A992-225

Final Report

TRANSPORTATION CONTROL MEASURE ANALYSIS PROCEDURES

SYSAPP-91/141

25 November 1991

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ABSTRACT

This study was completed by Systems Applications and K. T. Analytics for the California Air Resources Board (ARB) to develop methodologies for analyzing travel and emission changes resulting from individual transportation control measures (TCMs) and TCM packages. The work establishes new conceptual and analytical methodologies useful for transportation and air quality planners who must evaluate TCMs as part of air quality attainment plans. Four major steps were conducted as part of this project: (1) a brief literature review and conceptual discussion linking specific TCMs to travel and emission changes; (2) development of a conceptual framework for analyzing TCMs, (3) creation of quantitative methodologies to evaluate specific measures and measure packages; and (4) application of the methodologies to a sample area to demonstrate their use. Support to conduct this work was provided by the Analysis Section of the Air Resources Board's Mobile Source Division.

Disclaimer

This report was submitted in fulfillment of Contract No. A992-225: "Development of a Methodology for Analyzing Emission Reductions due to Implementation of Transportation Control Measures" under the sponsorship of the California Air Resources Board. The statements and conclusions in this report are those of the contractors and not necessarily those of the California Air Resoucres Board. The mention of commercial products, their source or their use in connection with material herein is not to be construed as either an actual or implied endorsement of such products.

Contents

1 INTRODUCTION

The California Clean Air Act (CCAA) requires nonattainment areas to adopt TCMs to reduce vehicle activity levels, and growth in these levels due to population increases. The Federal Clean Air Act Amendments (CAAA) of 1990 also require TCMs to be adopted in many nonattainment areas. Both State Implementation Plans and attainment plans required under the CCAA must include detailed evaluations of the emission reductions associated with the TCMs proposed. However, when these provisions were promulgated, no comprehensive methodology for evaluating the effects of TCMs was available. This study was sponsored by the Mobile Source Division of the California Air Resources Board in order to provide such a methodology.

This report presents detailed quantitative techniques for analyzing the effects of transportation control measures (TCMs) on travel activity such as trips, miles travelled, and speeds. While complementing other available techniques, those presented here are the most comprehensive techniques currently available and address numerous key issues not addressed elsewhere.

INTENDED USE OF THE METHODOLOGIES

The purpose of this study was to develop a comprehensive methodology for TCM analysis which accounts for primary and secondary effects of individual TCMs and TCM packages. The methodologies will be used for three broad purposes:

1. The methodologies may be used by air quality management districts and transportation planners to assess TCM effectiveness.

2. The ARB will use these methodologies to evaluate state implementation plans that include TCMs and more generally to improve its capabilities in emission inventory analysis.

3. The ARB will also use these methodologies as a foundation for the development of a TCM analysis model.

While most of the focus in the report is on regulatory and planning agencies, private companies implementing TCMs to reduce the driving activity of their employees may also utilize the methodologies presented here without adaptation.

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PURPOSE OF THIS STUDY

In the past a number of overly simplistic assumptions have been made in efforts to quantify the effects of individual TCMs and TCM packages. These assumptions tend to exaggerate the benefits of TCMs, making it difficult to rely on control strategies which utilize them. For example, it is often assumed that each new ridesharer will reduce a trip, or that employees working a four-day forty hour work week reduce trips by 20%. However, a ridesharer may drive to park and ride lots (thus reducing miles travelled but not trips and related start emissions), while compressed work week workers may make extra non-work trips on their days off work.

Other simplifying assumptions have been made regarding TCM packages. Combinations of TCMs have been assumed to be additive in their effects although some may not be (i.e. one cannot ride a bus and be in a carpool at the same time) and some may be synergistic (i.e. ridesharing incentives or parking price increases alone each may increase ridesharing by 5% but together by 20%). This report presents a quantitative approach for estimating the effects of TCM packages.

A number of other efforts to develop TCM analysis methodologies are currently underway, including studies performed for the Sacramento Metropolitan Air Quality Management District and the California Department of Transportation through the San Diego Association of Governments, or SANDAG for short. Both were performed under schedules driven by deadlines in the CCAA. There are a number of important limitations in these approaches which reduce the accuracy of estimates of TCM effectiveness. For example, the methodologies developed for Sacramento utilized qualitative rankings of TCM effectiveness. While qualitative approaches may be useful, explicit, quantitative approaches are more desirable. The methodologies developed for SANDAG do not address secondary effects of TCMs (i.e. increased use of a vehicle by household members of ridesharers or telecommuters) and in many cases require the user to supply the effect of the TCM on vehicle activity. Further, they do not provide approaches for assessing the effects of TCM packages.

The report addresses primary effects in a more detailed manner which avoids limitations such as those described above, and explicitly covers key secondary effects. For example, the ridesharing methodology presented here distinguishes between ridesharers who drive to park and ride lots, ridesharers who do not, and the fact that some ridesharers are carpool drivers. Trip reductions are limited to trips which may actually be reduced. VMT (Vehicle miles travelled) reductions are then related to trip reductions and reductions in trip length (i.e. VMT to a park and ride lot instead of VMT all the way to the work site). The methodology also calculates indirect effects such as potential increases in trips by members of the ridesharer's household. This report also presents a step-by-step methodology that assesses the potential for overlap and synergism between TCMs adopted in a package and calculates the number of participants in each. For example, if 100 individuals could potentially rideshare or use transit, an analyst can estimate how many individuals will choose each option by applying the methodology.

LIMITATIONS OF METHODOLOGIES

This study is a first effort to treat TCMs more comprehensively than they have been in the past. In order to provide the maximum amount of detail in the methodologies, the number of individual TCMs specifically covered here is limited. These methodologies include:

(1) Ridesharing,

(2) Telecommuting,

(3) Parking management,

(4) Flextime/Staggered work hours,

(5) Compressed work weeks,

(6) Traffic flow improvements, and

(7) Traffic signalization improvements

The set was chosen to represent most of the key analytical problems associated with TCM analysis as well as to include commonly implemented TCMs. Although other TCMs are not covered, many can be assessed by slightly modifying the approaches to similar approaches presented here. It should also be noted that TCMs which are highly area and/or program specific necessitate input of the number of participants. Ridesharing, telecommuting, and alternative work schedules all fall into this category.

The packaging methodology is the first attempt of its kind and will likely be improved upon over time. In some cases it uses approaches that have alternative applications in transportation models; for example, the way mode choices are calculated by the packaging methodology differs from the way mode choices are treated in modal choice models used in general transportation forecasts.

More specific limitations to note are the treatment of temporal and spatial variations in vehicle activities. The temporal treatment is currently limited to peak/off-peak definitions which do not provide as much detail as may be desired for time-dependent problems such as exceedances of the CO or ozone standards. The spatial variability in emissions caused by TCM implementation (for example, diurnal emissions occurring in a park and ride lot rather than a downtown work site) is not treated.

Finally, reduced congestion resulting from TCMs or similar measures often makes driving more inviting, thus offsetting at least some of the gains. This phenomena, known as 'latent demand' is not covered in these methodologies although an initial approach developed for this study is included in Appendix A.

ORGANIZATION OF REPORT

This report contains general information about the mechanisms through which TCMs affect travel activity but focuses on actual analysis techniques and examples of how they are applied. Prior knowledge of TCMs is not necessary in order to use the methodologies. Except for introductory material and the chapter on TCM packages, each chapter covers an individual TCM and discusses how the TCM works and provides a summary of effects reported in the literature. Overall the report is organized as follows:

> Chapter 2 summarizes effects that are common to the TCMs, and characterizes important distinctions between direct and indirect TCM effects. Important considerations for use in TCM analysis are detailed, along with the relationship of such considerations to data requirements.
>
> Chapters 3 - 7 address the individual TCMs. Each chapter covers a single TCM, reviewing key effects noted in the literature, presenting the quantitative methodology to estimate the TCM's effects, and providing an example application of the methodology.
>
> Chapter 8 discusses TCM packages and presents a methodology for quantifying their effects, along with an example application.
>
> Appendix A includes a methodology for calculating increased travel due to speed increases resulting from TCMs; Appendix B contains technical information regarding the derivation of speed changes utilizing basic traffic flow theory; Appendix C presents a distribution of elasticities derived from MTC's travel forecasting model, and Appendix D presents considerations in using BURDEN and DTIM to calculate emission changes resulting from TCMs after calculating travel activity changes in the manner described in this report.

2 ISSUES AND DATA NEEDS COMMON TO TCM ANALYSES

INTRODUCTION

Transportation control measures are strategies for reducing vehicle activities. On-road motor vehicles contributed over 50% of CO and NO_x and close to 40% of ROG emissions in California in 1987 (ARB, 1990) and are an obvious target for controls aimed at improving California's air quality. Most current control efforts focus on reducing emissions from vehicles when they are being driven (i.e. more stringent tailpipe controls and requirements for reformulated or alternative fuels). As the limits of emission control technology are approached, efforts to limit or reduce vehicle activity become more attractive. There are literally hundreds of specific TCMs which may be implemented as part of a strategy to reduce vehicle activity. Some attempt to reduce the demand for vehicle use by making other modes such as walking, bicycling, transit, or carpooling more attractive. Others attempt to reduce demand by eliminating the need for some trips by instituting telecommuting or compressed work week programs. Still others reduce demand by making driving more expensive through such mechanisms as parking price increases or congestion pricing.

While there are many different types of TCMs, the ways in which they affect travel and emissions, and the data needed to evaluate these effects are very similar. An understanding of these mechanisms can provide a framework for quantifying TCM effects. This chapter provides an overview of TCMs effects on travel activity and emissions. There are also elements common to analysis approaches for quantifying TCM effects; these common elements are also discussed, partly to avoid repetition later, and partly to provide a conceptual framework for the detailed methodologies presented in chapters 3 - 8.

OVERVIEW OF TCM EFFECTS ON TRAVEL ACTIVITY

The methodologies developed in this study focus on quantifying how TCMs affect travel behavior. From an air quality perspective, TCM evaluations must quantify mobile source emission reductions associated with TCM-induced changes in "travel variables" such as trips, VMT, and speeds. Quantifying these changes in travel behavior is the most difficult challenge facing the TCM analyst. Once changes in travel variables are appropriately quantified, the motor vehicle emissions models EMFAC and BURDEN or

DTIM can be used to quantify emission changes. The main difficulty lies in correctly calculating the effects of TCMs on trips and/or VMT. Once changes and VMT changes have been calculated, the analyst may calculate the resulting speed changes as a function of the net VMT change.

