characterization of road soil or dust is somewhat less important for industrial than for public paved roads, given the same traffic volumes. (In this context, public roads are those used by a typical cross section of the vehicle fleet, and industrial roads are those most used by heavy industrial vehicles.)

TABLE A-1. An approximate ranking of the important factors contributing to PM-10 conditions.*

<u>Factors of primary importance</u>
VMT
Road dust (and silt loading and silt content of rock soil)
Percent of VMT on paved versus unpaved roads
<u>Factors of secondary importance</u>
Exhaust emissions of NO_x (to the extent they contribute to secondary PM-10 problems)‡
Exhaust emissions of SO_2 and evaporative emissions of VOC‡
Exhaust PM-10
Tire and brake wear

* This is a general ranking; some variability is to be expected from one area to another, and factors are not ranked within the two categories listed.

‡ These factors are appropriate to the extent that control of such sources proves to be beneficial in reducing PM-10 concentrations; there are substantial scientific uncertainties concerning the fraction of secondary PM-10.

Traffic Characterization

Traffic characterization can be subdivided into the categories of public and industrial road usage. For public roads and parking lots, it is appropriate to use the average vehicle weights and number of wheels that can be derived from vehicle registration records for the county or state. For industrial roads, parking lots, loading areas, and so on, traffic volumes and vehicle weights and numbers of wheels are likely to depend on exactly which industries are served. (The main guidance document discusses modeling approaches to estimate traffic volumes; consult with regional transportation planners for industrial road-related information.)

Road treatment practices must also be considered. Road salting and sanding during the winter tend to produce high particulate loadings on roads in the spring. Road construction workers may typically redirect traffic onto unpaved shoulders or through construction dirt, increasing PM-10 emissions, rather than delaying traffic. Particulate control practices that are already in use, or definitely planned, should also be included in the baseline.

Exhaust Characterization

Vehicle exhaust emissions follow traffic and soil characterization in importance. If secondary particulate is an important part of PM-10 ambient concentrations, then vehicle exhaust NO_x emissions (and to a lesser extent, SO_2 and VOC emissions) should be estimated. Otherwise, only exhaust PM-10 need be estimated.

To produce an inventory of primary exhaust particulate, it is necessary to know the traffic volume (generally in VMT), the vehicle speed distribution for the traffic, the types and ages of the vehicles in the fleet, the lead content of the local gasoline, and whether or not there is a local vehicle inspection and maintenance (I&M) program. (An I&M program reduces organic particulate emissions as well as VOC emissions.) It is more accurate to calculate the particulate emissions by means of a complete speed distribution rather than an average speed for all travel since the average speed is not averaged with respect to emission-producing potential but only with respect to traffic volume. Of the several vehicle classes, the one producing the greatest emissions of vehicle exhaust particulates is heavy duty diesel vehicles. If resources are limited, this vehicle class should receive the most attention.

Several more traffic and fleet variables must be known to produce an inventory of exhaust emissions of secondary particulate precursors (NO_x, SO_2, and VOC). Emissions of these pollutants depend on whether vehicles are in cold start, hot start, hot soak, or hot stabilized mode. Therefore, the number of trips that are made and their timing (how soon one trip is made after the previous one has ended) are needed to estimate the number of hot starts, cold starts, and hot soaks that accompany the regional VMT. The ambient temperature is also used to estimate precursor exhaust emissions. It should be an average over the inventory region rather than an average for one particular subregion. These details are not needed to estimate SO_x emissions, which depend only upon how much sulfur is in the fuel consumed by vehicles. Of this sulfur, between 90 and 98 percent becomes SO_2; the remainder is emitted as sulfate particulate (Somers, 1989).

Only VMT is required to estimate tire and brake wear particulate emissions. Emission estimates may be refined if the fraction of vehicles with radial tires is known, but this emission source is small enough that such a refinement is not critical.

4. EFFECT OF TRANSPORTATION CONTROLS ON PM-10 EMISSIONS

Introduction

Transportation control measure scenarios typically differ from baselines in both the total VMT and its distribution among different road types, vehicle types, vehicle speeds, or times of day. These changes must be reflected in the vehicle-related PM-10 emissions inventory by using methods of calculation that are consistent with those used to estimate the baseline inventory. We discuss next factors to consider in determining the amount of emissions reduction that can be attributed to transportation control measures (TCMs).

Effects of TCMs

All vehicle-related PM-10 emissions are proportional to VMT, which is the dominant factor controlling PM-10 emissions. In general, TCM effectiveness in reducing PM-10 emissions depends upon a measure's ability to reduce or control VMT. As an example, tire and brake wear are proportional only to VMT; thus, a TCM must reduce VMT to reduce PM-10 emissions associated with tire or brake wear. TCMs can also reduce road dust PM-10 emissions even if the measure does not reduce VMT if they either shift traffic to roads with less dust or reduce exhaust emissions by changing vehicle speeds or operating mode. Finally, TCMs can have a variety of effects on vehicle exhaust emissions. If a TCM changes the time of day at which traffic peaks occur, the emissions of secondary particulate precursors may be increased or decreased depending on the temperature at that time of day, even if VMT is not changed.

The net emissions reduction attributable to TCMs may be decreased by applying TCMs simultaneously with other types of control measures that also affect vehicle-related emissions. For example, assume that a control measure yields a 10 percent reduction in road dust by requiring spraying of unpaved road parking lots. Any TCM subsequently applied to unpaved road dust will produce 10 percent less emissions reduction than it would if it were applied to the baseline emissions. The control effectiveness (fractional emissions reduction) is not changed, but the amount of emissions reduction is because the inventory to which the TCM is applied is smaller. Attribution of inventory reductions to controls with overlapping effects (TCMs or tailpipe or dust controls) is a bookkeeping problem that should be handled consistently.

Users should refer to the main guidance document for a discussion of individual TCMs and their traffic-related effects.

5. SOURCES OF PM-10 INFORMATION

Introduction

Two types of information are needed for calculation of an emission rate. The first is the activity rate. VMT is the most commonly needed measure of activity for vehicle-related PM-10 emissions. The number and timing of trips is also important to determine relative numbers of cold and hot starts and hot soaks accompanying VMT. Both of these activity rates are completely locality-specific and cannot be taken from generalized references. The second type of information is the emission factor, or the amount of emissions per unit of activity. Emission factors are commonly obtained from general information or standard relationships, although they may be adjusted for local conditions. The purpose of this section is to list some of the standard references from which emission factor data and relationships can be obtained. Some of the known limitations of these sources of information are also discussed.

Data Bases

The most fundamental source of emission factor data is the EPA AP-42 document (EPA, 1985a), which continuously updates PM-10 emission factor data in support of the new PM-10 requirements (Martinez et al., 1988). This document contains some vehicle-related PM-10 emission factors, including those for paved and unpaved road dust, as well as a number of other stationary sources. However, AP-42 (and other references) should be used in light of their limitations:

> Investigators may have difficulties analyzing PM-10 source measurements. A set of tests in which different contractors collaborated to analyze the particulate material from the same source gave widely varying results, without any demonstrable error in measurement procedures. These tests show the difficulty of obtaining precise and accurate PM-10 source measurements (Eggleston, 1988). In the 6 June 1989 Federal Register (EPA, 1989c), EPA proposed a reference stack test method for stationary sources; investigators may find this to be a useful resource.

The PM-10 source samplers have a higher PM collection efficiency than do the samplers that measure ambient PM-10 concentrations (according to the EPA reference method). Since this difference in collection efficiency varies with particle size, the two types of devices produce different PM-10/TSP ratios for the same particulate material. This discrepancy can lead to model overprediction of ambient PM-10 concentrations with respect to measured ambient concentrations, and excessive controls may be required on the basis of the model's overpredictions (Eggleston, 1988).

Road reentrainment factors were developed from data that included very few samples of some road types, no studies or samples west of Kansas City, and no wintertime sand or silt sampling (Mohr, 1988). In general, the use of AP-42 non-site-specific silt loading data significantly increases the uncertainty of emission rates calculated using AP-42 equations.

Another important source of information on fugitive dust emissions and control methods is Cowherd and co-workers (1988). This document gives detailed information on a variety of fugitive dust sources (including road dust) and demonstrated dust control techniques. The document also includes example regulations, a general costing procedure and some control cost data, and general recordkeeping and inspection procedures. Only source controls are discussed, not transportation control measures.

MOBPART, a computer model to calculate motor vehicle exhaust, tire wear, and brake wear particulate emission factors, is available from EPA (EEA, 1985). This model calculates only PM emissions for different size cutpoints, including PM-10, and is intended as a supplement to the motor vehicle emissions model MOBILE4. (MOBILE4 calculates motor vehicle NO_x, CO and VOC emission factors.) Program inputs include the vehicle type and age distribution in the fleet and the lead content of the gasoline. The PM-10 emission factors produced by MOBPART are broken down in terms of composition (organics, diesel organics, lead, and sulfates). The program can estimate the effect of a vehicle I&M program on reducing organic particulate emissions. Fleet composite emission factors are calculated only for vehicle model years up through 1995. MOBPART is scheduled for update during 1991 (Somers, 1989).

MOBILE4 is the current version of the EPA MOBILE motor vehicle emission factor program. The MOBILE4 program can be used to calculate emission factors for the secondary particulate precursors NO_x and VOC. It can produce emission factors for a variety of different I&M programs. Inputs include the ambient temperature, I&M program and gasoline Reid vapor pressure (RVP) definitions, and the vehicle type and age distribution in the fleet. Motor vehicle SO_2 emission factors are not calculated by MOBILE4 (or MOBPART) but can be derived from the fuel sulfur content and fuel consumption rate.

6. EFFECT OF TRANSPORTATION CONTROLS ON PM-10 AMBIENT CONCENTRATIONS

Introduction

Proving that control measures reduce the regional PM-10 inventory by a certain percentage is not sufficient by itself to demonstrate attainment. It is also necessary to conduct air quality modeling to demonstrate that the ambient concentrations as well as the inventory are sufficiently reduced. The air quality impact can be estimated by the use of both receptor and dispersion models. SIP development guidelines (EPA, 1987c) recommend that both be used, and their results reconciled, as a means of minimizing errors in control strategy projections. In this section we first discuss the issues that air quality modeling should address and, second, some of the modeling approaches that have been applied.

Modeling Issues

Both the 24-hour average and the annual average PM-10 standards must be addressed. Showing compliance with the 24-hour standard may require that peak 24-hour concentrations be modeled. In such cases, it may be necessary to develop more than one inventory because different sources are the dominant contributors at different times of year. The sources producing 24-hour peak concentrations can therefore be different from those producing the highest annual average. This principle applies strongly to vehicle-related PM-10 sources, whose emissions depend on meteorological conditions such as precipitation and seasonal conditions such as road sanding and variation in vehicle activity.

It may be necessary to model PM-10 concentrations in the immediate vicinity of a point source as well as neighborhood- or urban-scale concentrations. Transportation control measures, per se, are unlikely to affect sources that produce high local concentrations. An exception to this premise might be a TCM that (for example) routed traffic away from unpaved parking lots or similar localized sources of road dust. In that case, it would be appropriate to model near-field as well as neighborhood-scale concentration changes resulting from the TCM.

Another issue that arises in air quality modeling is that of secondary particulate formation. This is chiefly an urban-scale modeling concern, although there are exceptions: for example, a large ammonia source such as a livestock lot could conceivably increase the concentration of secondary particulate immediately downwind. However, possible local effects are not directly relevant to the vehicle exhaust precursor emissions that are affected by TCMs. There are no EPA guideline models or analysis techniques to judge the effects of reducing precursor emissions upon PM-10 concentrations. Rollback is not applicable because of the non-linear effects of the atmospheric reactions that are involved in secondary particulate formation. EPA, together with those regions that cannot reach attainment with primary particulate controls, has pledged to work to characterize secondary particle formation (Woodard and Bauman, 1988).

Trade-offs between PM-10 reductions and increases that may result in other pollutants, such as ozone and CO, must also be considered. For example, TCMs that decrease PM-10 by re-routing traffic away from dusty areas may increase congestion, thereby increasing emissions of VOC and CO. TCMs that reduce VMT reduce emissions of both VOC and NO_x (as well as exhaust PM-10); although VOC emission reductions consistently lead to ozone reductions, NO_x emission reductions can lead to local ozone increases, with ozone decreases eventually occurring only further downwind. Thus, depending on local conditions and the relative magnitudes of VOC and NO_x reductions, a TCM that unequivocally reduces PM-10 may have an ambiguous effect on ozone.

Modeling Approaches

Three basic approaches can be used to model the air quality impacts of PM-10 emissions reductions: use of an appropriate dispersion model alone, receptor modeling techniques with rollback adjustments, and receptor and dispersion modeling combined. In the second approach, a receptor model can be used together with some form of linear rollback. Receptor models statistically analyze the composition of a sample of ambient particulate matter to infer the relative contributions from a number of types of sources with known emissions composition. With these contributions known, rollback can be used to re-scale the amounts contributed to reflect reductions in the source emissions. In the third approach, receptor and dispersion models are used in combination to make source allocations; then the correctly allocated sources are used with the dispersion model to predict control effects. EPA prefers this approach to consider all sources and both averaging periods (O'Connor, 1988). The receptor modeling element of the analysis is considered to be necessary as a check on the emission rates, source description, and wind speeds and directions used in the dispersion model. Ryan and co-workers (1989) present an example of the refinement of dispersion model inputs in which receptor model results are used as guidance. The unaided use of dispersion models that is appropriate when analyzing other pollutants may not be appropriate for PM-10 analysis in specific situations where there is high uncertainty in emission factors.

Receptor Modeling

The foremost receptor model is the Chemical Mass Balance (CMB) model, which has been used in SIP analyses and other efforts since the late 1970s. CMB requires extensive data bases of emission compositions ... all the applicable source types.

This requirement is not prohibitive since such data bases are available and have been used in several modeling efforts (Watson et al., 1989). CMB also requires a data base of ambient PM-10 measurements that is representative of peak concentration events and that includes detailed composition data as well as total PM-10 concentration. However, CMB may not fully resolve all source contributions. For example, source composition profiles may be so similar for road dust and windblown soil dust as to make it impossible for CMB to allocate those two sources separately (Cooper et al., 1988). It is also impossible to distinguish between gasoline burned in on-road and off-road vehicles. One approach to this problem is to include more tracer species or to examine particle characteristics other than composition. One such study included CO and NO_x among the tracer species on which CMB based its analyses (Benedict and Naylor, 1988).

Dispersion Modeling

The other method for performing source allocation is to use a dispersion model in conjunction with CMB. The protocols for applying CMB and for reconciling CMB with dispersion model results have already been used; see Ryan and co-workers (1988) for a discussion of a demonstration SIP effort for Hayden, Arizona. These protocols allow CMB and the dispersion model of choice to be evaluated against historical measurements before they are used to predict the effects of control scenarios.

Two scales of dispersion modeling may be appropriate for PM-10 modeling in general and TCM PM-10 modeling in particular. One is the urban-scale model, which looks at the portion of ambient concentration that comes not from sources in the immediate vicinity but from sources throughout the urban area. The other is the near-field (or microscale) model, which looks only at the immediately neighboring sources. The two models are usually distinct and are supported by different types of inventory data.

EPA recommends the RAM or CDM 2.0 dispersion model for urban-scale PM-10 analysis (EPA, 1986a). Other dispersion models that have been used for urban-scale PM-10 modeling include a 3D Lagrangian model developed by Cass and Gray (Gray et al., 1988) and the Urban Airshed Model (UAM). These modeling techniques have not received EPA approval. The urban-scale models have certain general inventory requirements in common. They need PM-10 emission inventories that are spatially allocated to small sub-areas or grid cells and that are broken down to hour-by-hour emission rates for each cell. More details about the urban-scale air quality models already listed are given in Table A-2.

In these gridded urban inventories, large point sources should be represented by their actual plume parameters and locations in such an inventory. Minor point sources, fugitive emissions, and mobile sources can be distributed into grid cells according to the population or VMT in the grid cells or according to other appropriate indicators for specific source categories. Historical data can be used to produce gridded urban

TABLE A-2. Sample applications of urban-scale air quality models to PM-10 problems.*

UAM: In addition to an emission inventory of the type already described, the UAM requires gridded data bases of winds at several elevations, temperatures, mixing heights, and other dispersion parameters, and spatially resolved ambient concentrations to supply the initial and boundary ambient concentrations. The UAM is used to model single episodes; it can model stagnation events and multi-day episodes since it tracks air parcel trajectories. The Maricopa Association of Governments (Phoenix, Arizona) is currently using the UAM with CMB to model primary PM-10 as part of its SIP analysis (Bird, 1989). Since the UAM (which is usually used to model ozone episodes) includes some of the atmospheric chemical reactions involved in secondary particulate formation, it is possible in theory to use the model to estimate secondary particulate ambient concentrations. This use of the UAM has not received EPA approval.

Cass and Gray 3D Lagrangian particle-in-cell model (Gray et al., 1988): This model has been used with CMB by the South Coast Air Quality Management District in southern California to model PM-10 dispersion and formation in the 1985 South Coast/Ventura County region. The model requires gridded three-dimensional wind fields, spatially resolved aerometric data (from which hourly nitrate and sulfate conversion rates are calculated), and a gridded inventory of the type already discussed. The model was used with historical data to calculate source apportionment transfer matrices of secondary sulfates, nitrates, and organics for representative winter and summer months. Although nonlinear photochemistry was used to calculate the precursor/secondary relationships in the transfer matrices, the matrices were used in a linear manner to relate predicted secondary concentrations to source controls. These transfer matrices were used to estimate future baseline and SIP control scenario PM-10 concentrations for annual and 24-hour averaging periods. Since this SIP has not been reviewed by EPA, the adequacy of this linear estimate of secondary PM-10 impacts has not been determined.

RAM: Currently, the Denver area is being modeled with the RAM model (Graves, 1989). This methodology uses seasonal average meteorological data and accepts as inputs (a) NO_x to nitrate and SO_2 to sulfate conversion factors, and (b) inventory data for multiple sources. RAM does not follow trajectories for more than one hour. An advantage of using RAM is its ability to calculate 24-hour average as well as annual concentrations. RAM has EPA-preferred status for modeling multiple sources in urban areas, and is designed to calculate short- and long-term averages.

* Users should check EPA's modeling guidelines (EPA, 1986a) to learn the current status of each of these tools.

inventories for the episode(s) to be evaluated. Projections of population, VMT, fuel consumption, construction and so on can be used to produce future baseline (no new control) inventories. The amount of emissions contributed by each source category must be tracked so that the reductions from control measures can be accurately applied.

The vehicle-related portion of an urban-scale gridded inventory is generally constructed from VMT and vehicle speed data from an urban traffic planning model. Some of the models in common use for traffic planning purposes include UTPS, MINUTP, EMME2, and TRANPLAN. (See main guidance document text for a more complete discussion.) A traffic planning model that is to be used for TCM analysis should be able to directly address all of the types of TCMs that might be considered. For example, it should consider the modal split of traffic (the split between public transit, one-person vehicle use, and so on) so that ride-share and transit system upgrades can be explicitly evaluated. Traffic planning models usually predict only ADT (average daily traffic) and average peak and off-peak speeds for each major roadway in the system. Traffic counts or survey information on the timing of different trip types must be used to generate hourly traffic values. Since much road dust comes from minor (unpaved) roadways, these should be explicitly represented in the traffic planning network if possible.

The second type of PM-10 modeling that may be needed is the near-field (or microscale) model. The type of "hot spot" most likely to be affected by a TCM is either a heavily traveled intersection in an inherently dusty area, or an unpaved parking lot downwind of the center of town and of the urban PM-10 emissions. Microscale models require intersection- or facility-specific traffic data and emission factors on an hourly basis. Most of them use this type of input to internally generate their own microscale emission inventories as part of the process of calculating ambient concentration impacts.

One of the difficulties of modeling the effects of TCMs on a "hot spot" as well as on the urban area is the problem of arriving at microscale traffic scenarios that are consistent with each other and with the urban-scale traffic scenarios. Intersection models can be particularly sensitive to the number of cars in the idle queue in the intersection in a given hour, although this sensitivity is reduced by the 24-hour minimum averaging period used for PM-10 analyses. Some different levels of analysis for various traffic facilities have been detailed by the Transportation Research Board (TRB, 1985); California-specific parameters are also available (ITS, 1985). A report from the National Cooperative Highway Research Program discusses some techniques for linking urban traffic scenarios with project traffic studies (Pedersen and Samdahl, 1982).

To our knowledge, TCM PM-10 analyses have not to date included microscale analyses. Two of the models that could be used in such an analysis include the following:

CALINE3 is the EPA preferred roadway model in the EPA Modeling Guidelines (EPA, 1986a). This model requires inputs of the roadway (or other "hot spot") geometry, receptor locations, and hourly meteorology, emission factors, traffic volume and speed, and background concentrations. The emission factors can be obtained from MOBILE4, MOBPART, and/or road dust emission factor calculations. CALINE3 does not include a specific intersection submodel (Benson, 1979, 1980).

APRAC-3 is an urban/microscale traffic emissions/dispersion model that is listed in the EPA Guidelines, but does not have preferred status. It requires an "extensive" traffic inventory to estimate contributions from several scales--extraurban, intraurban, and local (street canyon). It also uses hourly meteorology and appropriate emission factors.

Appendix B

ADDITIONAL RECOMMENDED REFERENCES

Appendix B

ADDITIONAL RECOMMENDED REFERENCES

Technical Analyses

Purpose: Review Previously Published TCM-Related Guidance

Overview TCM Guidance Published by EPA

1. "Transportation-Air Quality Planning Guidelines" (and appendices). U.S. EPA and U.S. DOT; June 1978. This document overviews SIP policy regarding transportation controls, identifies TCM evaluation criteria, and generally discusses the process by which TCMs should be chosen and adopted (e.g., which government and public officials to include, what progress reports to file).

2. "Transportation System Management: An Assessment of Impacts." UMTA-VA-06-0047. Prepared by F. A. Wagner and K. Gilbert for the Office of Policy and Program Development, Urban Mass Transportation Administration, U.S. DOT, in cooperation with the U.S. EPA. November 1978. Classifies management actions and, for each class, calculates how a major multiyear application of the measures would affect vehicle miles traveled and vehicle hours traveled. Six working papers are included describing experience with specific actions.

3. "How to Prepare the Transportation Portion of Your State Air Quality Implementation Plan." Technical Guidance of the U.S. DOT, Federal Highway Administration, with the cooperation of the U.S. EPA. November 1978 (reprinted February 1979). This document, though outdated, is a comprehensive guide to preparing an emissions inventory, determining growth factors to project emissions activity, estimating needed emissions controls to meet NAAQS, and calculating the emissions benefits derived from each measure.

4. "Transportation Air Quality Analysis—Sketch Planning Methods" (Volumes 1 and 2). EPA 400/1-800-001a and b. Prepared by Cambridge Systematics, Inc. for the U.S. EPA; December 1979. Volume 1 describes sketch planning

methodologies to evaluate TCMs' air quality effects (techniques to analyze travel demand impacts, facility operations, emissions impacts). Volume 2 illustrates the use of these techniques through case studies.

EPA-Published Guidance Specific to Individual Measures

5. "Air Quality Impacts of Transit Improvements, Preferential Lane, and Carpool/Vanpool Programs." EPA 400/2-78-002a. Prepared for the U.S. EPA in cooperation with the U.S. DOT; March 1978. Addresses, at a sketch planning level of analysis, how to evaluate the cost-effectiveness of these measures.

6. "Transit Improvement, Preferential Lane, and Carpool Programs, An Annotated Bibliography of Demonstration and Analytical Experience." EPA 400/2-78-002b. Prepared for the U.S. EPA in cooperation with the U.S. DOT; March 1978. Provides an annotated bibliography of useful reports describing the use and cost-effectiveness of these strategies to lower emissions, improve air quality, reduce energy consumption, and mitigate noise impacts.

Related Guidance Materials

7. "Traveler Response to Transportation System Changes." Second Edition. Prepared by R. H. Pratt and J. N. Copple for the U.S. DOT, Federal Highway Administration, Office of Highway Planning, Urban Planning Division. July 1981. Summarizes available literature on experiences with nine broad TCM categories; also includes an annotated bibliography of important references for each category.

8. "Measures of Effectiveness for TSM Strategies." FHWA/RD-81/177. Prepared by C. M. Abrams, J. F. DiRenzo, S. A. Smith, and R. A. Ferlis for the U.S. DOT, Federal Highway Administration, Office of Research and Development. December 1981. Reviews and categorizes TSMs; discusses TSM impacts and methods of estimating these impacts.

9. "Transit Project Planning Guidance: Estimation of Energy and Air Quality Impacts." Draft. Prepared by M. Jacobs and P. W. Shuldiner for the U.S. DOT; May 1984. Includes information on estimating motor vehicle operating emissions and resulting pollutant concentrations.

10. "Traffic Mitigation Reference Guide. A Review of Options Available to the Public and Private Sectors." Prepared by C. Brittle, N. McConnell, and S. O'Hare for the Oakland, California, Metropolitan Transportation Commission and the U.S. DOT, Office of the Secretary of Transportation.

December 1984. Covers traffic mitigation options for developers, employers, and cities; building mitigation policies into local city regulations; and financing mitigation programs.

11. "National Ridesharing Demonstration Program: Comparative Evaluation Report." Final Report. UMTA-MA-06-0049-85-1. Prepared by R. Booth and R. Waksman for the U.S. DOT, Research and Special Programs Administration, Transportation Systems Center. August 1985. Provides detailed analyses of five sites where rideshare programs have been implemented.

12. "Transportation Management for Corridors and Activity Centers: Opportunities and Experiences." Final Report. DOT-I-86-21. Prepared by the Office of Planning, U.S. DOT, Federal Highway Administration. May 1986. Focuses on case studies of transportation management strategies for corridors and activity centers; identifies specific strategies for potential application in other areas.

Purpose: Understanding EPA Requirements and Guidelines

1. "State Implementation Plans; Approval of Post-1987 Ozone and Carbon Monoxide Plan Revisions for Areas Not Attaining the National Ambient Air Quality Standards, Notice." Vol. 52 Federal Register, pp. 45044-45122. U.S. Environmental Protection Agency. 24 November 1987. Contains criteria for EPA approval of TCM strategies; deadlines and guidance for overall ozone and carbon monoxide attainment requirements.

2. U.S. EPA/U.S. DOT Transportation-Air Quality Planning Guidelines and Appendices. June 1978. These documents, though out of date with respect to funding, deadlines, and implementation requirements, provide good background material on planning processes that emphasize interagency coordination.

3. "Emission Inventory Requirements for Post-1987 Ozone State Implementation Plans." EPA-450/4-88-019. Prepared by D. C. Misenheimer, Technical Support Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. December 1988.

4. "Emission Inventory Requirements for Post-1987 Carbon Monoxide State Implementation Plans." EPA-450/4-88-020. Prepared by T. N. Braverman, Technical Support Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency. December 1988.

5. "Example Emission Inventory Documentation for Post-1987 Ozone State Implementation Plans (SIPs)." EPA-450/4-89-018. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. October 1989.

Purpose: TCM Screening

See documents referred to in Table 2-4.

Purpose: Traffic Effects Analyses

1. A transportation demand model from which vehicle miles traveled (VMT) and speeds can be estimated with necessary spatial and temporal resolution. All areas with metropolitan planning organizations (MPOs) will have access to UTPS or an equivalent traffic demand modeling system.

2. For areas without transportation demand modeling tools, sketch planning documents for transportation analyses. The primary air quality-related reference is:

   a. "Transportation Air Quality Analysis, Sketch Planning Methods (Volumes 1 and 2)." EPA 400/1-800-001a and b. Prepared by Cambridge Systematics, Inc., for the Office of Transportation and Land Use Policy, U.S. Environmental Protection agency. December 1979.

3. Other relevant reports include:

   b. "Transit Corridor Analysis, A Manual Sketch Planning Technique." UMTA-MD-06-0046-79-1. Prepared by M. M. Carter, R. H. Watkins, J. D. O'Doherty, M. Iwabuchi, G. W. Schultz, and J. J. Hinkle. Prepared for the Department of Transportation, Urban Mass Transportation Administration, Office Planning Methods & Support. April 1979; and

   c. "Quick Response Urban Travel Estimation Techniques and Transferable Parameters, User's Guide." National Cooperative Highway Research Program Report 187. Prepared by A. B. Sosslau, A. B. Hassam, M. M. Carter, and G. V. Wickstrom. Prepared for Transportation Research Board, National Research Council. 1978.