Direct and Indirect Effects

The difficulties in quantifying travel activity changes relate to the multitude of effects any given TCM may produce. TCMs have both direct (or primary) and indirect (or secondary) effects. Direct effects are those which are intended to occur as a result of implementing a TCM; for example, a compressed work week program may be implemented to achieve the direct effect of reducing vehicle work trips. Indirect effects occur when individuals participating in a TCM, members of their household, or others change their travel behavior as a result of the direct effects of the TCM. For example, compressed work week workers may drive more on their days off, or members of their households may use the vehicle. If the direct effects are large enough to lower congestion, non-participants may choose to drive more because of increased roadway speeds. Direct effects of commonly implemented TCMs often result in reductions in work-related travel while indirect effects often result in increases in non-work-related travel, and changes in the timing and location of emissions. For example, a direct effect of adding an HOV lane may be to encourage more transit use and carpooling. An associated indirect effect may be to attract more travellers into the rush hours when the lanes may be used.

The key point is that each TCM has one or more direct effects and one or more associated indirect effects which are generally smaller than the direct effects but tend to offset the direct effects. The identification of direct and indirect effects provides guidance on what parts of the analysis to focus on. Indirect effects that cannot be quantified do not pose as significant an issue of concern as direct effects that cannot be quantified.

Each of the chapters on individual TCMs contains a discussion of the direct and indirect effects of the TCM and reports on evidence from the literature on the nature and magnitude of both types of changes. One may readily conceptualize direct and indirect effects for TCMs not included here by employing similar logic.

DATA REQUIREMENTS

The analytical approaches in this report require various data or estimates from transportation planning agencies and census documents. These data are usually very region-specific. Use of data for regions other than those under study can bias the results. The data requirements are driven by the way in which the methodologies address changes in travel behavior. This section summarizes important considerations for quantifying trip, VMT, and speed effects from TCMs, and details the relationship of these considerations to the data collection effort.

Trip Considerations

Net trip changes must reflect changes in work and non-work trips. Key considerations include:

1. The number or percent of new participants in a TCM.

2. The participants' previous mode of travel (for example, transit riders who choose to rideshare will not reduce trips).

3. The number of participants who travel first to a central pick-up point such as a park and ride lot. Mode of travel to the park and ride lot should also be noted; it is possible that the lot is close enough to some participants' homes to allow walking or bicycling.

4. The number of days per week of participation (few telecommuters or ridesharers do so all five days of every week).

5. The potential reduction in non-work trips by TCM participants who rideshare during the work-day as a result of not having a vehicle at the workplace. This benefit may be offset by an increase in the number of non-work trips taken during the weekend.

6. Net trip reductions for participants may be offset somewhat by trip increases by members of the participants' household, and by general nonparticipants. For example, household members may drive more in response to increased availability of a vehicle.

VMT Considerations

VMT changes are realized through two mechanisms: trip reductions and trip length changes. Key considerations include:

1. Average work trip lengths of participants and any unique attributes of participants; for example, work trip lengths for ridesharers may be longer than average.

2. Length of vehicle trips to intermediate sites, such as park and ride lots or bus stations.

3. Average non-work trip length.

4. Extra VMT due to picking up passengers for TCMs that encourage ridesharing.

Speed Considerations

Decreased VMT resulting from TCM implementation can result in increased average speeds. The approach for calculating speed changes is simple; multiply the percent change in VMT by the elasticity of speed with respect to volume (elasticity represents the percent change in a variable resulting from a percent change in another variable; for instance, a 1 percent decrease in VMT may result in a 0.75 percent increase in speed if the elasticity of speed with respect to volume is 0.75).

The user of the methodologies presented in this report should be aware that the calculation of speed changes is likely to be the most uncertain portion of the analysis. Most traffic planning estimates consist of a single average speed throughout a region or subregion of analysis for peak and off-peak periods. This may not be adequate for a TCM that affects surface streets and freeways differently given that different average speeds are typical of different roadways. The methodology as presented here does not consider such differences although it can be applied in a way that does if enough local data is available.

Potential Effects That Are Not Considered

A number of potential effects of TCMs are conceivable but are not addressed by the methodology presented here. They include the following:

Work habits. TCMs may lead to gains in productivity and/or less sick leave and employee turnover. In a study of Southern California Association of Governments (SCAG) employees, there was some evidence that telecommuting reduced the amount of time employees took off for trips to medical facilities (a couple of hours instead of an entire day or half day), and increased their ability to shift work to evening hours. Such changes may or may not change the number of trips to medical facilities, but may change their length.

Auto hold/purchase decisions. TCMs may affect vehicle purchase and sale patterns. Telecommuting may allow commuters to hold older vehicles longer, or telecommuters may sell a second or third household vehicle sooner than otherwise would be the case.

Employee residence location. Commuters may decide to move further from work as a result of TCMs such as ridesharing or telecommuting. For example, in a recent SCAG program at least one employee considered moving a longer distance due to telecommuting. Net effects depend on the results for all household members.

Employee mix. To the extent TCMs are perceived as an employee benefit, companies offering telecommuting may be able to attract more geographically remote workers than would otherwise be the case. Such workers, when they do commute to the worksite, will make longer trips than employees not telecommuting.

Employee office space location. Employers may make certain office location decisions due to telecommuting. For example, they may open satellite offices which would not be opened without telecommuters, or may open the offices in different locations. Depending on the types of trips these offices generate (delivery, work trips, midday meetings, etc.), the net effects may be positive or negative for VMT.

Other Considerations

TCM analysis methodologies need to incorporate feedback effects which tend to offset the benefits. For example, increased speeds along roadways tend to attract drivers, which results in increased VMT and trips, and decreased speeds. Such effects are not easily calculated by hand although they can be using a software package. An algorithm for addressing these effects is shown in Appendix A.

Relationship of Data Needs to TCM Considerations

The considerations detailed above are the basis for identifying the data required to conduct a TCM analysis. The data required falls into four basic categories: (1) TCM participants, (2) travel data, (3) TCM data, and (4) census data. As stated above, the use of region-specific data when possible minimizes the potential for biased results. TCM participant data is usually specified by the user of the methodology and/or the employer or agency implementing a TCM. Examples of such participant data are the number of new ridesharers, or the number of employees participating in a telecommuting program. TCM participant data can also be calculated with the methodologies for some cases. For example, the packaging methodology presented in chapter 8 describes how many participants will accrue for overlapping TCMs adopted together. The parking management methodology presented in chapter 5 also calculates the number of participants.

Travel data is gathered from local metropolitan planning organizations (MPOs), ridesharing agencies, and the department of transportation. Such data includes the number of vehicle work and non-work trips per day, the modes of travel (single occupant vehicles, carpools, transit, bicycling) for work and non-work trips, the distribution of work and non-work trips in peak and off-peak travel periods, average work and non-work trip distances, and average (or roadway specific) speeds for peak and off-peak periods (or by hour).

TCM data include items such as the average number of people per carpool, the fraction of carpoolers who use park and ride lots, the fraction of carpoolers who form new carpools, and frequency of participation in TCM programs. Most such data is collected from MPOs although some is also program specific and will be specified by the agency implementing a TCM or TCMs.

Some census data is also necessary, including the number of individuals of driving age, the number of people per household, employment rates, and the fraction of the population not owning a vehicle.

Data Used in Example Applications

The example applications presented in chapters 3 - 8 draw mostly from data and estimates for the San Francisco Bay Area made by the Metropolitan Transportation Commission (MTC), RIDES for Bay Area Commuters, and local census data. When necessary, data from studies performed for other areas or that is not specific to a particular region has been used. Each application assumes that 3 percent of the workforce is affected by each TCM. This assumption was used to facilitate comparisons of TCM effectiveness.

KEY EMISSIONS EFFECTS

This section summarizes how each component of motor vehicle emissions may be affected by TCMs.

Cold and Hot Start Emissions

Changes in cold and hot start emissions resulting from TCMS are proportional to changes in trips. The number of TCM participants and the number of days per week they participate are good indicators of changes in start emissions. This change should be offset by estimated changes in non-work trips.

The average speeds driven in hot and cold start modes may also change as will the relative proportions of trips taken in various operating modes. Conceptually this can change emissions; for a given trip, the number of miles driven in cold start mode as opposed to hot stabilized mode may change. The EMFAC7E motor vehicle emissions model currently does not model cold and hot start emissions in a way that allows explicit consideration of such changes.

Exhaust and Running Loss

Exhaust and running loss emissions would change due to a TCM's effects on VMT and trip speeds. A frequent "back of the envelope" approach to estimating TCM emission changes is to linearly link emissions with VMT. However, there are some serious flaws in such an approach. Assume, for example, that a telecommuter reduced his or her total work trip VMT from a 50-mile round-trip commute to a 5-mile round-trip commute to a nearby satellite work center (i.e., a 90 percent VMT reduction). A rough emissions reduction estimate that assumed emissions changes were proportional to VMT reductions would fail to account for the fact that trip end emissions from cold starts and hot soaks would continue to occur. Trip end emissions are a substantial fraction of the total emissions associated with shorter trips; merely linking estimated emissions reductions to VMT reductions would be a poor approximation of the resulting change. In addition, it is also important to consider any shifts in the timing of VMT since exhaust and running loss emissions can be temperature-sensitive.

Speed increases along affected roadways may also result in significant emissions benefits. Exhaust HC and CO emissions drop exponentially between speeds of zero to 20 mph and continue to drop rapidly between 20 and 58 mph, although at a slower rate. NOx emissions also decrease with higher speeds, although at a far slower rate than for HC and CO; more importantly, Nox emissions <u>increase</u> sharply at speeds above 55 mph; HC and CO emissions also rise substantially at higher speeds.

Running loss evaporative emissions also decrease with increasing speed, dropping from a high of approximately 0.95 grams per mile (at 95 degrees) when idling, to zero at approximately 48 mph.

Idle, Hot Soak, and Diurnal Emissions

Idle emissions will drop due to decreased trips and to increases in average roadway speeds. This effect is difficult to model since EMFAC7E does not explicitly calculate idle emissions. Hot soak emissions will change as a function of reduced trips. There will be some shift in the number of vehicles undergoing full and/or multi-day diurnal emission cycles. This shift can be significant but is difficult to model; currently assumed proportions of vehicles undergoing partial, full, and multi-day diurnal cycles are embedded in EMFAC7E.

Location/Time Shifts

Changes in geographic location of emissions can result from (1) trips being taken to satellite work centers instead of downtown areas, (2) changes in the location and timing of non-work trips, (3) changes in travel routes. Such spatial/temporal considerations are not addressed by the methodologies contained in this report.

Refueling Emissions

Refueling emissions may drop primarily due to decreased VMT.