These documents offer techniques to manually assess the impacts of TCMs; when applying the documents' methodologies, the most recent data available should be used (e.g., data relating to trip generation rates, household person trips, trip production estimates).

Purpose: Evaluating Emission Effects

1. "EPA Regional Workshops for Ozone and Carbon Monoxide State Implementation Plan Emission Inventory Development." These documents are available from EPA's Office of Air Quality Planning and Standards, Technical Support Division, Research Triangle Park, North Carolina.

2. Compilation of Air Pollutant Emission Factors; Volume II: Mobile Sources. U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. AP-42, Fourth Edition. September 1985 (provides information for estimating sulfur oxides (SO_x) emissions factors for highway vehicles; SO_x control is not addressed in this guidance document). (Consult regional EPA office for most recent version of this document.)

3. Emissions modeling tools: MOBILE4 for all non-California applications; EMFAC and either DTIM (for gridded emissions) or BURDEN (for county-wide emissions) for California applications.

4. "Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources." EPA-450/4-81-026d (Revised). U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards (Technical Support Division), and Emission Control Technology Division (Office of Mobile Sources). December 1988.

5. "Guidance for the Preparation of Quality Assurance Plans for O3/CO SIP Emission Inventories." EPA-450/4-88-023. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. December 1988.

Purpose: Evaluating Air Quality Effects

1. Air quality model guidance for carbon monoxide analyses. Examples:

   a. "CALINE3—A Versatile Dispersion Model for Predicting Air Pollutant Levels near Highways and Arterial Streets." Report No. FHWA/CA/TL-79/23. Interim Report. Prepared by P. E. Benson for the Office of Transportation Laboratory, California Department of Transportation. November 1979.

b. "Carbon Monoxide Hot Spot Guidelines, Volumes I-III." EPA-450/3-78-033, 034, 035. Prepared by T. P. Midurski for the U.S. Environmental Protection Agency, Research Triangle Park, North Carolina. 1978.

c. "Guidelines for Air Quality Maintenance Planning and Analysis, Volume 9 (Revised): Evaluating Indirect Sources." EPA-450/4-78-001. U.S. Environmental Protection Agency, Office of Air, Noise, and Radiation; Office of Air Quality Planning and Standards; Research Triangle Park, North Carolina. 1978.

2. Air quality model guidance for ozone air quality analyses using either the Empirical Kinetics Modeling Approach (EKMA) or the Urban Airshed Model (UAM). References:

a. For EKMA: "Procedures for Applying City-Specific EKMA." EPA-450/4-89-012. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. July 1989.

b. For UAM: Formal EPA guidance is due to be released by late 1990: currently available users' guides and systems manuals include

- "User's Guide for the Urban Airshed Model. Volume I: User's Manual for UAM(CB-IV)." SYSAPP-90/018a. Prepared by Systems Applications, Inc., San Rafael, California. June 1990.

- "User's Guide for the Urban Airshed Model. Volume II: Preprocessors and Postprocessors for the UAM Modeling System." SYSAPP-90/018b. Prepared by Systems Applications, Inc., San Rafael, California. June 1990.

- "User's Guide for the Urban Airshed Model. Volume III: User's Manual for the Diagnostic Wind Model (Version 1.1)." SYSAPP-90/018c. Prepared by Systems Applications, Inc., San Rafael, California. May 1990.

- "User's Guide for the Urban Airshed Model. Volume IV: User's Guide for the Emissions Preprocessor System." SYSAPP-90/018d. Prepared by Systems Applications, Inc., San Rafael, California. June 1990.

Transportation Monitoring for Air Quality

Deakin, E. 1983. "Transportation and Air Quality Programs: Case Studies on Monitoring and Decision Processes, and Recommendations on EPA Assistance." Report to the U.S. Environmental Protection Agency, Region IX, Institute of Transportation Studies, University of California, Berkeley.

Deakin, E. 1984. "Monitoring the Effectiveness of Transportation Air Quality Programs" (ITS-RR-85-8), Dec. 1984, 46 pp. Institute of Transportation Studies, University of California, Berkeley.

Cambridge Systematics, Inc. 1984. "Monitoring Transportation/Air Quality Measures: Improving the State of the Practice." Report to U.S. Environmental Protection Agency.

Harvey, G. W. 1984. "Growth Monitoring and Decision-Making for Transportation-Air Quality Planning." Report to the U.S. Environmental Protection Agency, Region IX, Department of Civil Engineering, Stanford University.

New Financing Strategies

Barker, M. (ed.). 1984. Rebuilding America's Infrastructure: An Agenda for the 1980s. Duke University Press, Durham, North Carolina. (Includes Choate, Pat, and Susan Walter, America in Ruins and Vaughan, Roger, Rebuilding America: Financing Public Works in the 1980s).

Bauman, G., and W. H. Ethier. 1987. Development exactions and impact fees: A survey of American practices. Law and Contemporary Problems, 50(1):51-67.

Cervero, R. 1987. Paying for off-site road improvements through exactions and special assessments: Lessons from California. Public Administration Review, 48(1):531-541.

Colman, S. B., et al. 1987. "A Survey and Analysis of Traffic Impact Fee Experience in the U.S." Institute of Transportation Engineers District 6.

Deakin, E., and W. L. Garrison. 1985. "Private Sector Funding for Urban Transportation: Some Comments on Public-Private Partnerships" (ITS-WP-85-9). Institute of Transportation Studies, University of California, Berkeley.

Deakin, E. 1987. "Use of Special Assessments for Transportation Demand Management Programs." Paper prepared for Orange County Transportation Commission.

Duncan, J. B., et al. 1986. Drafting impact fee ordinances: 30. Implementation and administration. Zoning and Planning Law Report, 9(8):57-63.

Johnson, G. T., and L. A. Hoel. 1987. Review of financing options for highways and transit. J. Transportation Engineering, 113(1):72-83.

Kirlin, J. J. 1985. "Bargaining for Development Approval." Urban Land, 44(5):34-35.

Knack, R. 1984. How impact fees are working in Broward County. Planning, 50(6):24-25.

Krause, R. A., D. I. Patel, and B. Gathy. 1987. "Financing the Future: Changing Roles in Mass Transit." Washington: Urban Mass Transportation Administration (DOT-T-88-4).

Minnesota House of Representatives, Research Department. 1987. "Minnesota's Fiscal Disparities Program: Tax Base Sharing in the Twin Cities Metropolitan Area." St. Paul, Minnesota.

Morgan, T. D., et al. 1986. Drafting impact fee ordinances: A legal foundation for exactions. Zoning and Planning Law Report, 9(7):49-56.

Nicholas, J. C. (ed.). 1985. Changing Structure of Infrastructure Finance. Lincoln Institute of Land Policy, Cambridge, Massachusetts.

Rao, K., and D. Nagin. 1982. Addressing the highway funding crisis: A review of alternative petroleum-related taxes. Transportation Quarterly, 36(1):113-126.

Snyder, T. P., and M. A. Stegman. 1986. Paying for Growth: Using Development Fees to Finance Infrastructure. The Urban Land Institute, Washington, D.C.

Urban Mass Transportation Administration. 1988. Memorandum on Tax Policy for Ridesharing and Parking. Washington, D.C.

New Institutional Approaches

Deakin, E. 1989. "Trip Reduction Ordinances." University of California, Berkeley (ITS-WP-89-X).

Deakin, E. 1989. "State Programs for Managing Land Use, Growth, and Fiscal Impact." Report prepared for the California Senate Office of Research. Department of City and Regional Planning. University of California, Berkeley.

Deakin, E. 1987. "Transportation System Management Ordinances: An Overview." Paper prepared for the Fourth Annual Association of Commuter Transportation Southern California Regional Conference, Long Beach, California.

Deakin, E. 1986. "The Pleasanton, California, Trip Reduction Ordinance: Can It Work?" Institute of Transportation Studies, University of California, Berkeley (UCB-ITS-WP-86-3).

Schreffler, E. N. 1986. Transportation management organizations: An emerging public/private partnership. Transportation Planning and Technology, 10(4):257-266.

Weiner, E. 1984. Devolution of the federal role in urban transportation. J. Advanced Transportation, 18(2):113-124.

Political Considerations

Deakin, E. 1988. "The Politics of Exactions." In R. Alterman (ed.), Private Supply of Public Services, New York University Press.

Deakin, E. 1989. "Market and Intervention Failures in Transport Policy: Case Study on the United States." Report prepared for the Organization for Economic Cooperation and Development, Paris.

DeGrove, J. M. 1984. Land, Growth and Politics. APA Planners Press, Washington, D.C.

Huff, N. 1981. "Negotiating Rezoning Conditions in Fairfax County, Virginia." Urban Land, November 1981, pp. 13-15.

Popper, F. 1981. The Politics of Land Use Reform. University of Wisconsin Press, Madison, Wisconsin.

Popper, F. 1988. Understanding American land use regulation since 1970: A revisionist interpretation. Journal of the American Planning Association, 54(3):291-301.

Rosenbaum, N. 1976. Land Use and the Legislatures: The Politics of State Innovation. The Urban Institute, Washington, D.C.

Speilberg, F. 1985. "How Citizens' Associations View Developers' Offers of Innovative Transportation Solutions." Proceedings of the Symposium on Innovations for Transportation.

Suhrbier, J. H., E. Deakin, and J. Loos. 1987. "The Role of the Public in Public/Private Partnerships." Paper prepared for presentation at the 1987 Annual Meeting of the Transportation Research Board, Washington, D.C.

Appendix C

TCM PROFILES

This appendix profiles real-world examples of TCM implementation. The profiles include (1) TCM descriptions, (2) a TCM screening effort, (3) TCMs targeted to ozone and carbon monoxide problems, (4) a sample travel demand modeling effort, and (5) sample evaluations of motor vehicle emissions changes due to specific measures.

PROFILE 1

PROFILE: Trip Reduction Ordinances (TROs) in Small Areas

Location:	Pleasanton, California (site of one of the country's first successful TROs). Pleasanton is a small but fast-growing northern California city of approximately 52,000 people. The city went from 38 medium-sized employers in 1985 to over 100 in 1988. Since 1984, total employment has grown over 65 percent, and population has increased over 35 percent.
Problems:	Business parks were proposed in 1982; city wanted to avoid traffic congestion problems while promoting growth. Few traffic problems existed when the ordinance idea was first considered.
Solutions:	Development of a Transportation Systems Management Ordinance. A citizens advisory committee recommended adoption of a traffic control law; the city council directed city staff to draft the law with cooperation of local employers and developers. Under the law, adopted October 1984, employers are required to (1) respond to the annual Transportation Survey, (2) medium-sized employers must implement information programs to educate employees on commute options, (3) large employers and complexes must design and implement a TSM program to cut (by 1988) peak-hour vehicle trips by 45 percent (by 1988, average reductions for large employers were 41.5 percent). The city is reconstructing four interchanges on interstate highways; it has a new traffic control computer and a transportation systems manager; it began (in 1986) a local transit service; and it is improving arterial lanes and adding bicycle lanes.
Comments:	The law applies equally, across the board, to all employers and developers. The city has committed staff and dollars to the TRO effort—staff train private sector coordinators, prepare marketing materials, and provide personal assistance. A transportation task force (with city and private sector representatives) fosters communication about the TRO and projects that work well.
Source:	Gilpin, 1989

PROFILE 2

PROFILE: Trip Reduction Ordinance for a Large Urban Area

Location:	South Coast Air Quality Management District (SCAQMD) (greater Los Angeles, California metropolitan area).
Problem:	Country's number one ozone problem area. Severe traffic congestion problems with forecasted worsening conditions.
Actions:	11 December 1987 SCAQMD board approval of Regulation XV, a regional indirect source and work trip reduction ordinance. 1 July 1988—implementation of "Reg XV" begins.
Regulatory Provisions:	Regulates (over a phased schedule with full implementation by 1 January 1990) businesses with 100 or more employees who arrive at work between 6:00 a.m. and 10:00 a.m.; approximately 8,000 businesses are affected. Requirements include: (1) submittal of plans by employers to achieve average vehicle ridership (AVR) of from 1.3 to 1.75, depending upon location (current AVR is approximately 1.13); (2) plans will be prepared by a trained transportation coordinator; (3) plans must include coordinator designation, a verifiable estimate of worksite's existing AVR, current and future measures to meet target AVR within 12 months of plan approval.
Implementation:	Beginning 180 days after Board adoption of Reg XV, District issued notices to businesses to submit plans. Employers had 90 days from receipt of notice to submit a plan. Plan approval or disapproval was within 60 days of plan submittal (employers had 30 days to resubmit disapproved plans). Annual plan updates and resubmittals are required. Employers will not be penalized if they exhibit a "good faith" effort and comply with all plan provisions, but they still fail to achieve the AVR.
Other Comments:	Program marketing is an essential component of implementation; the SCAQMD has completed over 100 presentations to businesses throughout the air quality management district. To better manage plan review, the SCAQMD is staggering the implementation requirements. In an attempt to provide businesses with maximum flexibility in trip reduction/rideshare program design, the SCAQMD has not outlined explicit criteria for submitting an "approvable Reg XV plan." As of March 1989, 35 to 40 percent of all submitted plans have been disapproved.
Sources:	Dunlap, 1989; SCAQMD, 1987.

PROFILE 3

PROFILE: Bicycle Parking Program at an Urban CBD Office Plaza

Location: Empire State Office Plaza, Albany, New York (a state office facility).

Problem: Need to promote bicycle use.

Actions: Questionnaires are mailed to office workers to establish (a) the number of bicycle riders at the Empire State Plaza, (b) where they work, (c) where they begin their commute. Data are used to determine where bicycle parking facilities should be placed. The facilities are secure, enclosed areas; riders are given keys; visitor bicycle parking is provided by front and rear locking bicycle racks. Shower facilities are provided for men and women.

Comments: Facilities have been operating since June 1988. The program is a pilot project to determine whether similar facilities will be provided at other state office sites. More information is available from the Division of Albany Utilities, Corning II Tower, Room 3980, Empire State Plaza, Albany, New York 12242.

Source: CENTRANS, 1988.