Fleet-Specific Effects

Trip and VMT changes resulting from most TCMs will affect motorcycles, light duty autos, and light and medium duty trucks. They will likely not affect heavy duty trucks. Speed increases on freeways will be experienced by all portions of the vehicle fleet. Speed increases on surface streets may or may not affect all portions of the vehicle fleet (local roadway use restrictions for heavy duty truck travel will need to be considered).

3 AREAWIDE RIDESHARING

Areawide ridesharing is a TCM designed to increase vehicle occupancy during peak traffic periods. Common ridesharing mechanisms include carpools, vanpools, and subscription bus services. Implementation can be accompanied by regional ride-matching services to encourage car and vanpooling, tax incentives for employers sponsoring pooling programs, public information programs to promote ridesharing, removal of parking subsidies, or direct funding of private pools. Ridesharing programs are typically offered by regional rideshare agencies, employers, transportation management associations, and some cities and counties. Regional programs are carried out by state-supported agencies such as RIDES for Bay Area Commuters, or Commuter Computer in southern California. These services offer direct ridematching services as well as support to employer-based programs.

SUMMARY EFFECTS OF RIDESHARING ON TRAVEL

Table 3-1 summarizes the primary direct and indirect effects of ridesharing. Ridesharing directly affects vehicle activities by reducing vehicle work trips. Regional ridesharing programs can be especially effective in reducing lengthy as opposed to shorter trips. For example, the average trip length for persons placed in carpools through the San Francisco Bay Area RIDES program is approximately 50 miles (the majority of work trips in the Bay Area are 20 miles or less) (Burch, 1990).

Trips between home and work account for 20 to 25 percent of all trips and approximately 30 percent of VMT in many cities (ARB, 1990a). Because of the large proportion of VMT potentially affected, employer-based ridesharing programs have long been key components of efforts to reduce regional congestion and air pollution. In 1978 the EPA sponsored a study of the effects expected from 10 ridesharing scenarios. The study concluded that areawide carpool and vanpool programs aimed at over 40 percent of a city's workforce would result in a 1.5 percent decrease in regional VMT on weekdays (EPA, 1978). An evaluation of areawide ridesharing programs in 38 urban areas also performed in 1978 found reductions in annual work VMT ranging from .03 to 3.6 percent (Wagner and Gilbert, 1978).

More recently, the South Coast Air Quality Management District reported an average increase in vehicle occupancy from 1.22 to 1.3 for 71 employers affected by their

TABLE 3-1. Effects of ridesharing program.

Areawide Ridesharing	
Direct Effects	**Indirect Effects**
Trips: • The number of work trips (primarily by those with relatively longer commutes) will decrease for commuters who are picked up at home or are carpooled to a pickup location and who did not previously use mass transit. • For commuters who drive to a pickup location, the number of trip start and ends will be constant, but their location will change from the work site to the pickup site.	Trips: • Work-based non-work trips could decrease due to unavailability of autos at the work place. • Home-based non-work trips could increase due to increased availability of autos at home.
VMT: • Work-related VMT will decrease for commuters who were not previously utilizing mass transit. • VMT per work trip is expected to increase due to additional distance required to pick up passengers or distance required to travel to pickup location.	VMT: • Non-work VMT changes will occur if significant changes (increases or decreases) in non-work trips are observed. Speed: • Increases in occupants per vehicle and reductions in total vehicles will result in increases in speed during peak hour commutes.

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implementing the employer trip reduction ordinance (Regulation XV). The increased vehicle occupancy resulted in a reduction of 1,562 commute trips per week (out of a total of 20,083 before the programs were implemented) (SCAQMD, 1991). It should be noted that although the trip reduction ordinances rely heavily upon ridesharing to reduce trips, they also incorporate features such as alternative work schedules and telecommuting, so the reported trip reductions may not be due entirely to ridesharing. Another successful example is the Pro>Motion program in Pasadena (Pro>Motion is a package of TCMs designed to increase ridesharing): Pro>Motion reported an average increase in vehicle occupancy from 1.12 to 1.45 (ARB, 1990a).

The benefits of carpooling are not simply a function of the number of carpoolers. For example, if carpools are formed by people who used to use transit services, or switch from another carpool, vanpool, or cycling, little if any VMT reduction will result. Additionally, not all ridesharers carpool every day; for example one study (Wiersig, 1982) noted that approximately 16 percent of carpoolers carpool less than five days per week. Finally, carpoolers may drive out of their way in order to pick up passengers. This phenomenon, called "circuity," is thought to add approximately half a mile to the work trip (CSI, 1976).

The way in which employers implement ridesharing programs significantly affects the amount of ridesharing that results. Employers who actively promote ridesharing by providing personalized ride-matching services, a rideshare coordinator, parking subsidies for carpoolers, guaranteed rides home, and other measures have more successful ridesharing programs than employers who do not.

QUANTITATIVE METHODOLOGY FOR ESTIMATING RIDESHARING EFFECTS ON TRAVEL

Ridesharing Effects on Work Trips

A methodology to estimate the effect of ridesharing on trips is outlined below. The methodology breaks ridesharers into several groups, each of which has a different effect on trip making. The groups and their effects on trips are:

Group	Effect
Ridesharers who drive to park and ride lots or some other central location	Vehicle trips are unchanged; VMT is decreased
Ridesharers who are picked up at home or who travel to park and ride lots by walking or bicycling	Vehicle trips and VMT are reduced

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Ridesharers who do not drive to park and ride lots and join existing carpools	Every ridesharer in this group reduces vehicle trips
Ridesharers who do not drive to park and ride lots and form new carpools	On average, saves part of a vehicle trip; for new carpools, all but the driver reduce trips

Below several equations to use for calculating trip making effects for these groups are presented. Estimates for the number of individuals in each can be derived from local ridesharing surveys (for instance, the example application draws from the Bay Area RIDES program and from the National Ridesharing Demonstration Program).

Work Trips Reduced by Ridesharers Joining Existing Carpools

Work trips reduced by carpoolers who join existing carpools and also leave their vehicles at home are equal to:

$$WRKTRP_e = CARP \times P_e \times F_r/D \times 2 \qquad (3\text{-}1)$$

where

$WRKTRP_e$	=	Number of work trips eliminated (average reduction per day) by carpoolers joining existing carpools
CARP	=	Number of new carpoolers attracted by TCM
P_e	=	Percent of carpoolers who are picked up at home or who travel to a park and ride lot by some mode other than single occupant vehicle and who join existing carpools (in the San Francisco Bay Area approximately 33 percent).
F_r	=	Frequency per week of ridesharing (number of days)
D	=	Frequency per week of work (number of days).

Note: This equation does not consider prior mode; it is assumed here that "CARP" is made up of previous single occupant vehicle users. If this is not the case, simply divide "CARP" by the region's (or affected workforce's) average vehicle occupancy.

Work Trips Reduced by Ridesharers Forming New Carpools

The above equation assumes all ridesharers who do not drive to park and ride lots decrease trips. However, this is only true if new ridesharers join existing carpools.

Otherwise, the trip reduction effectiveness equals the number of new ridesharers − 1, for each new carpool; if three individuals form a carpool together, only two trips have been saved. Trip reductions by ridesharers who form new carpools can be represented as follows:

$$WRKTRP_n = \frac{CARP}{NCAR}(NCAR - 1) \times P_n \times F_r/D \times 2 \qquad (3\text{-}2)$$

where

$WRKTRP_n$	=	Number of work trips eliminated (average reduction per day) by carpoolers forming new carpools
CARP	=	Number of new carpoolers attracted by TCM
P_n	=	Percent of carpoolers who are picked up at home or who travel to a park and ride lot by some non-SOV mode and who join new carpools
NCAR	=	Average number of people per carpool (including vanpools)
$F_{r=}$	=	Frequency per week of ridesharing (number of days)
D	=	Frequency per week of work

which estimate average SOV work trips per day reduced by ridesharing.

Work Trip Increases by Ridesharer Household Members

There is also a possibility that vehicles left at home by ridesharers will be used by household members who were previously using transit or other non-SOV modes to travel to work. If household members use the vehicle for their work trips it will offset the benefits of ridesharing somewhat. This increase can be calculated as follows:

$$WRKTRP_{ih} = CARP\ (P_e + P_n) \times NOCAR \times DRVAGE \times (HSHLD - 1) \times EMPL \times F_r/D \times TRIPGEN_w \qquad (3\text{-}3)$$

where

$WRKTRP_{ih}$	=	Extra vehicle work trips made by ridesharer household members
CARP	=	Number of new carpoolers attracted by TCM
$(P_e + P_n)$	=	Percent of carpoolers who leave their vehicles at home
NOCAR	=	Percent of population not owning a vehicle
DRVAGE	=	Percent of population of driving age

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HSHLD = Average household size

EMPL = Percent of population that is employed

$TRIPGEN_w$ = Average number of SOV work trips demanded per person per day

Note that this equation represents the maximum potential increase as if all switch from previous mode (i.e., transit or ridesharing) to SOV.

The total work trip reduction from ridesharers will be referred to as $WRKTRP_r$, where

$$WRKTRP_r = WRKTRP_e + WRKTRP_n - WRKTRP_{ih} \tag{3-4}$$

Ridesharing Effects on Nonwork Trips

Changes in Non-Work Trips for Ridesharers

Work-to-work trips (such as travel to business meetings) are assumed to be unchanged; the need for single occupant vehicles for such purposes is implicit in the assumption that carpoolers will generally not carpool to work five days per week (due in part to needs for single occupant vehicles such as work-to-work trips). Further, many work-to-work trips are made by two or more employees together so that the probability of all employees in the group carpooling and not having their vehicles on the day of travel is small.

Work-to-other trips (such as running errands or going out to lunch) are also assumed to be unchanged. It is assumed the need for such trips will be reserved by ridesharers for days on which they do not carpool or in cases involving the need for a single occupant vehicle. Work-to-other trips not requiring single occupant vehicles can also be assumed to be unchanged since they can be scheduled on days when a ridesharer drives to work or can make use of vehicles used by non-participants. There is a possibility that ridesharing to work will encourage ridesharing for work-based non-work trips; however, this effect is likely to be fairly small, and a conservative estimate of trip reduction benefits can be calculated using the assumption that these trip types are unchanged.

Non-Work Trip Increases by Ridesharer Household Members

Non-work trips by members of the ridesharer's household may increase due to increased vehicle availability. Ridesharing provides vehicles to household members who previously did not have access to one when (1) ridesharers do not drive to a park and ride lot and (2) when household members of these ridesharers do not have their own vehicle. The equation describing trip increases for household members is

$$NONWRK_h = CARP\ (P_e + P_n) \times (HSHLD-1) \times DRVAGE \times NOCAR \times UNEMPL \times F_r/D \times TRIPGEN_h \quad (3\text{-}5)$$

where

$NONWRK_h$	=	Change in non-work trips (average per day) by ridesharer household members
CARP	=	Number of new carpoolers attracted by TCM
$(P_e + P_n)$	=	Percent of carpoolers who leave their vehicles at home
DRVAGE	=	Percent of population of driving age
UNEMPL	=	Percent of population that is unemployed
HSHLD	=	Average household size
NOCAR	=	Percent of population not owning a vehicle
$TRIPGEN_n$	=	Average non-work vehicle trips per day demanded (per person)

As for the work trip increases by household members, this equation represents the maximum increase. It is also conservative in another sense; taken together, Equations 3-3 and 3-5 could potentially double count increases although on average they do not.

Total Trip Reductions from Ridesharing

The total trip effect of a ridesharing program equals

$$TRPR_r = WRKTRP_r - NONWRK_h \quad (3\text{-}6)$$

Ridesharing Effects on VMT

Ridesharing will result in decreased work-trip VMT for all ridesharers and increased VMT associated with any increase in non-work trips. The decreased work trip VMT is a function of average work trip lengths for ridesharers who do not drive to park and ride lots, and a function of decreased work trip lengths for ridesharers who do drive to park and ride lots. Both decreases are related to the frequency of ridesharing.

VMT Reductions due to Work Trip Reductions

Decreased VMT for ridesharers who do not drive to park and ride lots is

$$\Delta VMT_t = WRKTRP_r \ x \ WRKDIST_r \tag{3-7}$$

where

ΔVMT_t	=	Change in VMT due to work trip reductions
$WRKTRP_r$	=	Average work trips per day reduced by ridesharers
$WRKDIST_r$	=	Average distance of work trips for ridesharers

VMT Reductions due to Trip Length Changes

Decreased VMT for ridesharers who do drive to park and ride lots is related to the difference between the distance of the work sites and the distance of park and ride lots. On days when these carpoolers rideshare, they reduce VMT by

$$\Delta VMT_{pe} = CARP \ x \ P_{pe} \ x \ (WRKDIST - LOTDIST) \ x \ 2 \ x \ F_r/D \tag{3-8}$$

where

ΔVMT_{pe}	=	Change in VMT due to decreased work trip lengths by ridesharers joining existing carpools
CARP	=	Number of new carpoolers attracted by TCM
P_{pe}	=	Percent of ridesharers who drive to park and ride lots and who join existing carpools
$WRKDIST_r$	=	Average distance to work for ridesharers
LOTDIST	=	Average distance to park and ride lots
F_r	=	Frequency of ridesharing (days per week)
D	=	Number of days per week worked

However, as discussed above, new carpools reduce VMT for all but the driver. VMT reductions for new carpools equal

$$\Delta VMT_{pn} = CARP \text{ x } P_{pn} \text{ x } (NCAR - 1)/NCAR \text{ x } (WRKDIST_r - LOTDIST) \text{ x } F_r/D \text{ x } 2 \tag{3-9}$$

where

ΔVMT_{pn}	=	Change in VMT due to decreased work trip lengths by ridesharers forming new carpools
CARP	=	Number of new carpoolers attracted by TCM
P_{pn}	=	Percent of new carpoolers who drive to park and ride lots and who form new carpools
NCAR	=	Number of people per carpool

Extra VMT associated with passenger pick-up must be added in. We assume this extra will be a function of the average distance to park and ride lots, from the freeway to the park and ride lot (generally located near off ramp) and the average distance out of the normal route to pick up passengers at home and should be added for each carpool. The extra is

$$\Delta VMT_x = CARP/NCAR \times CIRC \tag{3-10}$$

where

ΔVMT_x	=	Extra VMT associated with passenger pick-up
CIRC	=	Accounts for people who go out of their way to pick up other carpoolers.

Therefore, total work trip VMT saved equals

$$\Delta VMT_w = \Delta VMT_t + \Delta VMT_{pe} + \Delta VMT_{pn} - \Delta VMT_x - \Delta VMT_{ih} \tag{3-11}$$

Extra VMT due to Non-Work Trips

Extra VMT associated with non-work trips must also be added:

$$\Delta VMT_n = NONWRK_n \text{ x } NONDIST \tag{3-12}$$

where

ΔVMT_n	=	Increased VMT resulting from increased non-work trips

$NONWRK_n$	=	Additional non-work trips and
NONDIST	=	Average distance for non-work trips

Total VMT Reduction due to Ridesharing

The total daily VMT changes associated with ridesharing equal

$$\Delta VMT = \Delta VMT_w + \Delta VMT_n \qquad (3\text{-}13)$$

Ridesharing Effects on Speeds

The change in speeds associated with VMT decreases can be calculated using elasticities of speed with respect to volume. The derivation of the relationships among vehicle flow, density, and speed is described in Appendix A. Work-related VMT changes should be allocated between peak and non-peak hours in proportion to the proportion of trips occurring in these hours (equations below show how to do this).

Speed changes caused by non-work-related changes are assumed to be negligible since they are small, are also spread throughout the region, and because most occur during less congested periods.

The peak period VMT change is equal to the change in VMT multiplied by the ratio of peak work trip VMT and total work trip VMT minus the peak period non-work VMT.

$$\Delta VMT_p = \left[\Delta VMT_w \times \frac{VMT_{pw}}{VMT_w}\right] - \left[\Delta VMT_n \times \frac{VMT_{pn}}{VMT_n}\right] \qquad (3\text{-}14)$$

where

ΔVMT_p	=	Change in peak work VMT (miles per day)
ΔVMT_w	=	Change in work VMT
VMT_{pw}	=	Work trip VMT during peak hours (base)
VMT_w	=	Total work trip VMT (base)
ΔVMT_n	=	Change in non-work VMT (miles per day)
VMT_{pn}	=	Non-work VMT during peak hours (base)
VMT_n	=	Total non-work trip VMT (base)

Change in peak speeds (in percent) =

$$\Delta SPD_p = \Delta VMT_p / VMT_p \times \epsilon_s \tag{3-15}$$

where

ΔSPD_p	=	Percent change in speed
ϵ_s	=	Elasticity of peak speed with respect to volume
VMT_p	=	Total VMT in peak period

The change in off-peak speeds is calculated in a similar fashion except that the ratio of off-peak VMT to total VMT is used in place of peak to total.

EXAMPLE APPLICATION OF RIDESHARING METHODOLOGY

Below an example of how to apply the ridesharing methodology is presented. Each equation is represented separately on a page with all variables summarized in a table so that the units, information sources, and the relationships between the variables can be more clearly understood. As discussed, not all equations can be calculated because this methodology is intended to show the elements that are necessary for a complete analysis and to identify necessary factors that are not yet available.

Ridesharing Effects on Work Trips

Work Trips Reduced by Ridesharers Joining Existing Carpools

$$WRKTRP_e = CARP \times P_e \times \frac{F}{D} \times 2$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_e$	Number of work trips eliminated by carpoolers joining existing carpools	Calculated by methodology	35,656
CARP	Number of new carpoolers	User enters. We assume 3% of the workforce (3,001,367). This is close to the increase in ridesharing between 1980 and 1987 documented by MTC (111,084)	90,041
P_e	Percent of carpoolers that join **existing** pools and who are picked up at home or who travel to park and ride lot by non-SOV mode	(a) % of carpoolers joining existing pools (UMTA, 1985) (35%) (b) % using park and ride lots (RIDES, 1990) (18.7%) (c) % of (b) not using SOV to travel to park and ride lot (71.5%) (d) % of ridesharers not using park and ride lots (81.3%) Pe = a x ((b x c) + d)	33% (0.33)
F_r	Frequency per week of ridesharing	User input	3
D	Frequency per week of work	User input	5

$$WRKTRP_e = (90{,}041) \times (0.33) \times (0.6) \times 2$$

$$WRKTRP_e = 35{,}656$$

Work Trips Reduced by Ridesharers Forming New Carpools

Most (about 62 percent) of ridesharers form new carpools when they begin ridesharing (Maltzman, 1987). This becomes a key consideration when calculating the number of work trips that are reduced; when a new carpool is formed, one ridesharer is still making a work trip and it is important not to count this trip as one of those saved by a ridesharing program. Work trip savings from ridesharers forming new carpools is calculated as shown below.

$$WRKTRP_n = \frac{CARP}{NCAR}(NCAR-1) \times P_n \times \frac{F_r}{D} \times 2$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_n$	Number of work trips eliminated by carpoolers forming new carpools	Calculated by methodology	37,609
P_n	Percent of carpoolers who form new pools and who either are picked up at home or travel to park and ride lot via non-SOV mode	(a) % of ridesharers who form new carpools (UMTA, 1985) (65%) (b) % using park and ride lots (RIDES, 1990) (c) % of (b) not using SOV to travel to park and ride lots (d) % of ridesharers not using park and ride lots (81.3%)	62% (0.62)
NCAR	Average number of people per carpool (including vanpools)	Weighted average of average number of people in both 2+ and 3+ carpools (MTC, 1991)	2.28

$$WRKTRP_n = \frac{90{,}041}{2.28}(2.28-1) \times (0.62) \times (0.6) \times 2$$

$$WRKTRP_n = 37{,}609$$

Work Trip Increases by Ridesharer Household Members

The vehicles left at home by ridesharers who are picked up at home (as opposed to driving to park and ride lots) are available to household members who may previously have been ridesharing or using transit. An increase in SOV work trips is possible if household members who previously used transit or ridesharing choose to drive the vehicle rather than use their previous travel mode.

$$WRKTRP_{ih} = CARP(P_e + P_n) \times NOCAR \times DRVAGE \times (HSHLD - 1) \times EMPL \times \frac{F_r}{D} \times TRIPGEN_w$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_{ih}$	Potential new SOV work trips made by ridesharer household members	Calculated by methodology	7,224
NOCAR	Percent population not owning a vehicle	Percent of work trips made via transit mode (MTC, 1991) (see note in introductory text)	13%
DRVAGE	Percent of population of driving age	Regional population over 16 (USDOC, 1988)	77.1%
HSHLD	Average household size	Regional average (MTC, 1990)	2.56
EMPL	Percent of population that is employed	(a) Total population (regional) (MTC, 1991) (b) Number of employed residents (MTC, 1991) (c) Percent of total population over 16 years (USDOC, 1988)	52.8% (0.528)
$TRIPGEN_w$	Average number of SOV work trips demanded per person per day	(a) Number of vehicle work trips per day (MTC, 1991) (b) Working population over age 16 (total over 16 times EMPL) (MTC, 1991; USDOC, 1988)	1.705

$$WRKTRP_{ih} = 90{,}041 \times (0.33 + 0.62) \times (0.13 \times 0.771) \times (2.56 - 1) \times (0.528) \times (0.6) \times 1.705$$

$$WRKTRP_{ih} = 7{,}224$$

Total Work Trip Reduction from Ridesharers

$$WRKTRP_r = WRKTRP_e + WRKTRP_n - WRKTRP_{ih}$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_r$	Total work trip reduction by ridesharing	Calculated	66,041
$WRKTRP_e$	Work trips reduced by ridesharers joining existing carpools	Calculated	35,656
$WRKTRP_n$	Work trips reduced by ridesharers forming new carpools	Calculated	37,609
$WRKTRP_{ih}$	Potential new SOV work trips made by ridesharer household members	Calculated	7,224

$$WRKTRP_r = 35{,}656 + 37{,}609 - 7{,}224$$

$$WRKTRP_r = 66{,}041$$

This value accounts for most of the trip effects caused by a ridesharing program. In the San Francisco Bay Area, approximately 2,608,928 SOV work trips are made per day. The decrease calculated above translates to a 2.5 percent decrease in vehicle work trips resulting when 3 percent of the workforce participates in a ridesharing program (note that the change calculated depends heavily upon the frequency of ridesharing, the number of ridesharers who join existing versus new carpools, the number of people in each carpool, and whether some of the carpoolers used to use transit or other shared modes (see note following Equation 3-1), all of which may be different in other study areas from those used here).