PROFILE 4

PROFILE: Using the Freeway Shoulder Lane During Peak-Hour Traffic

Location: Honolulu, Hawaii. H-1 Freeway between the Pearl City and Stadium Interchanges.

Problem: Morning peak-hour traffic congestion on central freeway system serving the CBD.

Solution: Rather than widen the freeway, the shoulder of a two-mile stretch of the inbound lanes of the H-1 Freeway was modified for use as a travel lane. The lane is utilized from 5:00 a.m. to 8:30 a.m., Monday through Friday. Two emergency pull-outs were constructed to assist disabled vehicles. A tow truck service was contracted to remove disabled vehicles during the morning commute period.

Results: Increased traffic capacity (from five to six travel lanes during the morning commute) saves motorists approximately 15 minutes of travel time for average commutes.

Source: CENTRANS, 1988.

PROFILE: Portland, Oregon's Transit Mall, Constructed 1975–1977

Location: An 11-block area of downtown Portland, Oregon (the city of Portland is part of the Portland-Vancouver Air Quality Maintenance Area). The city of Portland's 1980 population was approximately 400,000.

Problems: Portland in the 1970s was experiencing decreasing mass transit use, increasing automotive use, increasing traffic and parking difficulties, and a desire among civic leaders to improve the aesthetic quality of the downtown area (e.g., many historic buildings had been torn down to increase surface parking).

Goals: To provide more efficient transportation for commuters and shoppers, and to revitalize the downtown area.

Actions: Local agencies including the Columbia Region Association of Governments and the Tri-County Metropolitan Transportation District (Tri-Met), with funding from the federal Urban Mass Transportation Administration, constructed a transit mall over a 26-month period during 1975-1977. The mall was designed to carry up to 200 buses per hour in each direction (up to 260 buses per half-hour if simultaneous signal systems are installed). When complete, it provided widened sidewalks, two continuous 12-foot bus lanes, two bus loading areas on each block of the mall (most with rain shelters), and a "fare-less square" providing free bus service to downtown area destinations. Simultaneous to the transit mall actions (1975), Portland adopted a downtown parking and circulation policy that placed a ceiling on the number of parking spaces and established stringent maximum parking space ratios for new development projects.

Effects: Overall, businesses and pedestrians favor the mall. Instant traffic improvements were realized when the mall opened in December, 1977. By 1980, the mall was credited with reducing the Portland area's total VMT by 4.9 percent, and the downtown area's VMT by 2.3 percent, over levels that would have existed without the mall. Important for the mall's success was Portland's supportive parking policy. An air quality modeling analysis compared 1980 traffic volumes assigned to with-mall and without-mall street networks, and assessed HC, CO, NOx, and suspended particulate emissions changes. Estimates indicated that without the mall, some emissions would have been higher in the mall's immediate vicinity—CO by 600 to 1,400 percent, HC by 250 percent. Other emissions changes are more difficult to generalize: NOx emissions would have been somewhat less (2 percent) on some streets and higher on

continued

PROFILE: Portland, Oregon's Transit Mall, Constructed 1975-1977

others (3 to 50 percent); and particulate emissions changes were mixed. Overall, HC, CO, and NOx emissions on mall streets were reduced. However, to the extent that VMT was not reduced, these emissions have been shifted to other streets (though with fewer people directly exposed to the pollutants).

Sources: Harris, 1989; Dueker et al., 1982.

PROFILE 6

PROFILE: Developer Impact Fees to Mitigate Traffic in a Small-to-Medium-Sized Area

Location: Oxnard, California (western Ventura County in southern California). Oxnard has grown from a small city in the 1960s to one with a population over 120,000.

Problems: Projected revenue shortfall of $40 million needed to support roadway improvements for a forecasted 440,000 new daily vehicle trips by the year 2000 (or, a shortfall of about $90 per trip); lack of a long-term general plan that systematically considered roadway needs; traffic congestion rapidly exceeding citizens' tolerance; and stagnating growth due to traffic circulation problems.

Solutions: Development of a circulation impact fee and "paveout" policy. The paveout policy requires developers to fund construction of portions of the arterial system. Impact fees are collected when building permits are issued; fees of approximately $90 per trip generated by the development are charged to mitigate the financial shortfall. Basis for calculations are trip generation rates developed by the Institute of Transportation Engineers and by the California Department of Transportation.

Other Comments: Policy supports TCMs by encouraging a reduction in projected trip generation from development sites. Data gathering to support the policy is time consuming. Ordinance is being adjusted to address two problems: (1) gas stations and fast food restaurants attract a high number of trips, but these are trips shared with other trip-attractors; and (2) commercial development attracts more trips than office development, but offices generate peak-hour trips.

Source: Kamhi, 1985.

89058p1 15

PROFILE: Minnesota's I-394 HOV Lane (the "Sane Lane")

Location: Western suburbs of the Twin Cities (Minneapolis and St. Paul), Minnesota area.

Problems: Need to introduce riders to the HOV lane concept, and to alleviate congestion problems during reconstruction of the roadway (Highway 12) into I-394. Carpooling in the Twin Cities suburbs was not extensive prior to the HOV lane's implementation.

Actions: A 1983 study by the Metropolitan Transit Commission (Minnesota Rideshare) found that 60 percent of the people using Highway 12 to commute to downtown Minneapolis would consider carpooling if an HOV lane were available. A Corridor Management Team was assembled to promote and coordinate the HOV lane development and implementation. Marketing programs were developed; arrangements for aggressive lane enforcement were made; express bus service was planned for the HOV lane; "before" data on ridership, vehicle occupancy, and travel times were collected; and an interim parking lot (free to carpoolers) was built in downtown Minneapolis. On 19 November 1985, the Minnesota DOT opened an interim four-mile "two-plus" HOV lane on Highway 12/I-394. The "Sane Lane" is a physically separated, single reversible lane in the median of a four lane, signalized highway.

Effects: First-year operating results showed the lane to be a success: the lane was carrying 1,600 people in 540 vehicles during the morning peak hour (mixed lanes were carrying only 1,000 people in 890 vehicles). Total carpools in all lanes increased 129% during the a.m. peak hour; bus ridership increased 16% in the morning (6:00-9:00) and 20% in the afternoon (3:00-7:00); 46% of carpoolers and 9% of the express bus riders previously drove alone; overall vehicle occupancy went from 1.17 to 1.29 during the morning peak hour; average time savings were approximately 8 minutes (time savings were greatly increased in bad weather); the free downtown carpooler lots were filled within a few months of opening; only known accidents in the lane were minor and related to severe winter weather or drunk drivers hitting the closed gates at night.

Source: SRF, 1987.

PROFILE: Parking Management and Shuttle Service Operations in Orlando, Florida (the "Meter Eater" System)

Location: Downtown Orlando, Florida CBD and arterial streets leading to the CBD.

Problems: Congestion related to peak-hour home-to-work trips.

Goals: To increase auto occupancy and transit ridership; reduce number of autos, demand for parking facilities, and energy consumption; and improve air quality and traffic flow. Shuttle service targeted to encourage long-term peripheral and fringe parking adjacent to the CBD.

Actions: In February 1982, the city implemented a transportation management program which included traffic signal timing improvements, transit improvements, ridesharing, parking supply management, and alternative work schedules. The downtown park-and-ride shuttle system was one of the program's most innovative components. One route connected public-owned parking facilities adjacent to the CBD with local businesses and state and local government offices in the CBD (operated morning and evening peak periods). A second route (operating midday) started in the fall of 1982 and connected downtown office facilities and eating establishments. Employers were encouraged to participate by offering employees incentives to ride the shuttle. In October 1983, the Meter Eater trolley buses were made part of the regional transit system. Additional Friday midday services were also provided to senior citizen highrises.

Effects: Ridership of the peak period shuttle rose from 1,200 persons per week 2 months after start-up, to 2,000 persons per week within 4 months (June 1982). Combined with the midday shuttle, ridership was 3,750 persons per week by February 1984. 64 percent of those using the shuttle did not drive through the CBD to park in the peripheral lots (those that did may have added to CBD traffic congestion). The system's revenue/cost ratio is approximately 40 percent.

Source: FHWA, 1986.

PROFILE: One Urban Area's Approach to Selecting Potential TCMs

Location: Toledo, Ohio (population of approximately 340,000).

Problem: Forecasted severe congestion on major arterials and on freeways and expressways by the year 2010. Forecasted budget limitations to address problems.

Actions: Reviewed TCM literature to select potential strategies applicable to Toledo; formulated demand management strategies to address forecasted peak-period traffic congestion; computer simulated year 2010 peak-period traffic under each control strategy; evaluated strategies' cost-effectiveness; and recommended TCMs for adoption.

Results: Literature review: reviewed (1) Ottawa, Canada's successful busway system with priority bus lanes (over 30% of all person-trips in the region and 60% of all CBD-destined peak-hour trips made on transit); (2) HOV lane successes in Washington D.C. and Houston (40% to 70% of persons moved during inbound a.m. peak are in multi-occupant vehicles); (3) "timed-transfer" bus systems in Edmonton, Canada that link employment, shopping, and residential areas (cutting travel times 20%); (4) successful linking of on-site transit facilities with shopping malls and residential development (again, in both Ottawa and Edmonton; travel times dropped 20%); (5) the Singapore area's peak-period road-pricing/vehicle-licensing plan (lowering by 73% cars entering the core area during the peak period, and increasing carpooling by 60%); (6) electronic toll-charging facilities (e.g., planned demonstration along the Dallas North Tollway).

Strategy formulation: developed base case forecast and three alternative demand management strategies; each strategy an extreme version of policies that might be adopted.

Strategy 1: "transit preferential" including express bus service on reserved rights-of-way; new freeway lanes reserved for transit; park and ride lots; feeder bus services; 50% reduction in peak-period transit fares; doubling of cost to use auto for peak-period commute.

Strategy 2: "ridesharing-preferential" including system-wide implementation of HOV lanes; all new freeway lanes reserved for HOVs; pricing policies same as in "transit" strategy.

continued

Strategy 3: "transit/ridesharing-preferential" covering a combination of the first two strategies.

Computer simulation: base case and three control strategies simulated using computerized travel demand models. Analyses focused on work trips. Separate mode choice model runs were made for each strategy—but only for work trips (assumption that nonwork trips were not substantially affected). Daily travel was broken down, by percent, into different trip purposes (using Sosslau et al., 1978); then peak-period travel was estimated by taking appropriate percentages of daily travel. Work trip and total trip reductions were estimated by the mode choice model. Highway performance was estimated by running a traffic assignment model with the mode choice model's results.

Cost-effectiveness: considered (1) highway user costs—based on vehicle operating and accident costs; (2) highway facility costs—for lane widening and new facilities; (3) parking costs for commuters—capital and maintenance; (4) transit costs—extra buses, park and ride lots, and ramp metering required to service peak users (operation and maintenance costs); and (5) employer and agency costs—for rideshare programs and commuter parking management programs.

Recommendations: based on average volume-to-capacity ratios, VMT per work person trip, transit system cost per rider, and costs per work trip, analysts recommended a strategy combining rideshare and transit measures, given opportunities to further study potential impacts and to implement demonstration programs.

Source: Decoria-Souza, 1988.

PROFILE: Transportation Controls in a Large Urban Area to Attain the Carbon Monoxide Standard

Location: New York City. New York has had to take creative and drastic steps to attempt to control traffic; their traffic control experiences, though unique, shed light on potentially effective strategies for other areas.

Problems: Severe traffic congestion and carbon monoxide (CO) problems. CO hotspots are found throughout Manhattan CBD and along major corridors leading to the CBD. Congestion includes a.m. and p.m. "commute peaks" and a midday peak (10:00 a.m. to 2:00 p.m.) resulting from an overload of taxis, livery cars, commercial vehicles, and private cars.

Solutions: The city implemented a Transportation Control Plan in 1973, but worked particularly hard over the past decade to implement effective controls. Measures implemented include: enhanced law enforcement efforts plus a 47 percent reduction in traffic signs; priority bus lanes on 15 major streets; numerous curb-side bus lanes and a contra-flow bus lane; a bus transitway which limited curblane use, through-movements, and on-street passenger loading/offloading. The city also operates a taxi I&M program (complements state's I&M program). In 1986 the city restricted parking privileges for government staff--removing 200 spaces and 98 curbside locations. In the fall of 1987, the city began project SMART (Strategies for Mobility, Access and Reduction of Traffic), a voluntary no-drive program modeled after programs in Denver and other cities. By 1992 Manhattan will have a computerized traffic control system that will adjust traffic signals to meet traffic conditions. Peripheral park and ride lots will be constructed outside Manhattan. The city is also considering alternative fuels use (it is testing methanol-fueled buses) and (as a last resort) congestion pricing strategies and car bans.

Results: Parking management and priority bus services have trimmed illegal parking 61 percent since 1981 and raised crosstown bus and taxi speeds 30 percent with no adverse effects on adjacent streets. However, small improvements in street speeds and capacities often increase vehicle use on these streets. Drivers, rather than changing lifestyles, become more congestion-tolerant. Measures that work best and that will be emphasized through project SMART include more enforcement, stricter illegal parking fines, and voluntary reductions in vehicle use by individuals and businesses.

Source: Soffian et al., 1988.

PROFILE: Reducing Urban Ozone with TCMs, the Olympics Experience

Location:	The South Coast Air Quality Management District (SCAQMD), Los Angeles, California (during the July-August 1984 summer Olympic Games).
Problem:	Reducing normally congested traffic and high ozone levels during the summer season.
Actions:	Establishment of an interagency coordination center; a public relations program to educate the driving public; a joint highway patrol-department of transportation program to reduce truck traffic during peak hours; a massive system surveillance and monitoring program; development of 18 separate traffic management plans to coordinate traffic at 24 Olympic activity sites. Example elements included promotion of work schedule changes, intensified (i.e., all-day) ramp metering, making peak-hour only shoulder lanes available all day, heavily promoting voluntary shift in truck travel times.
Results:	Traffic conditions: daily bus ridership increased by about 250,000 riders per day; start times for motorists averaged one-half hour earlier earlier than usual, thus spreading the morning peak traffic period and increasing traffic flow; a 10 percent drop in work-trips occurred; truck traffic shifted to evening hours; average daily traffic varied from -25% to +10% of normal levels; freeway congestion ranged from -90% to -20% of normal levels (compared to the 1983 summer period). Air quality: district-wide observed maximum ozone concentrations were 12 percent less than what would normally be expected given the meteorological conditions that prevailed during the Olympic Games. This is equivalent to a 44 percent decrease in the number of station days "stage I episodes" that occurred in the SCAQMD (a stage I episode occurs when one-hour average ozone concentrations equal or exceed 20 pphm at an air quality monitoring station).
Sources:	Davidson and Cassmassi, 1985; Giuliano, 1985.

PROFILE: Travel Demand Modeling by Oakland, California's Metropolitan Transportation Commission (MTC)

Location: The MTC assists the Bay Area Air Quality Management District (BAAQMD), which covers parts of nine counties in the San Francisco Bay Area.

Task: VMT forecasting using travel demand models.

Approach: The MTC has developed a comprehensive transportation demand modeling tool, known as MTCFCAST-80/81. MTCFCAST-80/81 (equivalent in concept to UTPS) comprises 24 separate models to simulate residential travel behavior. Important steps and assumptions used by the MTC to forecast travel demand include:

Data Collection and Model Input Preparation:

1. Document demographic/economic/land use projections as prepared by the Association of Bay Area Governments (ABAG).

2. Document exogenous modeling assumptions associated with travel costs: gasoline and nongasoline auto operations/maintenance costs, parking charges, transit fares.

3. Prepare zonal and network level-of-service inputs for model.

Model Assembly and Validation:

1. Assemble "observed" work and nonwork trip tables; included data from the 1980 census, a 1981 MTC-sponsored small-scale household travel survey, and data from the Urban Transportation Planning Package (UTPP) purchased from the U.S. Bureau of the Census for the MTC's area.

2. Validate travel model 1980 base year simulations by comparing simulations to "observed" trip data and traffic and transit counts.

3. Cross-check MTCFCAST-80/81 modeling results against other travel demand models that use alternative algorithms (e.g., Fratar, Gravity, etc.; see Table 5-6 for a sample list of alternative model approaches for each of the four traditional transportation demand modeling steps).

Travel Forecasting:

1. Prepare forecasted trips and VMT based on projected household, employment, population, and auto ownership projections (e.g., MTC's San Francisco Bay Area projections

continued

show: population lagging behind jobs and consequent VMT growth greater for work than for nonwork trips; household sizes declining; therefore, trip rates per household may decline as well; auto ownership near "saturation" levels for the San Francisco Bay Area, indicating near universal auto availability).

2. Conduct analyses for years 1980 and 2000.

3. Limit bulk of analysis to intra-regional personal travel.

4. Divide home-based work trips into 3 groups: drive alone, shared ride with two occupants, shared ride with three-plus occupants.

5. Because assignment process will not account for intra-zonal trips, use an intra-zonal correction process.

6. Make estimates for intra-regional commercial and inter-regional trips and VMT (this is the least formal of the modeling techniques—ballpark approximations are generated).

- Intra-regional commercial: apply Caltrans (California State Department of Transportation) estimates for "percent trucks on state highways" for 1980 and current (1986) years to all roads (state, local, highways); assume 1986 "percent truck" factors are valid for 2000; assume 52 percent growth in intra-regional truck traffic from 1980 to 2000.

- Inter-regional vehicle trips: use Caltrans' annual traffic "census" for 1980 and 1985 at regional "gateways" and extrapolate the growth to the year 2000 (165 percent growth in inter-regional VMT from 1980 to 2000); assume average trip length of 40 miles for inter-regional trips for both 1980 and 2000.

Source: Purvis, 1988a.

PROFILE: Estimating Current and Future Emissions from On-Road Motor Vehicles

Location: South Coast Air Quality Management District (SCAQMD) (southern California).

Task: Estimating motor vehicle emissions.

Three-Step Approach:

1. Estimate traffic demand from existing and predicted land use patterns; analysis yields **traffic volumes.**

- Southern California Association of Governments (SCAG), the South Coast's regional transportation planning agency, generates traffic demand predictions.
- SCAG uses LARTS (a travel demand model equivalent to UTPS) to analyze socioeconomic data and produce traffic volumes. Submodels within LARTS analyze socioeconomics, trip generation, trip distribution, mode choice, and trip assignments.

2. Aggregate emission factors for individual vehicles into "fleet representative" factors; analysis yields **vehicle emissions factors.**

- California Air Resources Board (ARB) uses EMFAC (the California equivalent to MOBILE) to generate vehicle emission factors (for NOx, CO, TOG, ROG, exhaust particulate matter, and tire wear particulates).
- ARB uses BURDEN and fuel use totals to generate county-level SOx and Pb emissions (counties use gridded VMT data to grid SOx and Pb emissions).

3. Multiply vehicle volumes and emission factors to derive a **total mass emission rate** for the study area (usually in tons per day per pollutant).

- SCAG (with ARB) uses California Department of Transportation software (DTIM) to geographically grid emissions; DTIM combines traffic volume and speed outputs from LARTS with emission factors from EMFAC; DTIM outputs these emissions to grid cells (usually 5 km by 5 km).

continued

- DTIM also calculates cold start, hot start, and hot soak emissions in each grid cell; it does this by using the "trip end" information available from LARTS. DTIM also uses the total number of vehicles in the cells to allocate diurnal emissions to grid cells.

Source: Oliver et al., 1987.

PROFILE 14

PROFILE: Three of the TCM Analyses Conducted by the Maricopa Association of Governments (MAG) for Maricopa County, Arizona

Location: Maricopa County is in the south-central portion of Arizona and includes the city of Phoenix.

General Approach: TCM analyses conducted for Maricopa County used the MAG Regional Transportation Model, calibrated according to 1980 travel data, and implemented by the use of UTPS software provided by the U.S. Department of Transportation. The model forecasted daily traffic for a base year (1985) and various transportation scenarios in 1987, 1990, 1995, and 2005. Updates to the highway networks used in the model were based on the region's Transportation Improvement Program (TIP); analyses were conducted in conjunction with the Arizona Department of Transportation.

Bicycling: Approach estimated emissions changes due to replacing 1 percent of all vehicle trips less than six miles with bicycle trips. Modeling analysis covered:

1. Assumed average regional vehicle speed of 30 mph; therefore, average travel of 12 minutes for six-mile trips.

2. Used output from gravity model (trip distribution step in the travel demand modeling process) to determine the number of person trips that were 12 minutes or less, broken down by category—home based work (HBW), home based nonwork (HBNW), nonhome based (NHB) (key to the analysis was tapping the gravity model's output for trips based on expected time of travel).

3. Converted person trips to vehicle trips by dividing person trips by auto occupancy (e.g., 311,000 HBW person-trips, divided by an average auto occupancy of 1.1 for HBW trips, yields 283,000 vehicle trips).

4. One percent of the vehicle trips are assumed to be replaced by bicycle trips.

5. Average trip length assumed to be three miles (half of six miles); total VMT savings calculated by multiplying vehicle trips replaced by bicycles with average trip length.

6. Calculated VMT reductions based on total VMT for each geographic location.

continued

Ridesharing:

1. Assumed that a rideshare program targeted in 1987 to firms with 350 or more employees would involve approximately 120,000 employees at 125 locations.

2. MAG employment files were used to generate data on firm size and location by transportation analysis zone (TAZ).

3. Solo drivers assumed to join carpools averaging 2.18 persons per vechicle (1985 average for MAG area).

4. Success rate of 2.33 percent was assumed (233 carpool converts per 10,000 employees contacted) (this was based on reported success rates for other cities; see for example: Booth and Waksman, 1985).

5. Estimated number of employees exposed to the ridesharing message (100 percent at the contacted firms) was divided by total employment in each TAZ, to yield percent exposed per TAZ.

6. Percent exposed per TAZ was factored by success rates and carpool occupancy to yield work trip reductions by TAZ.

7. For 1995, assumed program expansion to include companies with 100 to 349 employees; assumed success rate was 1.17 percent for these smaller sized firms; overall program success rate assumed to be 1.8 percent; work trip reductions were calculated as in the 1987 scenario.

Short-Range Transit Improvements:

1. Regional transit planners estimated that new bus funding would increase ridership by 6 percent in 1987 over 1985 data.

2. Transit planners advised that 1985 transit network (used to establish modeling parameters) would provide a reasonable approximation of network available in 1987.

3. Travel demand modeling forecasted 33,643 transit trips per weekday without funding additions; a 6 percent (2,019 trips) increase was added.

4. Since average auto occupancy for the area is 1.3 persons per vehicle, transit trip increase (2,019) was divided by 1.3 to yield number of vehicle trips replaced by increased transit services (i.e., 1,552 vehicle trips).

Source: MAG, 1987.

Appendix D

PAST EXPERIENCE AND POTENTIAL RULES OF THUMB ASSOCIATED WITH TCM EFFECTIVENESS

Appendix D

PAST EXPERIENCE AND POTENTIAL RULES OF THUMB ASSOCIATED WITH TCM EFFECTIVENESS

Overview

One of the principal points this guidance attempts to convey is: TCM effectiveness varies substantially from region to region depending upon a wide range of factors (e.g., extent of prior transportation controls implemented, nature of traffic congestion and network configuration, availability of transit services, trends in business and population growth). For approximately a dozen TCMs, the guidance identifies the factors that contribute to the successful implementation of a particular measure; information sources are referenced so analysts can research additional measures and the factors contributing to their success. This information is provided to assist the guidance user in evaluating how applicable a measure is to his or her own urban area, and then to allow analysts to judge for themselves, based on these factors, how effective a measure might be.

Although independent analysis of the potential effectiveness of individual measures is recommended, insights can and should be drawn from TCM implementation experiences to-date. This appendix summarizes broad observations on the reported effectiveness of TCMs. To gain a complete understanding of the information provided, users should refer to the original documentation for a more complete description of the basis for these observations (references cited are mostly from those listed in Table 3-4—recommended information sources mentioned in the TCM descriptions section of this guidance). For example, data on the effectiveness of park and ride lots also reflect synergistic effects of rideshare promotion activities—synergistic effects such as these are not detailed in the guidance's descriptive information section. The observations in this appendix are provided as a "common sense" check—if your analyses do not seem to agree with the results profiled below, your assumptions and analytical methodologies may need a second review. These observations should not be an analytical starting point; a review of these findings should be part of your overall approach.

The findings cover nine broad TCM categories:

- Pooling and bus service priority facilities
- Vanpools and buspools

Employer-sponsored rideshare programs
Pool/transit fringe parking
Variable work hours
Transit improvements
Traffic flow improvements
Parking management
Pricing strategies

Findings

1. Pooling and Bus Service Priority Facilities

(from Pratt and Copple, 1981)

a. Various priority programs mean an average of a doubling in bus on-time performance.

b. Mode shifts attributable to priority systems are often small, but transit market share increases of up to 50 percent can occur over an entire metropolitan corridor (even with substantial prior transit service).

c. Facilities offering moderate time advantages often realize increases of 100 to 300 pooling vehicles per hour in the peak period.

d. Bypass lanes on metered freeway ramps have increased HOVs an average 25 percent.

e. Highway person-volume increases of 8 to 15 percent have been typical with freeway and medium distance arterial HOV facilities; vehicle volumes have increased 5 percent or less, or decreased.

f. Person-volumes declined with "take a lane" strategies that were later discontinued.

g. 40 to 60 percent of bus and carpool passengers on newly opened freeway and medium distance arterial facilities formerly drove alone.

h. 35 to 45 percent of the gross VMT reductions achieved through HOV use will be counterbalanced by "new" VMT from other activities.

(from CSI, 1986)

i. Area-wide ridesharing programs resulted in annual work trip VMT reductions of from 0.03 to 3.6 percent, 0.3 percent on average (1.2 percent on average for programs with "before and after" evaluations).

j. Average daily VMT reduction per carpooler was 10.8 percent (44 percent of the roundtrip length).

k. Area-wide rideshare programs account for between 2 and 5 percent of total carpoolers in five urban areas.

l. Vehicle volume per person reductions achieved with HOV lanes averaged 6 percent during peak-period commutes (data through 1985); highest reductions achieved were 18 percent in the morning peak period and 33 percent in the afternoon peak period.

m. HOV lanes physically separated from other lanes have the potential to reduce peak period corridor vehicle trips and VMT by 10 percent; maximum reductions appear to be 5 percent on HOV lanes not physically separated from routine traffic.

(from Levinson et al., 1987)

n. HOV ramp bypasses provide travel-time savings of from 1-3 minutes per vehicle.

2. Vanpools and Buspools

(from Pratt and Copple, 1981)

a. Majority of employer-sponsored vanpool programs serve less than 5 percent of the employees (typically 1 to 2 percent); over 20 percent of programs, however, serve 10 to 58 percent.

b. Programs are most successful where one-way trip length exceeds 15 miles, where work schedules are fixed or regular, where employer size allows for matching of 10 to 12 people from the same residential area, and where congestion is a problem and transit options are inadequate.

c. About half (45 to 65 percent) of new vanpool/buspool riders formerly drove to work (except in some CBD programs); 50 to 100 percent of these former drivers drove alone; most programs do not divert transit users to pooling.

d. Rule of thumb: programs will be successful if the time spent picking up and dropping off passengers does not exceed the travel time.

e. Attendance is usually 80 to 90 percent of total participants (due to vacation, illness, need to work overtime, etc.).

(from Levinson et al., 1987)

f. An effective ridesharing program would reduce VMT an estimated 0.2 percent in suburban areas and 0.1 percent in larger cities (e.g., New York or Chicago).

3. Employer-Sponsored Rideshare Programs

(from CSI, 1986)

a. Programs with subsidized carpool parking and mandatory return of rideshare application forms achieve a switch to ridesharing in 12 to 15 percent of drive-alone employees (this translates into VMT reductions of 7 to 9 percent).

b. Programs at multi-employer sites are less successful than programs serving a single, large employer; typically, multi-employer sites achieve a decrease of 3 to 4 percent in drive-alone employees.