Calculation of Non-Work Trip Increases by Ridesharer Household Members

$$NONWRK_h = CARP(P_e + P_n) \times (HSHLD-1) \times DRVAGE \times NOCAR \times UNEMPL \times F_fD \times TRIPGEN_h$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$NONWRK_h$	Non-work trip increases for ridesharer household members	Calculated	9,262
P_e	New ridesharers joining **existing** carpools and who do not use SOV to travel to park and ride lots (%)	See Equation 3-1	33% (0.33)
P_n	New ridesharers who form **new** carpools and do not use SOV to travel to park and ride lots (%)	See Equation 3-2	62% (0.62)
HSHLD	Average household size	Regional (MTC, 1991)	2.56
DRVAGE	Percent of population of driving age	Regional population over age 16 (%) (USDOC, 1988)	77.1% (0.771)
NOCAR	Percent of population that does not own a car	(USDOC, 1988)	13% (0.13)
UNEMPL	Percent of population that is unemployed	100% minus EMPL (MTC, 1991)	32% (0.32)
$TRIPGEN_n$	Average non-work SOV trips demanded per person per day	Total number of "auto" non-work trips per day (MTC, 1991) divided by total population over age 16 (USDOC, 1988)	2.92

$$NONWRK_h = 111{,}084(0.33 + 0.62) \times (2.56 - 1) \times (0.77) \times (0.13) \times (0.32) \times (0.6) \times (2.92)$$

$$NONWRK_h = 9{,}262$$

Total Trip Effect of a Ridesharing Program

The total vehicle trip reduction from the ridesharing program is equal to the work trip decreases minus the non-work trip increases by ridesharer household members:

$$TRPR_r = WRKTRP_R - NONWRK_h$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$TRPR_r$	Total trip effect of a ridesharing program	Calculated	56,779
$WRKTRP_R$	Total work trip reduction from ridesharers	Calculated	66,041
$NONWRK_h$	Change in non-work trips by ridesharer household members	Calculated	9,262

$$TRPR_r = 66{,}041 - 9{,}262$$

$$TRPR_r = 56{,}779$$

As a point of reference, this value is significantly higher than that calculated using the recent TCM methodology developed for SANDAG (Sierra, 1991). Using the same inputs for the number of person commute trips, percent increase in non-drive-alone modes, the percent of work trips made by non-SOV modes, and the number of people per carpool, the SANDAG methodology calculates approximately 19,818 trips reduced. It appears that their methodology is tied to the existing mode share by multiplying the number of ridesharers by the number of non-SOV work trips.

Ridesharing Effects on VMT

Ridesharing effects on VMT are relatively simple to calculate once the trip changes have been calculated. VMT saved from reduced trips is calculated by multiplying the number of reduced trips by the VMT associated with them. VMT saved by ridesharers who drive to park and ride lots rather than being picked up at home is calculated according to the difference between the distance to park and ride lots and the distance to work for ridesharers. The following pages illustrate how to calculate each of these VMT changes.

Decreased VMT for Ridesharers Who Do Not Drive to Park and Ride Lots

$$\Delta VMT_t = WRKTRP_r \times WRKDIST_r$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_r$	Average trips per day reduced by ridesharers	Calculated	56,779
$WRKDIST_r$	Average distance of work trips for ridesharers	Average commute distance for carpools (RIDES, 1990) (one-way)	27 miles

$$\Delta VMT_h = 56{,}779 \times 27$$

$$\Delta VMT_h = 1{,}533{,}033$$

Decreased VMT for Ridesharers Who Drive to Park and Ride Lots and Join Existing Pools

$$\Delta VMT_{pe} = CARP \times P_{pe} \times (WRKDIST-LOTDIST) \times 2 \times \frac{F_r}{D}$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
CARP	Number of new ridesharers	User input	90,041
P_{pe}	Percent of ridesharers who drive to park and ride lots and who join existing carpools	CARP times (a) percent of carpoolers joining existing pools (UMTA, 1985), times (b) percent using park and ride lots (RIDES, 1990), times (c) % who use SOVs to travel to lots (Maltzman, 1987). Then divide by CARP	2% (0.02)
$WRKDIST_r$	Average distance to work for ridesharers (one-way)	Regional average one-way distance for carpools (RIDES, 1990)	27 miles

LOTDIST	Average round-trip distance to park and ride lots	Average distribution of values presented by Maltzman (Maltzman, 1987)	5.56 miles

$$\Delta VMT_{pe} = 90{,}041 \times (0.02) \times (27 - 2.78) \times 2 \times (0.6)$$

$$\Delta VMT_{pe} = 52{,}339$$

<u>VMT Reductions for New Carpoolers Who Form New Carpools and Drive to Park and Ride Lots</u>

$$\Delta VMT_{pn} = CARP \times P_{pn} \times (NCAR - 1)/NCAR \times (WRKDIST_r - LOTDIST) \times \frac{F_r}{D}$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
P_{pn}	Percent of ridesharers who drive to park and ride lots and who form new carpools	CARP times (a) % of ridesharers joining new carpools (UMTA, 1985), times (b) % of ridesharers using park and ride lots (RIDES, 1990), times (c) % of (b) using SOVs to travel to lots (Maltzman, 1987). Then divide by CARP.	3% (0.03)
NCAR	Average number of people per carpool	Weighted average of both 2+ and 3+ carpool average occupancies (MTC, 1991)	2.28

$$\Delta VMT_{pn} = 90{,}041 \times (0.03) \times \frac{(2.28-1)}{(2.28)} \times (27 - 2.78) \times (2) \times (0.6)$$

$$\Delta VMT_{pn} = 44{,}075$$

Consideration of Additional VMT from Picking Up Passengers

$$\Delta VMT_x = CARP/NCAR \times CIRC$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
CIRC	Average round-trip distance to park and ride lot from freeway and/or from freeway to ridesharers' homes	User input	2 miles

$$\Delta VMT_x = \frac{90{,}041}{2.28} \times 2$$

$$\Delta VMT_x = 78{,}983$$

Total Work Trip VMT Saved

$$\Delta VMT_w = \Delta VMT_t + \Delta VMT_{pe} + \Delta VMT_{pn} - \Delta VMT_x$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_t	Decreased VMT for ridesharers who do not drive to park and ride lots	Calculated	1,533,033
ΔVMT_{pe}	Decreased VMT for ridesharers who **do** drive to park and ride lots	Calculated	52,339
ΔVMT_{pn}	VMT reductions for new carpools	Calculated	44,075
ΔVMT_x	Extra VMT from picking up passengers	Calculated	78,983

$$\Delta VMT_w = 1{,}533{,}033 + 52{,}339 + 44{,}075 - 78{,}893$$

$$\Delta VMT_w = 1{,}550{,}554$$

VMT from Non-Work Trips

$$\Delta VMT_n = NONWRK_n \times NONDIST$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$NONWRK_n$	Additional non-work trips	Calculated	9,262
NONDIST	Average trip distance for non-work SOV trips	Regional weighted average for "auto" mode (MTC, 1991)	5.32 miles

$$\Delta VMT_n = 9{,}262 \times 5.32$$

$$\Delta VMT_n = 49{,}274$$

Ridesharing Effects on Speeds

Peak Period Changes

$$\Delta VMT_p = (\Delta VMT_w \times PCT_{pw}) - (\Delta VMT_n \times PCT_{pn})$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_p	Change in peak work VMT	Calculated	928,546
ΔVMT_w	Change in work VMT	Calculated	550,554
ΔVMT_n	Change in non-work VMT	Calculated	49,274
PCT_{pn}	Percent of non-work travel occurring during peak hours	% non-work trips in the peak hours (Sierra, 1991)	28.8% (0.288)
PCT_{pw}	Percent of work trips occurring in peak hours	% of work trips during peak period (Sierra, 1991)	60.8% (0.608)

$$\Delta VMT_p = (1{,}550{,}554 \times 0.608) - (49{,}274 \times 0.288)$$

$$\Delta VMT_p = 928{,}546$$

Change in Peak Speeds (in percent)

$$\Delta SPD_p = \frac{\Delta VMT_p}{(VMT_w \times PCT_{pw}) + (VMT_n \times PCT_{pn})} \times \epsilon_s$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ϵ_s	Elasticity of peak speed with respect to volume	(Sierra, 1991)	-0.75
VMT_w	Total work trip VMT	Total daily VMT for work trips (MTC, 1990)	36,081,814
VMT_n	Total non-work trip VMT	Total daily VMT for non-work trips (MTC, 1990)	40,728,600
VMT_b (the denominator in the above equation)	Total VMT in peak periods	Calculated	33,667,580
ΔVMT_p	Change in peak VMT	Calculated	928,546

$$\Delta SPD_p = \frac{928{,}546}{(36{,}081{,}814 \times (0.608)) + (40{,}728{,}600 \times (0.288))} \times (-0.75)$$

$$\Delta SPD_p = -0.02 = 2\%$$

4 TELECOMMUTING

Telecommuting eliminates or reduces home-to-work trips by encouraging employees to work at home or work at satellite office centers. Employees may be linked to the workplace by computer and modem, or may simply take work home. Telecommuting employees usually work at home one or more days per week. Related options include allowing employees to use satellite work centers (run by single employers) or neighborhood work centers (run by multiple employers).