4. Pool/Transit Fringe Parking

(from Pratt and Copple, 1981)

a. Typical park and ride lots served by rail/rapid transit offer 400 parking spaces; all are full if the lot is free; three-quarters are full if a fee is charged.

b. Typical commuter and light rail lots are smaller; utilization varies, but tends to be high; park and carpool lots typically serve fewer than 60 vehicles (average of 20 to 30).

c. Approximately 80 to 90 percent of fringe lot users travel less than 5 miles to the park and ride service.

d. 40 to 60 percent of park and ride transit lot users previously commuted as auto drivers.

e. 60 percent of carpoolers at fringe lots drove alone prior to the parking lot's availability.

f. Peripheral lots (on the outskirts of the CBD) work only if their charges are significantly lower than downtown parking rates (cost savings of at least $0.75 per day (in 1981 dollars) appear to be necessary.

g. Park and ride/transit travel times must be no more than 10 minutes longer than drive-alone times or use will decline (total time increases over 25 minutes translate to minimal use).

(from CSI, 1986)

h. Data from several urban areas show that on average, about half of all park and ride lot users drove alone before using a park and ride lot.

5. Variable Work Hours

(from Pratt and Copple, 1981)

a. A quarter to a half of all employees in a localized area will take part in a variable-work-hours program if a major employer aggressively implements the program.

b. A large-scale program can reduce maximum 15-minute passenger and vehicle loads by 15 to 35 percent at terminal facilities (rapid transit, major parking lots); a 1 percent peak-hour volume reduction has been reported to save 0.6 to 1.2 percent in travel times.

c. The farther (geographically) the driver is from the employment source, the less is the impact/reduction in peaking volumes (program effects diminish by half on radial facilities serving an employment core).

d. In one example, a variable work hour program combined with corresponding carpooling improvements reduced VMT 14 percent (among participating employees).

e. Programs do not appear to affect overall mode choice decisions.

(from Batchelder et al., 1983)

f. Staggered work hours and flex time can yield 5 to 15 percent volume reductions during peak intervals in a major activity center with several employers; higher reductions are possible with larger, single employment centers.

6. Transit Scheduling and Frequency; Bus Routing and Coverage; Express Transit; Transit Fare Changes

(from Pratt and Copple, 1981)

a. Average response to transit improvements is a 0.5 percent gain in ridership for every 1 percent increase in service; express bus service is an exception: a 1 percent increase in express bus service to the CBD yields a 0.9 percent increase in ridership.

b. One out of every two or three new transit riders is a former auto driver.

c. New bus routes take 1 to 3 years to develop their full ridership (whole new transit systems take even longer).

d. Express buses using separate roadways (e.g., Shirley Highway in Washington, D.C.) produce travel-time savings of 10 to 30 minutes (in congested corridors).

e. Express buses using HOV freeway lanes save up to 5 minutes in travel time; large-scale programs carry from 1,000 to 11,000 passengers daily; smaller programs carry 200 to 600 morning peak-period travelers.

f. Express buses on surface street priority lanes carry 600 to 2,100 passengers daily, with some travel time savings over local bus service and auto travel.

g. Rule of thumb: ridership shrinks one-third as much in percentage terms as a fare increase (e.g., a 3 percent fare increase results in a 1 percent ridership loss); response rarely exceeds a 0.6 percent decrease in ridership per 1 percent increase in fares.

h. The larger the city and the more extensive the transit service is, the less responsive ridership is to fare increases.

i. One out of every two to three new transit riders attracted by a fare reduction is a former auto driver.

(from CSI, 1986)

j. Since transit typically accounts for a small (less than 10 percent) share of total regional trips, emissions reductions from short-range transit improvements are limited—major increases in transit ridership result in only small region-wide VMT reductions.

k. Greatest VMT reductions are associated with transit service expansions.

(from Levinson et al., 1987)

l. For transit fare or service changes (or changes in parking costs), general elasticity factors can help assess the impacts; a 100 percent increase in fares, headways, population coverage, or bus miles may result in transit ridership changes of the following (approximate) orders:

(1) 100% fare increase: 40% ridership decrease
(2) 100% headway increase: 40-60% ridership decrease
(3) 100% coverage increase: 60-90% ridership increase
(4) 100% bus miles increase: 70-100% ridership increase

Note that these estimates are highly dependent upon initial operating conditions, fares, the degree to which transit improvements carefully match potential markets, and service coverage (geographic) and frequency.

m. This reference includes a "look up" table to estimate the effects of reduced traffic congestion or frequency of stops on bus travel times and speeds.

n. Bus malls provide travel-time savings of from 2-5 minutes per mile.

o. Bus lanes on city streets provide travel-time savings of from 1-5 minutes per mile.

p. Bus lanes on freeways provide travel-time savings of from 0 to 1.2 minutes per mile.

q. Bus lanes around major queues provide travel-time savings of from 3-5 minutes per mile.

7. Traffic Flow Improvements

(from CSI, 1986)

a. Signal timing projects in 11 cities yielded estimated average annual impacts, on a per-intersection basis, of (1) a decrease of 15,470 vehicle hours of delay, (2) 455,921 fewer stops, (3) a savings of 10,524 gallons of fuel (results were computed by TRANSYT-7F).

b. Field surveys show signal timing projects reduce delay time 10 percent in p.m. and noon peak-periods, 26 percent during the a.m. peak period, and 34 percent during the off-peak period (fuel consumption reductions ranged from 4 to 13 percent).

c. A California signal timing program (also in 11 cities) yielded travel time reductions (over the whole system) of 6.5 percent; stops and delays were reduced more than 14 percent, and fuel consumption dropped 6 percent.

d. In six cities implementing freeway ramp metering, average traffic speeds increased nearly 30 percent—from 30 to 38.9 mph (taking delays at the ramp meters into account, average speed increases were about 22 percent, to 36.5 mph).

(from Levinson et al., 1987)

e. General traffic improvements result in person and vehicle roadway capacity gains of between 10-20 percent.

f. Traffic signal improvements provide travel-time savings of from 0.4 to 1.6 minutes per mile.

g. Auto restricted zones result in up to a 20 percent reduction in VMT across the screenline.

8. Parking Management

(from Levinson et al., 1987)

a. On street parking controls result in person and vehicle roadway capacity gains of between 50-100 percent.

b. On-street parking controls provide travel-time savings of from 0.2 to 2.4 minutes per mile.

9. Pricing Strategies

(from Levinson et al., 1987)

a. Bridge and tunnel tolls result in a 2 to 5 percent reduction in VMT per affected crossing.

b. Gas tax increase of $0.10 per gallon results in a 2 percent area-wide reduction in VMT.

References

Abrams, C. M., J. F. DiRenzo, S. A. Smith, and R. A. Ferlis. 1981. "Measures of Effectiveness for TSM Strategies." FHWA/RD-81/177. Prepared for the Office of Research and Development, Federal Highway Administration, U.S. Department of Transportation. December 1981.

Albersheim, S. R. 1982. An assessment of transportation control measures for improving air quality. Transportation Quarterly. Vol. 36, No. 3, July 1982.

Ames, J., T. C. Myers, L. E. Reid, D. C. Whitney, S. H. Golding, S. R. Hayes, and S. D. Reynolds. 1985. "Airshed Model Operations Manuals, Volume I—User's Manual, and Volume II—Systems Manual." EPA-600/8-85/007a,b. U.S. Environmental Protection Agency, Research Triangle Park.

Batchelder, J. H., M. Golenberg, J. A. Howard, and H. S. Levinson. 1983. "Simplified Procedures for Evaluating Low-Cost TSM Projects. User's Manual." National Cooperative Highway Research Program Report No. 263. Transportation Research Board, National Research Council. October 1983.

Benedict, R., and M. Naylor. 1988. "Fine Particulate Receptor Modeling in Las Vegas Using Combined Gaseous and Particulate Source Profiles." APCA/EPA Conference Transactions, February 1988, pp. 518-529.

Benson, P. E. 1979. "CALINE3—A Versatile Dispersion Model for Predicting Air Pollutant Levels near Highways and Arterial Streets." FHWA/CA/TL-79/23. Office of Transportation Laboratory, California Department of Transportation. November 1979.

Benson, P. E. 1980. "Background and Development of the CALINE-3 Line Source Dispersion Model." FHWA/CA/TL-80/31. Federal Highway Administration.

Benson, P. E. 1984. "CALINE4—A Dispersion Model for Predicting Air Pollutant Concentrations near Roadways." FHWA/CA/TL-84/15. Office of Transportation Laboratory, California Department of Transportation. November 1984.

Bird, A. 1989. Telephone conversation regarding Region IX SIP modeling efforts between A. Bird, U. S. Environmental Protection Agency, Region IX, and L. A. Mahoney, Systems Applications, Inc. 20 April 1989.

Booth, R., and R. Waksman. 1985. "National Ridesharing Demonstration Program: Comparative Evaluation Report." UMTA-MA-06-0049-85-1. U.S. Department of Transportation, Research and Special Programs Administration. Transportation Systems Center. August 1985.

Bowler, C. E., E. C. Noel, R. Peterson, and D. Christiansen. 1986. "Park and Ride Facilities: Guidelines for Planning, Design, and Operation." Daniel Consultants, Inc., Columbus, Missouri. January 1986.

Brittle, C., N. McConnell, and S. O'Hare. 1984. "Traffic Mitigation Reference Guide, A Review of Options Available to the Public and Private Sectors." Published by the Metropolitan Transportation Commission, Oakland, California, and the U.S. Department of Transportation, Office of the Secretary. December 1984.

Caltrans. 1983. California Highway Design Manual, Bikeway Planning and Design. Section 7-1000. California Department of Transportation, Sacramento, California. July 1983.

Caltrans. 1989. A Directory of California Trip Reduction Ordinances. California Department of Transportation, Division of Transportation Planning, Technical Assistance Branch, Sacramento. April 1989.

Cappelle, D. G., and S. Greene. 1988. "High-Occupancy Vehicle Lanes: An Incentive for Ridesharing?" Presented to the Institute of Transportation Engineers, District 6, 1988 Annual Meeting, Colorado Springs, Colorado. July 1988.

CARB. 1990. "Derivation of the EMFAC7E Emission and Correction Factors for On-Road Motor Vehicles." Mobile Source Division, Inventory Analysis Section, California Air Resources Board. July 1990.

CENTRANS. 1988. Transportation Innovation in the States: National Contest Entries for 1988. Produced by the Center for Transportation (CENTRANS), in cooperation with the Innovations Transfer Program, Policy Analysis Services Division of the Council of State Governments.

Cooper, J. A., D. C. Redline, J. R. Sherman, L. M. Valdovinos, W. L. Pollard, and T. Chapple. 1988. "Evaluating Resolvability of Crustal Sources in Eagle River, Alaska Using Singular Value Diagnostics." APCA/EPA Conference Transactions, February 1988, pp. 495-507.

Cowherd, C., G. E. Muleski, and J. S. Kinsey. 1988. "Control of Open Fugitive Dust Sources." EPA-450/3-88-008. Prepared for Emissions Standards Division, Office of Air Quality Planning and Standards, U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. September 1988.

CRA. 1988. "Characteristics of Urban Transportation Demand. An Update." Revised edition. DOT-T-88-18. Prepared by Charles River Associates, Inc. for the Urban Mass Transportation Administration. July 1988.

Crawford, W. 1987. "The Minneapolis Experience: I-394 Interim HOV Lane." Presented to the Second Annual HOV Lane & Transitway Conference. 25-28 October 1987.

CSI. 1979. "Transportation Air Quality Analysis—Sketch Planning Methods, Volumes I and II." EPA 400/1-800-001a and 001b. Prepared by Cambridge Systematics, Inc. for the U.S. Environmental Protection Agency, Office of Transportation and Land Use Policy. December 1979.

CSI. 1986. "Improved Air Quality in Maricopa and Pima Counties—The Applicability of Transportation Measures." Contract No. 68-02-4329, Work Assignment No. 1. Cambridge Systematics, Inc. Prepared for the U.S. Environmental Protection Agency, Region IX. November 1986.

Davidson, A., and J. Cassmassi. 1985. Ozone reductions during Olympic period due to congestion reducing measures. Journal of the Air Pollution Control Association, Vol. 35, No. 3, March 1985.

Deakin, E. 1988. Draft reports on transportation control measures. Prepared for Cambridge Systematics, Inc., and the U.S. EPA, Office of Mobile Sources. September 1988.

Deakin, E. 1989. "Suburban Congestion." In TRB News. TRB, Washington, D.C.

Deakin, E., and A. Skabardonis. 1985. "Assessing the Traffic Impacts of Transportation and Land Development Scenarios." Transportation Quarterly, Vol. 39, No. 4, pp. 605-626, October 1985. In: E. Deakin, Strategies to Alleviate Traffic Congestion, Proceedings of ITE's 1987 National Conference; Part 2, A Reader. Institute of Transportation Engineers. 1988.

Deakin, E., and A. Skabardonis. 1986. "Fuel-Efficient Traffic Signal Management: Three Years of Experience, 1983-85." University of California, Berkeley, Institute of Transportation Studies.

Decorla-Souza, P. 1988. "An Evaluation of Demand Management Strategies for Toledo's 2010 Transportation Plan." Paper No. 880066. Prepared for presentation at the 68th Annual Meeting of the Transportation Research Board. December 1988.

deRoeck, D. J. 1988. "New Source Review for Particulate Matter." APCA/EPA Conference Transactions, February 1988, pp. 21-29.

DiRenzo, J. F. 1979. "Travel and Emissions Impacts of Transportation Control Measures." Transportation Research Record No. 714.

DiRenzo, J. F., and R. B. Rubin. 1978. "Air Quality Impacts of Transit Improvements, Preferential Lane and Carpool/Vanpool Programs." Final Report. EPA-400/2-78-002a and b. Prepared for the Office of Transportation and Land Use Policy, U.S. Environmental Protection Agency. March 1978.

DOT-EPA. 1979. "How to Prepare the Transportation Portion of Your State Air Quality Implementation Plan." Technical Guidance of the United States Department of Transportation, Federal Highway Administration, with the cooperation of the U.S. Environmental Protection Agency. November 1978, reprinted February 1979.

DOT. 1983. Model Parking Code Revisions to Encourage Ridesharing and Transit Use. U.S. Department of Transportation. September 1983.

DOT. 1986. "Transportation Management for Corridors and Activity Centers: Opportunities and Experiences." Final Report. DOT-1-86-21. Prepared by Office of Planning, Federal Highway Administration, U.S. Department of Transportation. Distributed in cooperation with the Technology Sharing Program, Office of the Secretary of Transportation. May 1986.