Telecommuting potentially affects employers, employees and employee household members. Each party may alter travel patterns as a result of telecommuting. Travel may be affected directly or indirectly depending on to what extent telecommuting affects work and non-work trips, employee and employer location decisions, types of vehicles purchased for commuting and the mode choice of affected parties. For example, a direct effect may be a reduction in work-related VMT, while an associated indirect effect may be increased non-work trips because vehicles are left at home more often. Primary direct and indirect effects are summarized in Table 4-1.

SUMMARY EFFECTS OF TELECOMMUTING ON TRAVEL

Potential direct effects include a reduction in the number and length of work trips and possible switches in travel modes. These effects are largely dependent on policies set by employers regarding when and how often telecommuting may be used as an option. Further, employers must tailor their policies to the nature of their work force; some businesses lend themselves to telecommuting much better than others (e.g., firefighters or retail workers may not be able to telecommute, but computer scientists or accountants might).

Telecommuting potentially reduces the number of work trips as commuters work at home. For satellite center workers, trip length may be reduced, or the mode of travel may change. These changes can be significant; in a test among employees at the Southern California Association of Governments (SCAG), telecommuting reduced net person trips by 46 miles per telecommute occasion. Overall benefits were savings of 31 miles per telecommute occasion after accounting for the fact that some of the telecommuters previously commuted to work in carpools or by transit (SCAG, 1988). In preliminary findings among State of California telecommuters participating in the

TABLE 4-1. Effects of telecommuting.

Telecommuting	
Direct Effects	**Indirect Effects**
Trips: • For commuters opting to work at home, the number of work trips will decrease proportional to the number of days working at home if the telecommuter was previously a single occupant driver. • For satellite center workers, the number of work trip starts and ends will remain constant (assuming the commuter was previously a single occupant driver), but their locations will change from the work site to nearby satellite centers.	Trips: • Work trips by non-telecommuters could increase due to disruption of rideshare programs by telecommuters, causing an increase in solo occupant vehicles (synergistic). • Work trips by satellite center workers could decrease if the net mode change is from single occupant driver to walking or bicycling. • Non-work trips by telecommuters could increase due to ability to leave home freely; however, initial data show that overall household non-work trips decrease in telecommuting situations.
VMT: • For commuters opting to work at home, work-related VMT will decrease proportional to the number of days working at home if the telecommuter was previously a single occupant driver. • Work related VMT for satellite center workers will decrease due to a shorter distance to the satellite center compared to the work site if the commuter was not previously using carpooling or mass transit.	VMT: • Work-related VMT by non-telecommuters could increase due to disruption of rideshare programs by telecommuters, causing an increase in solo occupant vehicles. • Work-related VMT by satellite center workers could be further decreased if the net mode change is from single occupant driver to walking or bicycling. • Non-work VMT changes will occur if significant changes (increases or decreases) in non-work trips are observed.
	Speed: • Reductions in total vehicles on the road during peak hours will result in increases in speed during the peak hours.

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California Telecommute Pilot Project, work trip rates decreased 30 percent (from 0.9 to 0.63 trips per day). In the project, workers telecommuted one to two days per week (Kitamura et al., 1989). A recent evaluation of the State of Hawaii telecommute demonstration project documented fuel savings of 29 percent (from 18 to 12.7 gallons) (Hawaii DOT, 1990).

The volume and timing of vehicle work trips by telecommuters is dependent on employer telecommuting policies. The number of employees eligible to participate in a telecommuting program, the extent of encouragement to participate, the frequency of telecommuting (e.g., one day per week, two day per week, etc.) and which days of the week will be allowed all strongly affect the amount of travel activity. The characteristics of the regional workforce also affect telecommuting. Information industries such as accounting, data processing or reporting are more likely candidates for successful telecommunication programs than the construction, production or retail industries. California may be well suited to telecommuting since information workers constitute almost 60 percent of the work force (Kitamura et al., 1989).

A key indirect effect on work trips is the possibility of changes in travel mode. The benefits of telecommuting programs may be partly offset by the break-up of carpools, or the attraction of transit riders to single occupant vehicles. In a study of SCAG employees, 19 percent shared a ride prior to participating in the telecommuting program (SCAG, 1988). Three potential effects from this kind of mode switching are (1) the telecommuting program does not reduce work trip VMT for carpoolers who telecommute on days they normally would have carpooled, (2) overall VMT by telecommuters may increase if they stop carpooling altogether, and (3) some carpools may terminate due to lack of participation. Positive mode switching may also result. For example, telecommuters who commute to satellite work centers may be able to walk or bicycle or more easily take transit. They may also be able to rideshare to the site more easily.

Telecommuting may either reduce or increase non-work trips taken by participating employees or members of their households. The study of SCAG employees showed a small increase in non-work trips due to telecommuting. In the worst case, vehicle miles created were 14 percent of the miles saved. Thus, instead of 31 miles of travel saved per telecommute, only 26 miles were saved. Preliminary findings from the study of California state employees involved in telecommuting showed no increase in non-work trips by telecommuters compared to controls (Kitamura et al., 1989b). Furthermore, there was a reduction in non-work trips for other household members. Person trips per day for non-work trips fell from 3.6 to 2.3, a 35 percent drop. In this one experiment, it seems telecommuting favorably influenced overall household trip making.

QUANTITATIVE METHODOLOGY FOR ESTIMATING EFFECTS OF TELECOMMUTING ON TRAVEL

Work Trip Reductions from Telecommuting

The approach for estimating work trip changes is to look at the number of people telecommuting and the number of days per week they telecommute, and using these values to calculate the change in work trips:

$$WRKTRP_b = TEL/AVO \times P_h \times F_t/D \times 2 \qquad (4\text{-}1)$$

where

$WRKTRP_b$	=	Basic change in work trips (average per day) eliminated by telecommuters
TEL	=	Number of new telecommuters attracted by TCM
AVO	=	Average vehicle occupancy (before TCM implementation)
P_h	=	Percent of telecommuters who work from home rather than from satellite centers
F_t	=	Average frequency per week of telecommuting
D	=	Average frequency per week of work

The number of telecommuters is divided by the average vehicle occupancy to account for cases where transit users or ridesharers begin telecommuting; such individuals do not reduce trips.

Vehicle Work Trip Increases by Telecommuter Household Members

Equation 3-3 can be used to calculate this increase. Simply substitute the term "TEL/AVO" for "CARP (P_e + P_n)".

Vehicle Work Trip Increases by Telecommuters

Telecommuters also save time and out-of-pocket costs on days they telecommute. This increase in travel budget may provide incentive to switch from non-SOV to SOV modes on non-telecommuting days. This potential increase, $WRKTRP_m$, can be calculated as

$$WRKTRP_m = TEL \times F_t/D \times TRIPs \times NOSOV_w(C_0 - C_1)/C_0 \qquad (4\text{-}2)$$

where

$WRKTRP_m$	=	Average daily increase in work trips from mode shifting by telecommuters
TEL	=	Number of new telecommuters attracted by TCM
F_t	=	Frequency of telecommuting (days per week)
D	=	Frequency of work
TRIPS	=	Total number of work trips per day in study region via non-SOV mode
NOSOV	=	Percent of population using non-SOV modes for work travel
C_0	=	Base weekly travel costs for an SOV work trip (out-of-pocket + time costs evaluated at average hourly wage rate for study region)
C_1	=	Weekly travel costs when telecommuting

The total change in work trips calculated by our methodology is then

$$WRKTRP_t = WRKTRP_b - WRKTRP_{th} - WRKTRP_m \tag{4-3}$$

Telecommuting Effects on Non-Work Trips

Changes in non-work trips are possible for telecommuters, members of their households, and all other nonparticipants. The largest potential change is assumed to be for telecommuters since they experience a relatively large change in travel budget (e.g., they are saving time and out-of-pocket costs for each day they telecommute).

Telecommuter Non-Work Trip Changes

Two options for estimating non-work trip increases for telecommuters are (1) assume their demand for non-work trips is being met prior to the telecommute program and (2) assume their demand for non-work trips prior to telecommuting is not being met (e.g., they have latent demand) and that they will use their increased travel budget (more time, fewer out-of-pocket costs) to meet their latent demand for non-work trips. It is assumed based on some evidence in the literature that there is latent demand. Elasticities of trip demand with respect to cost are used to calculate a change in non-work trips. Therefore, for telecommuters, the change in non-work trips is equal to:

$$NONWRK_t = TEL \times \epsilon_n \times (C_0 - C_1)/C_0 \times F_t/D \times TRIPGEN_n \quad (4\text{-}4)$$

where

$NONWRK_t$	=	Average daily change in non-work trips for telecommuters
ϵ_n	=	Elasticity of non-work trip demand with respect to a percent change in cost
C_0	=	Base commute costs before telecommuting program (function of telecommuters' average distances and travel times to work and average out-of-pocket costs per mile of travel)
C_1	=	Commute costs after telecommuting program for telecommuters (function of above plus the average number of days per week of telecommuting, average distances, and times to satellite centers, etc.)
$TRIPGEN_n$	=	Base SOV non-work trip generation rate per person per day

Changes in Non-Work Trips for Unemployed Members of Telecommuters' Households

As mentioned above, there also may be an increase in non-work travel by members of telecommuters' households. This increase will be a function of the number of household members who do not work and do not have a vehicle of their own and can be calculated using Equation 3-5. (Substitute "TEL" for "CARP (P_e + P_n)".)

Then the total non-work trip increase equals

$$NONWRK_i = NONWRK_t + NONWRK_h \quad (4\text{-}5)$$

and the total trip change caused by telecommuting is

$$TRPR_t = WRKTRP_t - NONWRK_i$$

Telecommuting Effects on VMT

Telecommuting will result in a net decrease in VMT for telecommuters and possibly some increased VMT for members of telecommuter's households. The decreased VMT is a function of average work trip length for telecommuters who work from home, and a function of the difference between the average work trip lengths and average distances to satellite work centers for telecommuters who work from satellite centers.

Decreased Work Trip VMT

Decreased work trip VMT for telecommuters who work from home is equal to

$$\Delta VMT_w = WRKTRP_t \times WRKDIST_a \tag{4-6}$$

where

ΔVMT_t	=	Change in work trip VMT for home telecommuters
$WRKDIST_a$	=	Average work trip distance in study region
$WRKTRP_t$	=	Net work trip reduction from telecommuters

Decrease in VMT for Satellite Center Workers

$$\Delta VMT_s = TEL_s \times (WRKDIST_a - SATDIST) \times F_t/D \times 2 \tag{4-7}$$

where

TEL_s	=	Number of new telecommuters who work from satellite work centers
$WRKDIST_a$	=	Average work trip distance
SATDIST	=	Average distance to satellite centers

Increase in VMT for Household Members

$$\Delta VMT_{ih} = WRKTRP_{ih} \times WRKDIST_a \tag{4-8}$$

Increase in VMT due to Non-Work Trip Increases

Any increase in non-work trips will increase VMT somewhat; this increase is simply:

$$\Delta VMT_n = NONWRK_i \times NONDIST \tag{4-9}$$

where

ΔVMT_n	=	Change in non-work trip VMT
NONDIST	=	Average non-work trip distance

The total change in VMT is equal to

$$\Delta VMT = \Delta VMT_w + \Delta VMT_n \quad (4\text{-}10)$$

Ideally VMT changes should be calculated for each hour of the day; at a minimum changes in peak and off-peak hours should be calculated. This is accomplished as described in Chapter 3 using Equation 3-14.

Telecommuting Effects on Speeds

Use Equation 3-15 to estimate the percent change in speeds.

As with trips, to additionally allocate changes between weekday and weekend VMT, the proportion of travel occurring in these periods can be used to proportion the changes (e.g., if 25 percent of work travel occurs on weekends, then 25 percent of trip and VMT changes can be assumed to occur on weekends.

EXAMPLE APPLICATION OF TELECOMMUTING METHODOLOGY

An example of how to apply the telecommuting methodology is presented below. The structure is similar to that shown for ridesharing; work trip and non-work trip effects are calculated, then VMT changes resulting from trip effects, and then the resulting speed changes.

Telecommuting Effects on Work Trips

$$WRKTRP_b = TEL/AVO \times P_h \times F/D \times 2$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_b$	Basic change in work trips eliminated by telecommuters	Calculated	62,693
TEL	Number of telecommuters	User input (we assume 3% of working residents) (MTC, 1991)	90,041
AVO	Average vehicle occupancy	For work trips (entire region) (MTC, 1991)	1.126

P_h	Percent of telecommuters who work from home rather than from satellite centers	User input (we used telecommuting pilot projects (WSEO, 1989; SCAG, 1988)	98% (0.98)
F_t	Average frequency per week of telecommuting	User defined based upon telecommuting literature (WSEO, 1989; SCAG, 1988))	2.0
D	Average frequency per week of work	User assumption	5.0

$$WRKTRP_b = \frac{90{,}041}{1.126} \times (0.98) \times (0.4) \times 2$$

$$WRKTRP_b = 62{,}693$$

Here telecommuting has a slightly smaller effect than ridesharing did in the example application; ridesharing is assumed to be more frequent than telecommuting. Additionally, some telecommuters are assumed to be transit users or ridesharers whereas all ridesharers were assumed to be SOV users in the example application.

Work Trip Changes for Members of Telecommuters' Households

$$WRKTRP_{ih} = TEL/AVO \times NOCAR \times DRVAGE \times (HSHLD - 1) \times EMPL \times F_t/D \times TRIPGEN_w$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_{ih}$	Extra vehicle work trips made by telecommuter household members due to increased vehicle availability	Calculated	4,502
NOCAR	Percent of not owning a vehicle	USDOC, 1988	13%
HSHLD	Average household size	Regional average (MTC, 1990a)	2.56
TEL/AVO	Number of telecommuters in the population divided by AVO	User defined	79,965

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DRVAGE	Percent of population over 16 years of age	Percent of regional population over age 16 (USDOC, 1988)	77.1%
EMPL	Percent of population that is employed	(a) Total employed residents (MTC, 1991), divided by (b) Total regional population (MTC, 1991)	53% (0.53)
$TRIPGEN_w$	Average SOV work trips per day demanded per person	(a) Number of work trips per day (MTC, 1991), (b) Working population over age 16 (Total working population times EMPL) (MTC, 1991; USDOC, 1988)	1.705

$$WRKTRP_{ih} = 79{,}965 \times (0.13) \times (2.56 - 1) \times (0.771) \times (0.528) \times (0.4) \times 1.705$$

$$WRKTRP_{ih} = 4{,}502$$

Entire Change in Vehicle Work Trips

NOTE: Item in bracket is omitted due to lack of appropriate data.

$$WRKTRP_t = WRKTRP_b - WRKTRP_{ih} - [WRKTRP_i]$$

(Telecommuting Summary Equation 1)

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_t$	Entire change in work trips due to telecommuting	Calculated	58,191
$WRKTRP_b$	Basic change in work trips eliminated by telecommuters	Calculated	62,693
$WRKTRP_{ih}$	Extra vehicle work trips made by telecommuter household members due to increased vehicle availability	Calculated	4,502

[$WRKTRP_i$]	Extra SOV vehicle work trips made by telecommuters due to mode switching	Data unavailable	Not calculated in this example
[$WRKTRP_m$]	Average daily increase in work trips from mode shifting by telecommuters	Data unavailable	Not calculated in this example

$$WRKTRP_t = 62{,}693 - 4{,}502$$

$$WRKTRP_t = 58{,}191$$

Again, note that this value is similar in magnitude to the net work trip effect of ridesharing (66,011). It is somewhat smaller due to the differing frequencies of ridesharing and telecommuting; however, it is not proportionately smaller because all <u>home</u> telecommuters save work trips, whereas a smaller proportion of ridesharers do (since some drive to park and ride lots, and some must still drive the other carpoolers).

<u>Telecommuter Non-Work Trip Changes</u>

$$NONWRK_t = TEL \times \epsilon_n \times (C_0 - C_1)/C_0 \times F_t/D \times TRIPGEN_n/AVO_n \times 0.5$$

Telecommuting results in a net change in travel costs due to the time and out-of-pocket costs saved on telecommuting days. This equation offers a way to relate the increased travel budget resulting from the cost savings to potential trip making. Note that the equation up to the "0.5" adjustment factor at the very end provides a way to calculate the **maximum** potential increase in non-work trips assuming that all the cost savings are spent on extra travel. Note, however, that some pilot studies (e.g., Mokhtarian, 1991) indicate either a reduction or no net increase in non-work travel. Therefore, this methodology offers a conservative approach to estimate potential trip increases. Given the ambiguity of real-world data, this equation includes an arbitrary adjustment factor of 0.5 to reduce the estimated increase in non-work trips. Analysts may wish to bypass this portion of the methodology or to substitute their own adjustment factors or to substitute their own adjustment factors based on their own regional experience.

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$NONWRK_t$	Average daily change in non-work trips for telecommuters	Calculated	-7,955
ϵ_n	Elasticity of non-work trip demand with respect to a percent change in cost	Based upon 70% mode share for SOV work trips (MTC, 1991) and maximum ($5) base travel cost (Harvey, 1989)	-0.52
C_0	Base commute costs before telecommuting program	(a)Out-of-pocket costs (MTC, 1991) times average commute distance (RIDES, 1990), plus (b) Average distance times average commute speed (MTC, 1991) times average hourly wage (MTC, 1991)	$25.19/day
C_1	Commute costs after telecommuting program for telecommuters	Equal to C_0 times $(1-F_t/D)$	$15.11/day
AVO_n	AVO for non-work trips	(MTC, 1991)	1.3
$TRIPGEN_n$	Non-work trip generation rate per person per day	Non-work trips via auto per day (MTC, 1991)	2.76

$$NONWRK_t = 90{,}041 \times (-0.52) \times \frac{(25.19-15.11)}{25.19} \times (0.4) \times 2.76/1.3 \times 0.5$$

$$= -7{,}955$$

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Changes in Non-Work Trips for Unemployed Members of Telecommuters' Households

$$NONWRK_h = TEL \times (HSHLD - 1) \times DRVAGE \times NOCAR \times UNEMPL \times F_fD \times TRIPGEN_h$$

When telecommuters leave their vehicles at home, retired or other unemployed household members may use the vehicle for non-work trips. This potential increase in trip making can be calculated as follows:

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$NONWRK_h$	Increase in non-work trips due to increased vehicle availability to household members of telecommuters	Calculated	5,255
UNEMPL	Percent of population over age 16 that are unemployed and not students	100% minus EMPL (MTC, 1991)	32% (0.32)
NOCAR	Percent of population that do not own a vehicle	From (USDOC, 1988)	13% (0.13)
HSHLD	Average household size	Regional average (USDOC, 1988)	2.56
$TRIPGEN_n$	SOV non-work trips generation rate per person per day	Total auto non-work trips per day	2.92
DRVAGE	Percent of population over 16	Percent of regional population over age 16 (USDOC, 1988)	77% (0.77)

$$NONWRK_n = (90{,}041) \times (2.56 - 1) \times (0.77) \times (0.13) \times (0.32) \times (0.4) \times 2.92$$

$$NONWRK_n = 5{,}255$$

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Total Non-Work Trip Increase

$$NONWRK_i = NONWRK_t + NONWRK_h$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$NONWRK_i$	Total non-work trip increase	Calculated	13,250
$NONWRK_t$	Average daily change in non-work trips for telecommuters	Calculated	7,995
$NONWRK_h$	Increase in non-work trips due to increased vehicle availability to household members of telecommuters	Calculated	5,255

$$NONWRK_i = 7{,}995 + 5{,}255$$

$$NONWRK_i = 13{,}250$$

In this example application, non-work trip increases offset the work trip decreases by approximately 20 percent. Again, it is important to emphasize that some pilot studies have noted no increase or even a decrease in nonwork trips; this result is a function of the variable discussed above.

Total Trip Change due to Telecommuting

$$TRPR_t = WRKTRP_t - NONWRK_i$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$TRPR_t$	Total trip change	Calculated	44,941
$WRKTRP_t$	Total telecommuting change in work trips	Calculated	58,191
$NONWRK_i$	Total change in non-work trips	Calculated	13,250

$$TRPR_t = 58{,}191 - 13{,}250$$

$$TRPR_t = 44{,}941$$

Telecommuting Effects on VMT

Telecommuting reduces VMT because of reduced work trips for home telecommuters and reduced work distances for satellite center workers. This VMT reduction is offset slightly by increases in non-work trips by telecommuters and members of their households. The example below shows how to estimate these changes.