DOT. 1987a. "Microcomputers in Transition, Software and Source Book." UMTA-URT-41-87-1. U.S. Department of Transportation, Urban Mass Transportation Administration. June 1987.

DOT. 1987b. "Financing for the Future: Changing Roles in Mass Transit." Final Report. DOT-T-88-4. Prepared for the U.S. Department of Transportation, Office of Planning Assistance, Urban Mass Transportation Administration. December 1987.

Dresser, G. B., and C. E. Bell. 1986. "The Development of Traffic Information for Estimation of Mobile Source Emissions for Air Quality Modeling—Volume II, IMPACT: User's Guide." FHWA/TX-86/76-282-2F. Texas Transportation Institute, State Department of Highways and Public Transportation, Austin, Texas, in cooperation with the U.S. Department of Transportation, Federal Highway Administration. October 1986.

Dueker, K. J., P. Pendleton, and P. Luder. 1982. "The Portland Mall Impact Study." Final Report. DOT-I-83-7. Center for Urban Studies, Portland State University. Prepared for Office of Planning Assistance, Urban Mass Transportation Administration, U.S. Department of Transportation. December 1982.

Dunlap, J. 1989. Presentation at the California Air Resources Board Workshop on the Transportation Provisions of the California Clean Air Act. Sacramento, California. 30 March 1989.

Dynatrend, Inc. 1983. Alternate Work Schedules. Prepared for Federal Highway Administration, Transportation Management and Ridesharing Branch. Washington, D.C. August 1983.

EEA. 1985. "Program to Calculate Size Specific Particulate Emissions for Mobile Sources: A User's Guide." PB86-179694. Prepared for U. S. Environmental Protection Agency, Office of Mobile Sources. Ann Arbor, Michigan. August 1985.

Eggleston, A. E. 1988. "PM-10 Emission Measurements: Their Relationship to the Development of Emission Factors and Other Implementation Issues." APCA/EPA Conference Transactions, February 1988, pp. 267-286.

Eisinger, D. S., R. G. Ireson, and D. R. Souten. 1988. "Transportation Control Measures: Outline for a Technical Guidance Document." Final Report. Work Assignment 28, Contract No. 68-02-4393. Prepared for the U.S. Environmental Protection Agency and Pacific Environmental Services, Inc. 5 October 1988.

Emison, G. A. 1988. "Overview of PM-10 Policy and Regulations." APCA/EPA Conference Transactions, February 1988, p. 2-11.

EPA. 1979. "Bicycling and Air Quality Information Document." Final Report. EPA 400/2-79-001. U.S. Environmental Protection Agency, Office of Transportation and Land Use Policy. September 1979.

EPA. 1985a. "Compilation of Air Pollutant Emission Factors. Volume I: Stationary Sources." AP-42. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA. 1985b. "Compilation of Air Pollutant Emission Factors. Volume II: Mobile Sources." AP-42. Motor Vehicle Emission Laboratory, U. S. Environmental Protection Agency, Ann Arbor, Michigan. September 1985.

EPA. 1986. "Guideline on Air Quality Models (Revised)." EPA-450/2-78-027R. U.S. Environmental Protection Agency. Office of Air and Radiation, Office of Air Quality Planning and Standards. July 1986. See also, Requirements for Preparation, Adoption, and Submittal of Air Quality Implementation Plans; Final Rule; U.S. Environmental Protection Agency [revises EPA, 1986a]; Vol. 53 Federal Register, pp. 392-396. 6 January 1988.

EPA. 1987a. State Implementation Plans; Approval of Post-1987 Ozone and Carbon Monoxide Plan Revisions for Areas Not Attaining the National Ambient Air Quality Standards; Notice of Proposed Policy. Vol. 52 Federal Register, pp. 45044-45122. 24 November 1987.

EPA. 1987b. "Guideline for Use of City-Specific EKMA in Preparing Post-1987 Ozone SIP'S." Draft Report [final report expected to be released October 1989]. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. November 1987.

EPA. 1987c. "PM10 SIP Development Guideline." EPA-450/2-86-001. U.S. Environmental Protection Agency, Research Triangle Park, North Carolina.

EPA. 1987d. "Regulations for Implementing Revised Particulate Matter Standards." Final rule. Vol. 52 Federal Register, pp. 24672-24715. 1 July 1987.

EPA. 1988a. "EPA Lists Areas Failing to Meet Ozone or Carbon-Monoxide Standards." U.S. Environmental Protection Agency. 3 May 1988.

EPA. 1988b. Approval and Promulgation of Implementation Plans; Arizona State Implementation Plan Revision; Maricopa and Pima Counties Carbon Monoxide Plans; Notice of Proposed Rulemaking. Vol. 53 Federal Register, pp. 17378-17422. 16 May 1988.

EPA. 1988c. "Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources." EPA-450/4-81-026d (Revised). U.S. Environmental Protection Agency. Office of Air Quality Planning and Standards. December 1988.

EPA. 1988d. "Emission Inventory Requirements for Post-1987 Carbon Monoxide State Implementation Plans." EPA-450/4-88-020. Prepared by T. N. Braverman, Technical Support Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park. December 1988.

EPA. 1988e. "Emission Inventory Requirements for Post-1987 Ozone State Implementation Plans." EPA-450/4-88-019. Prepared by D. C. Misenheimer, Technical Support Division, Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park. December 1988.

EPA. 1989a. "User's Guide to MOBILE4 (Mobile Source Emission Factor Model)." EPA-AA-TEB-89-01. U.S. Environmental Protection Agency, Office of Air and Radiation, Office of Mobile Sources, Emission Control Technology Division, Ann Arbor, Michigan. February 1989.

EPA. 1989b. "Procedures for Emission Inventory Preparation, Volume IV: Mobile Sources." EPA-450/4-81-026d, U.S. Environmental Protection Agency, Research Triangle Park. September 1981. Revised July 1989.

EPA. 1989c. "Requirements for Preparations, Adoption, and Submittal of Implementation Plans; Methods for Measurement of PM-10 Emissions from Stationary Sources." Proposed Rule. Vol. 54 Federal Register, pp. 24213-24247. 6 June 1989.

Euler, G. W. 1983. "Traffic Signal Timing Optimization: Achieving National Objectives Through State and Local Government Actions." ITE Journal, Vol. 54, No. 9, pp. 14-17. September 1983. In: E. Deakin, Strategies to Alleviate Traffic Congestion, Proceedings of ITE's 1987 National Conference; Part 2, A Reader. Institute of Transportation Engineers. 1988.

Feldstein and Tranter. 1979. Anatomy of an air quality maintenance plan. Introduction (and subsequent four articles). Journal of the Air Pollution Control Association. Vol. 29, No. 4. April 1979.

FHWA. 1986. "Transportation Management for Corridors and Activity Centers: Opportunities and Experiences." Final Report. DOT-I-86-21. Prepared by Office of Planning, Federal Highway Administration, U.S. Department of Transportation. May 1986.

Fleming, L. 1989. The One-Minute Commuter, How to Keep Your Job and Stay at Home Telecommuting. Acacia Books, Davis, California.

Gilpin, G. 1989. Transportation Systems Manager, City of Pleasanton, California. Personal communication with Douglas Eisinger, January 1989.

Giuliano, G. 1985. "Olympics Transportation System Management Performance Analysis." Preliminary Report. UCI-ITS-85-3. Prepared for the California Department of Transportation, District 7, Research Contract RTA 13945-55B579. March 1985.

Gomez-Ibanez, J. A., and G. R. Fauth. 1980. "Using Demand Elasticities from Disaggregate Mode Choice Models." Transportation, Vol. 9, pp. 105-124.

Gordon, G. E. 1989. Personal communication between Gil Gordon of Gil Gordon Associates, Monmouth, New Jersey, and Douglas Eisinger of Systems Applications, San Rafael, California, 21 September 1989.

Gordon, G. E., and M. M. Kelly. 1986. Telecommuting; How to Make It Work for You and Your Company (a complete management guide). Prentice Hall, Inc., New York.

Grady, A. 1989. Five-year Evaluation Report of the Denver Better Air Campaign (forthcoming by September, 1989). Personal communication between Anne Grady, Denver Better Air Campaign Coordinator, and D. S. Eisinger, Systems Applications, 20 April 1989.

Granzow, E. 1988. Personal communication between E. Granzow, the Urban Analysis Group, and Douglas Eisinger, Systems Applications, 15 December 1988.

Graves, R. 1989. Personal communication regarding Denver area SIP modeling efforts between R. Graves, Colorado State Health Department, and L. Mahoney, Systems Applications, Inc. 20 April 1989.

Gray, H. A., C. S. Liu, and M. A. Nazemi. 1988. "Optimization of PM-10 Control Strategy in the South Coast Air Basin." APCA/EPA Conference Transactions, February 1988, pp. 589-600.

Greene and Associates. 1988. "Route 55 Travel Behavior Study." Draft Final Report. Prepared by Sharon Greene and Associates for the Orange County Transportation Commission. September 1988.

Hamerslough, J. 1989. Personal communication between J. Hamerslough, Senior Transportation Planner, Southern California Association of Governments, and Douglas Eisinger, Systems Applications, Inc. 3 May 1989.

Harris, H. W. 1989. Personal communication between H. W. Harris, Oregon Department of Environmental Quality, Air Quality Division, and F. W. Wicher, U.S. Environmental Protection Agency, Region IX, Air and Toxics Division. 17 July 1989.

Hawthorn, G. 1988. "Political and Regulatory Opportunities for Transportation Control Measures in the Post '87 Era." Presented at the Transportation Research Board, Transportation-Air Quality Committee Summer Meeting. 25 July 1988.

Hayes, S. R., R. G. Ireson, J. L. Fieber, R. G. Johnson, L. A. Mahoney, and A. S. Rosenbaum. 1989. "Technical Analyses in Determining PM10 and Other Control Requirements for the South Coast Air Basin." SYSAPP-89/044. Systems Applications, Inc., San Rafael, California.

Hlavinka, M. W., J. J. Korpics, and J. A. Bullin. 1987. TEXIN2: A versatile model for predicting carbon monoxide concentrations near intersections. J. Air Pollut. Control Assoc., 37(7):819-822.

Horowitz, J. L. 1977. "Packaging Transportation Elements to Meet Environmental Objectives." Transportation Research Board Special Report No. 172.

Horowitz, J. 1982. Air Quality Analysis for Urban Transportation Planning. MIT Press, Cambridge.

Huhn, F. J., R. Graves, and C. Selnick. 1988. "A Particulate Inventory Generation and Modeling System." APCA/EPA Conference Transactions, February 1988, pp. 387-397.

Ireson, R. G., and M. C. Dudik. 1987. "TRFCONV Application Guide." SYSAPP-87/155. Prepared for the Maricopa Association of Governments, Phoenix, Arizona. 26 August 1987.

ITE. 1988a. "The Effectiveness of High-Occupancy Vehicle Facilities. An Informational Report." Institute of Transportation Engineers, Washington, D.C.

ITE. 1988b. Strategies to Alleviate Traffic Congestion. Proceedings of ITE's 1987 National Conference. Institute of Transportation Engineers, Washington, D.C.

ITS. 1985. 1985 Highway Capacity Manual, Supplemental Report for California Conditions. Institute of Transportation Studies. University of California, Berkeley, California. 1985 [see TRB, 1985].

JALA. 1989. The State of California Telecommuting Pilot Project, Midterm Report. Prepared by JALA Associates, Los Angeles, California, for the State of California Department of General Services. June 1989.

Johnson, G. T., and L. A. Hoel. 1987. "Review of Financing Options for Highways and Transit." Journal of Transportation Engineering, Vol. 113, No. 1, pp. 72-83. In: E. Deakin, Strategies to Alleviate Traffic Congestion, Proceedings of ITE's 1987 National Conference; Part 2, A Reader. Institute of Transportation Engineers. 1988.

Kamhi, V. 1985. "Traffic Mitigation in a Small Urban Area." Presented at the Transportation Air Quality Symposium sponsored by the California Air Resources Board, the EPA, CALTRANS, CAPCOA, South Coast AQMD, Southern California Association of Governments, and the University of California Institute of Transportation Studies. Burbank, California, 6-7 June 1985.

Klusza, R. 1987. Route 55 Newport Costa Mesa Freeway Commuter Lane 18 Month Report. California Department of Transportation. 29 July 1987.

Levinson, H. S. 1987. "H.O.V. Lanes on Arterial Streets." Polytechnic University of New York. Presented at the Second National H.O.V. Lane & Transitway Conference, Houston, Texas. 27 October 1987.

Levinson, H. S., M. Golenberg, and K. Zografos. 1987. "Transportation System Management—How Effective? Some Perspectives on Benefits and Impacts." Transportation Research Record 1142: Urban Signal Systems and Transportation System Management. Transportation Research Board, National Research Council.

Ligas, J. F. 1989. Personal communication between F. P. Wicher of the U.S. Environmental Protection Agency and J. F. Ligas of the Chicago Area Transportation Study. 6 July 1979.

Lindley, J. A. 1987a. "A Methodology for Quantifying Urban Freeway Congestion." In: Freeway Management and Operations, Transportation Research Record No. 1132. Transportation Research Board, National Research Council.

Lindley, J. A. 1987b. Urban freeway congestion: quantification of the problem and effectiveness of potential solutions. ITE Journal, January 1987.

Lovelock, C. H., G. Lewin, G. S. Day, and J.E.G. Bateson. 1987. Marketing Public Transit, A Strategic Approach. Praeger Books, New York.

MAG. 1987a. "Documentation of Traffic Modeling and Transportation Control Measure Analysis for Use in Air Quality Modeling for the Maricopa County Nonattainment Area." Draft Report. Appendix B, Exhibit 5. MAG Transportation and Planning Office. April 1987.

MAG. 1987b. MAG 1987 Carbon Monoxide Plan for the Maricopa County Area. Prepared by the Maricopa Association of Governments. July 1987.

MAGTPO. 1988. Traffic Counting Results for the 1987-88 Voluntary No Drive Days Program. Maricopa Association of Governments, Transportation and Planning Office.

Market Analysis Professionals. 1988. Colorado Department of Health, Better Air Campaign, Market Research and Evaluation. March 1988.

Martinez, E. L., A. A. MacQueen, and F. M. Noonan. 1988. "PM-10 Emission Factors: Availability and Efforts/Alternatives to Fill Existing Gaps." APCA/EPA Conference Transactions, February 1988, pp. 259-266.

McTrans. 1989. "TRAF-NETSIM Released by FHWA." McTrans Newsletter, Vol. 3, No. 5. The Center for Microcomputers in Transportation, University of Florida. March 1989.

Meyer, M. D., T. F. Humphrey, C. M. Walton, K. Hooper, R. G. Stanley, C. K. Orski, and P. A. Peyser, Jr. 1989. "A Toolbox for Alleviating Traffic Congestion." Institute of Transportation Engineers, Washington, D.C.

Mohr, R. 1988. "PM-10 SIP Development in Colorado--A Case Study." APCA/EPA Conference Transactions, February 1988, pp. 561-574.

Mokhtarian, P. L. 1988. "An Empirical Evaluation of the Travel Impacts of Teleconferencing." Transportation Research-A. Volume 22A, No. 4, pp. 283-289.

Morris, R. E., T. C. Myers, H. Hogo, L. R. Chinkin, L. A. Gardner, and R. G. Johnson. 1989. "A Low-Cost Application of the Urban Airshed Model to the New York Metropolitan Area and the City of St. Louis (Five Cities UAM Study Phase I)." SYSAPP-89/070. Systems Applications, Inc., San Rafael, California.

Mounce, J. M. 1987. "Restoring Mobility in Houston." Texas Transportation Reporter, Official Research Publication of the Texas Transportation Institute. Vol. 23, No. 3, September 1987.

MTC. 1985. Commute Alternatives, A Manual for Transportation Coordinators. Third Edition. Metropolitan Transportation Commission, Oakland, California. May 1985.

Murray, G. 1986. "Promoting Commute Alternatives: Will It Work in Your City?" Western City, April 1986; pp. 5-6, 19, 32.

MWCOG. 1982. "Final Washington Metropolitan Air Quality Plan for Control of Ozone and Carbon Monoxide. Appendices, Volume II." Metropolitan Washington Council of Governments, December 1982.

Neffendorf, H. 1988. TRANSYT/9 vs TRANSYT-7F. McTrans Newsletter, Vol. 3, No. 3. University of Florida Transportation Research Center, Gainesville, Florida. September 1988.

Nilles, J. M. 1976. The Telecommunications-Transportation Tradeoff, Options for Tomorrow. John Wiley & Sons, Inc., New York.

Nollen, S. D., and V. H. Martin. 1978. Alternative Work Schedules. American Management Association, New York, 1978. In: CSI, 1986.

O'Connor, J. 1988. Closing Remarks for the PM-10 Implementation Conference and Opening Remarks for the Receptor Modeling Conference, San Francisco, California. APCA/EPA Conference Transactions, 24 February 1988, pp. xxvi-xxxi.

Oliver, W. R., T. W. Tesche, S. H. Peoples, R. R. Boyd, and R. Tate. 1987. "Planning Study for the Emission Inventory for the Southern California Air Quality Study." Final Report. Prepared for the Emissions Working Group, Southern California Air Quality Study. 17 April 1987.

Parody, T. E. 1984. "Predicting Travel Volumes for High-Occupancy-Vehicle Strategies: A Quick-Response Approach." In: Travel Model Development and Operations Research Methods, Transportation Research Record No. 976. Transportation Research Board, National Research Council.

PATH. Program on Advanced Technologies for the Highway, Institute of Transportation Studies, University of California, Berkeley (various publications).

Pedersen, N. J., and D. R. Samdahl. 1982. "Highway Traffic Data for Urbanized Area Project Planning and Design." National Cooperative Highway Research Program Report No. 255. Transportation Research Board, National Research Council. December 1982.

Perardi, T. E., M. Y. Kim, E. Y. Leong, and R. Y. Wada. 1979. Preparation and use of spatially and temporally resolved emission inventories in the San Francisco Bay region. Journal of the Air Pollution Control Association, Vol. 29, No. 4. April 1979.

Petersen, W. R. 1980. "User's Guide for HIWAY-2, A Highway Air Pollution Model." EPA-600/8-80-018. Environmental Sciences Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. May 1980.

Pratt, R. H., and J. N. Copple. 1981. Traveler Response to Transportation System Changes. Second Edition. Prepared under contract No. DOT-FH-11-9579 through Barton-Aschman Associates, Inc., R. H. Pratt & Co. Division. Prepared for the U.S. Department of Transportation, Federal Highway Administration, Office of Highway Planning, Urban Planning Division. July 1981.

PTI. 1986. "The Urban Transportation Planning System (UTPS), An Introduction for Management." Prepared by Public Technology, Inc. for the U.S. Department of Transportation, Urban Mass Transportation Administration, Federal Highway Administration, Office of the Secretary. April 1986.

Pultz, S. 1988. "Key Considerations for Developing Local Government TSM Programs." Final Report. Metropolitan Transportation Commission, Oakland, California. December 1988.

Purvis, C. L. 1988a. "VMT Forecasting Using Regional Travel Demand Models." Metropolitan Transportation Commission. Paper submitted to the Transportation Research Board, Committee A1F03, Transportation and Air Quality: Common Ground. Sacramento, California, 26 July 1988.

Purvis, C. L. 1988b. "High Occupancy Vehicle (HOV) Forecasting in the San Francisco Bay Region." Metropolitan Transportation Commission. Paper submitted to the 1988 National HOV Facilities Conference, Minneapolis, Minnesota, 17 October 1988.

Reynolds, S. D., T. W. Tesche, and L. E. Reid. 1979. "An Introduction to the SAI Airshed Model and Its Usage." EF78-53R4-EF79-31. Systems Applications, Inc., San Rafael, California. March 1979.

Roden, D. B. 1988. The development of a regional information system and subarea analysis process. ITE Journal, December 1988.

Rogers, F. 1986. "Airshed Modeling of Denver for Carbon Monoxide: A Comprehensive Overview." Technical Services Program Air Pollution Control Division, Colorado Department of Health. February 1986.

Rosenbloom, S. 1978. "Peak-Period Traffic Congestion: A State-of-the-Art Analysis and Evaluation of Effective Solutions." Transportation, Vol. 7, No. 2, pp. 167-191. June 1978. In: E. Deakin, Strategies to Alleviate Traffic Congestion, Proceedings of ITE's 1987 National Conference; Part 2, A Reader. Institute of Transportation Engineers. 1988.

Russell, A. G., and G. R. Cass. 1986. Verification of a mathematical model for aerosol nitrate and nitric acid formation. Atmos. Environ., 20:2011-2025.

Ryan, W. M., C. R. Badgett-West, D. R. Holtz, T. A. Peters, J. A. Cooper, and D. Ono. 1988. "Reconciliation of Receptor and Dispersion Modeling Impacts of PM-10 in Hayden, Arizona." APCA/EPA Conference Transactions, February 1988, pp. 419-429.

SAI. 1989. STAPPA/ACAPCD/EPA Urban Airshed Modeling Workshop. Prepared by Systems Applications, Inc., San Rafael, California; sponsored by the U.S. EPA. Presented at the Vanderbilt Plaza Hotel, Nashville, Tennessee. 11-12 April 1989.

SCAG. 1985. "The Telecommuting Phenomenon: Overview and Evaluation." Southern California Association of Governments, Transportation Planning Department, Special Studies Section. March 1985.

SCAG. 1989. "Telecommuting in the Air Quality Management Plan," Telecommunity Newsletter of the Southern California Association of Governments. Volume 4, Numbers 5,6. March/June 1989.

SCAQMD. 1987. Regulation XV, Trip Reduction/Indirect Source. Rules 1501-1505. South Coast Air Quality Management District, El Monte, California. As adopted, 11 December 1987.

SCAQMD. 1988. "Draft Air Quality Management Plan, 1988 Revision. Appendix IV-A, Tier I and Tier II Control Measures." South Coast Air Quality Management District, El Monte, California. June 1988.

SCAQMD/SCAG. 1988. "Proposed Modifications to the Draft 1988 Air Quality Management Plan." South Coast Air Quality Management District and Southern California Association of Governments (December 1988).

Scheuernstuhl, G. J. 1989. Personal communication between F. P. Wicher of the U.S. Environmental Protection Agency and G. J. Scheuernstuhl of the Denver Regional Council of Governments. 7 July 1989.

Schreffler, E. N. 1986. "Transportation Management Organizations: An Emerging Public/Private Partnership." Transportation Planning and Technology, Vol. 10, No. 4, pp. 257-266. In: E. Deakin, Strategies to Alleviate Traffic Congestion, Proceedings of ITE's 1987 National Conference; Part 2, A Reader. Institute of Transportation Engineers. 1988.

Schwartz, S. I., and L. Home. 1983. "Traffic Metering of High Density Sectors." ITE Compendium of Technical Papers, pp. 12-16 through 12-21.

Seiders, L. R. 1988. Personal communication between Douglas Eisinger, Systems Applications, Inc., and L. R. Seiders, COMSIS. 20 December 1988.

Seitz, L. 1989. Personal communication between L. A. Mahoney of Systems Applications and L. Seitz, California Department of Transportation, Division of Transportation Planning. 20 April 1989.

Seitz, L., and R. Baishiki. 1988. Coding Instructions, Direct Travel Impact Model (DTIM). California Department of Transportation. Updated 16 June 1988.

Shoup, D. 1982. Cashing out free parking. Transportation Quarterly. July 1982.

Skabardonis, A. 1986a. "Development of Air Quality Models for Traffic Signal Timing Programs." Workshop Presentation. Institute of Transportation Studies, University of California, Berkeley, California. 24 June 1986.

Skabardonis, A. 1986b. "Development of Emissions Models for Traffic Signal Timing Programs." Institute of Transportation Studies, University of California, Berkeley, August 1986.

Small, K. 1983. The incidence of congestion tolls on urban highways. Journal of Urban Economics, Vol. 13.

Soffian, G., I. Tsarnas, and J. Antokas. 1988. "New York City's Better Air Campaign: A Program to Attain the Carbon Monoxide Standard." Presented at the 81st Annual Meeting of the Air Pollution Control Association, Dallas, Texas, 19-24 June 1988.

Somers, J. 1989. Telephone conversation regarding the MOBPART program between J. Somers, U. S. Environmental Protection Agency, Ann Arbor, Michigan, and L. Mahoney, Systems Applications, Inc. 21 April 1989.

Sosslau, A. B., A. B. Hassam, M. M. Carter, and G. V. Wickstrom. 1978. "Quick Response Urban Travel Estimation Techniques and Transferable Parameters, User's Guide." National Cooperative Highway Research Program Report No. 187. Transportation Research Board, National Research Council.

Sperling, D. 1988. New Transportation Fuels. University of California Press, Berkeley.

SRF. 1987. "I-394 Interim HOV Lane: A Case Study, Phase I Report." Prepared by Strgar-Roscoe-Fausch, Inc. for the Minnesota Department of Transportation and the Federal Highway Administration. October 1987.

Stopher, P. R., and A. H. Meyburg. 1975. Urban Transportation Modeling and Planning. Lexington Books, Lexington.

Suhrbier, J. H., T. J. Atherton, and E. A. Deakin. 1979. "Improved Air Quality Through Transportation System Management." Transportation Research Record No. 722.

TRB. 1983. "Transportation Innovations: Ridesharing Techniques and Public-Private Cooperation." Transportation Research Record No. 914. Transportation Research Board, National Research Council, National Academy of Sciences.

TRB. 1985. "Highway Capacity Manual. Special Report No. 209." Transportation Research Board, National Research Council, National Academy of Sciences. [see also ITS, 1985].

TRC. 1988. "TRANSYT-7F User's Manual, Release 6." Prepared by the Transportation Research Center, University of Florida, Gainesville, Florida. October 1988.

UTPS Center. 1988. "UTPS Info, News from the Urban Transportation Planning System Center." UTPS Center, Washington State Transportation Center, Seattle. Vol I, No. 2. December 1988.

Van Aerde, M., S. Yagar, A. Ugge, and E. R. Case. 1987. "A Review of Candidate Freeway-Arterial Corridor Traffic Models." In: Freeway Management and Operations, Transportation Research Record No. 1132. Transportation Research Board, National Research Council.

Wade, D. 1989. Personal communication between Dennis Wade, California Air Resources Board, and Douglas Eisinger, Systems Applications, Inc. 1 May 1989.

Wagner, F. A. 1980. "Energy Impacts of Urban Transportation Improvements." Institute of Transportation Engineers, Washington, D.C.

Wagner, F. A., and K. Gilbert. 1978. "Transportation System Management: An Assessment of Impacts." UMTA VA-06-0047. Interim Report. Prepared for the U. S. Department of Transportation, Urban Mass Transportation Administration, and the Federal Highway Administration, in cooperation with the U.S. Environmental Protection Agency. November 1978.

Watson, J. G., J. C. Chow, and C. V. Mathai. 1989. "Receptor Models in Air Resources Management: A Summary of the APCA International Specialty Conference." J. Air Pollut. Control Assoc., Vol. 39, No. 4, pp. 419-426. April 1989.

Weisbrod, G. "Business and Travel Impacts of Boston's Downtown Crossing Automobile-Restricted Zone." Transportation Research Record 882, Washington, D.C. 1982, pp. 25-32. In: J. H. Batchelder, M. Golenberg, J. A. Howard, and H. S. Levinson. 1983. Simplified Procedures for Evaluating Low-Cost TSM Projects. User's Manual. National Cooperative Highway Research Program Report No. 263. Transportation Research Board, National Research Council. October 1983.

Wendt, J. G., and Y. Garza. 1988. "Motor Vehicle Contribution to PM-10 in California." APCA/EPA Conference Transactions, February 1988, pp. 302-313.

Wiersig, D. W. 1982. "Planning Guidelines for Selecting Ridesharing Strategies." Transportation Research Record No. 876: Ridesharing 1981. Transportation Research Board, National Research Council.

Wilbur Smith and Associates. 1981. "Measures of Effectiveness of Transportation Systems Management." Final Report. UMTA-IT-09-0089-81-1. Prepared for the Tri-State Regional Planning Commission, New York; and the Urban Mass Transportation Administration. April 1981.

Woodard, K. R., and R. D. Bauman. 1988. "Progress in PM-10 SIP Development." APCA/EPA Conference Transactions, February 1988, pp. 531-539.