Decreased Work Trip VMT

$$\Delta VMT_w = WRKTRP_t \times WRKDIST_a$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_w	Decreased work trip VMT for telecommuters who work from home	Calculated	1,658,443
$WRKTRP_t$	Total change in work trips due to telecommuting	Calculated	57,281
$WRKDIST_a$	Average round-trip work trip distance in study region	Average for SOV mode (RIDES, 1990) (one-way)	23.5 miles

$$\Delta VMT_w = 58{,}191 \times 28.5$$

$$\Delta VMT_w = 1{,}658{,}443$$

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Decrease in VMT for Satellite Center Workers

$$\Delta VMT_s = TEL_s \times (WRKDIST_a - SATDIST) \times \frac{F_t}{D} \times 2$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
TEL_s	Number of telecommuters who work from satellite work centers	User input (for this exercise we will assume 1% of TEL	13,320
$WRKDIST_a$	Average trip distance (non-shared modes)	Regional average work trip distance (RIDES, 1990) (one-way)	23.5 miles
SATDIST	Average distance to satellite centers	User input	5

$$TEL_s = 900 \times (23.5 - 5) \times (0.4) \times 2$$

$$TEL_s = 13{,}320$$

Increase in VMT due to Non-Work Trip Increases

$$\Delta VMT_n = NONWRK_i \times NONDIST$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_n	Change in non-work trip VMT	Calculated	70,490
$NONWRK_i$	Total non-work trip increase	Calculated	13,250
NONDIST	Average non-work trip distance	Regional weighted average for "auto" mode (MTC, 1990)	5.32

$$\Delta VMT_n = 13{,}250 \times 5.32$$

$$\Delta VMT_n = 70{,}490$$

Total Change in VMT

$$\Delta VMT = \Delta VMT_w - \Delta VMT_n$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_w	Change in work trip VMT	Calculated	1,658,433
ΔVMT_n	Change in non-work trip VMT	Calculated	70,490

Calculation of ΔVMT

$$\Delta VMT = 1{,}658{,}433 - 70{,}490$$

$$\Delta VMT = 1{,}587{,}943$$

Peak Period VMT Changes

$$\Delta VMT_p = [\Delta VMT_w \times PCT_{pw}] + [\Delta VMT_n \times PCT_{pn}]$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_p	Change in peak VMT	Calculated	945,168
ΔVMT_w	Change in work VMT	Calculated	1,587,943
ΔVMT_n	Change in non-work VMT	Calculated	70,490
PCT_{pw}	Percent of work trip VMT during peak hours	% work trip travel occurring during peak periods (Sierra, 1991)	60.8% (0.608)

PCT_{pn}	Percent non-work trip VMT during peak hours	% non-work trip travel occurring during peak periods (Sierra, 1991) (Sierra, 1991)	28.8% (0.288)

$$\Delta VMT_p = [1{,}587{,}943 \times (0.608)] - [70{,}490 \times (0.288)]$$

$$\Delta VMT_p = 945{,}168$$

Telecommuting Effects on Speeds

Change in Peak Speeds

$$\Delta SPD = \frac{\Delta VMT_p}{(VMT_w \times PCT_{pw}) + (VMT_n \times PCT_{pn})} \times \epsilon_s$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ϵ_s	Elasticity of peak speed with respect to volume	From (Sierra, 1991)	-0.75
ΔVMT_p	Change in peak VMT	Calculated	945,168
VMT_b	Total VMT in peak period	(MTC, 1991)	33,667,580

$$\Delta SPD = \frac{945{,}168}{33{,}667{,}580} \times (-0.75)$$

$$\Delta SPD = 0.0211 = 2.1\%$$

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5 PARKING MANAGEMENT

Parking management takes advantage of the relationships between travel behavior and travel costs. One study cited by Feeney (1989) found that daily parking charges had five times the relative effect of mileage related car costs on an individual's driving decisions. This exemplifies the power of parking management as a tool for reducing travel by single occupant vehicles. Parking pricing approaches are gaining increasing popularity with California districts implementing TCMs (Maertz, 1991; Sidhu, 1991).

Parking management efforts can be aimed at reducing peak and off-peak congestion, promoting ridesharing and transit use and discouraging vehicle use. Parking management measures fall into two general categories: pricing and supply. Pricing strategies include removing employer parking subsidies; increasing prices for solo drivers or long-term parkers; imposing parking taxes on providers of parking; and reducing parking prices for carpoolers. Parking supply strategies include preferential parking for carpoolers, increasing the availability of short-term (one or two hours) parking, and decreasing the availability of long-term parking, and restricting the overall supply of parking space.

Parking management potentially affects employers, employees and employee household members. A 1989 study (Higgins and Bhatt, 1989) surveying over 100 transportation demand programs concluded that successful programs incorporated parking pricing while unsuccessful programs generally did not. A summary of primary direct and indirect effects is presented in Table 5-1.

SUMMARY EFFECTS OF PARKING MANAGEMENT ON TRAVEL

Direct effects from parking strategies include VMT changes and mode shifts. Large reductions in the number of people driving alone to work have been documented in the literature as responses to increases in parking price. Documented evidence on the results of preferential parking privileges for preferred modes such as ridesharing is not as common, and results are mixed.

TABLE 5-1. Effects of parking management program.

Parking Management			
Direct Effects		Indirect Effects	
Trips:	• The number of work trips will decrease if the net mode shift is made from solo driver to transit or carpool. • Location of work trip starts and ends will change from work sites to nearby parking facilities if commuters opt to use fringe parking facilities. • Reduced-peak diurnal profile will occur for trips if commuters change their driving habits to obtain limited parking (i.e., travel earlier).	Trips:	• It is possible for an increase in non-work trips to CBD's due to increased availability of parking for shopping. • Non-work trips by commuters could decrease if autos remain at the home; however, home-based non-work trips could increase for the same reason.
		VMT:	• Non-work VMT changes will occur if significant changes (increases or decreases) in non-work trips are observed.
VMT:	• Work-related VMT will decrease if the net mode shift is made from solo driver to transit or carpool. • VMT will change very little if commuters opt to use fringe parking facilities near the work place. • Reduced-peak diurnal profile for VMT will occur if commuters change their driving habits to obtain limited parking (i.e., travel earlier).	Speed:	• If the net mode shift is from solo driver to transit or carpool, increases in occupants per vehicle and reductions in total vehicles will result in increases in speed during peak hour commutes. • Increases in speed could occur from spreading out of peak period driving if limited parking encourages earlier commutes.

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Mode Shift Effects of Parking Pricing Strategies

Parking pricing strategies potentially reduce solo driving to work as commuters take alternative modes of travel. In Bellevue, Washington, a suburb outside Seattle, Pacific Northwest Bell has reduced solo driving to only 19 percent of the workforce through a combination of scarce, expensive parking ($3.00 per day at the time of the study), reduced parking rates for carpoolers and intensive ridesharing assistance (Kenyon, 1984). Likewise, Commuter Computer outside the Los Angeles central business district reduced solo driving from 42 to 8 percent by eliminating free parking (Surber et al., 1984). Parking pricing is also a key component of effective demand management programs at several other employers.

Reducing prices for carpoolers in order to encourage ridesharing can have varied effects depending on whether new carpoolers were previously solo drivers or not. When Seattle reduced parking charges for carpools at two parking facilities downtown (from $25 to $5 per month at one facility and $0 at another), the main effect was to attract bus riders back to cars. Forty-five percent of the participants had switched from transit, 29 percent carpooled already, and only 25 percent were previously solo drivers (Oilstone and Miller, 1978). Likewise, a Portland program allowing carpool parking at street meters found about half of the users were previous carpoolers, and half of the new carpoolers were former bus riders (Direnzo et al., 1979).

Trip reductions due to pricing vary widely with the level of the charge, degree of employer subsidy for parking, and opportunities for parking at low or no-cost facilities ("spillover problem"). At best when all the key variables favor mode change, solo driving may decline up to 40 percent and vehicle trips may fall by up to 24 percent. In situations that are not as favorable for supporting alternative mode choices, trip reductions may be on the order of 5 percent or less (Higgins, 1990).

Parking Supply Strategies

There is less evidence on the effects of parking supply strategies, and results are also mixed. For example, preferential parking for carpoolers has shown relatively poor results in two case study cities, Seattle and Sunnyvale (Public Technology, Inc., 1982). Seattle requires developers to reserve a minimum of 20 percent of parking spaces for carpools. Early results from the set-aside policy showed very little use of preferential spaces. More recent evaluations by city staff continue to show mixed results (Higgins, 1989). In the Sunnyvale example, requirements for set-aside carpool parking at one development did not result in any carpooling.

Another supply strategy is to limit the supply of parking provided at new developments through requirements in parking codes. For example, Portland, Oregon sets a maximum number of parking spaces allowed depending on proximity to transit, with no minimum except for residential uses. The city is generally satisfied with its parking policies and city planners believe they have helped maintain high transit usage. As many as 48 percent of commuters into the downtown area have used transit in past years, though the proportion has fallen to 43 percent in 1987 (Higgins, 1989).

While trip attractors can set parking policies to discourage solo driving, their response to public sector parking policies set by others can also have significant effects on driving habits.

In response to taxes on parking facilities, parking providers (e.g., commercial operators, building owners or employers offering long-term parking to commuters) may or may not pass taxes along to parkers. Commercial providers may decide to absorb taxes and not alter prices. Employers providing parking to employees may be bound by union agreements with employees preventing changes in parking fees paid by employees. Or, employers may blunt the effect of parking prices aimed directly at employees. For example, prices may go up at public garages with no effect because employers continue to subsidize employee parking. One recent study estimates the proportion of commuters with employers paying for all or part of parking may be over 50 percent (Willson and Shoup, 1990). In other words, the success of an employer-based parking management program is highly dependent upon the employer's actions to curb SOV use.

Indirect Effects of Parking Management

When parking management succeeds in reducing work trips, vehicles may be available for non-work trips. For example, a family member who previously had no access to a commute vehicle may have more access and generate more shopping and errand trips. Further, if parking pricing or supply strategies reduce long-term parking demand in an area, parking space may be freed up to allow more and easier-to-find short-term parking. This may result in more shoppers going to an area but may also reduce idling emissions from searching for parking places. Added shopping activity is especially likely if more short-term parking is designated, or if short-term rates are lowered relative to long term-rates.

QUANTITATIVE METHODOLOGY FOR ESTIMATING EFFECTS OF PARKING MANAGEMENT ON TRAVEL

Number of Employees Affected by Parking Management/Pricing Programs

The following factors need to be considered in identifying the number of employees that will be affected by the measure:

Whether a parking management/pricing program affects privately owned spaces, municipal spaces, or both

Whether the policy affects paid, public use spaces only, or includes free private spaces also

Whether the policy consists of management of parking supply, parking price increases, or both

Existing opportunities for commuters to spill over to private untreated spaces in the vicinity and/or to neighborhood streets to avoid prices or use restrictions

Extent of employer subsidies for employee parking.

Conceptually, this methodology draws upon several key concepts covered in the methodologies for ridesharing and telecommuting. Specifically, the following steps are used to quantify the effects:

1. Identify the number of individuals affected by the pricing program (this should equal the number of parking spaces affected, with adjustments for the fact that some of these spaces may be used by carpoolers to begin with). If the program includes preferential parking for carpoolers, then this adjustment will be unnecessary.

2. Identify the number of spaces in surrounding areas that can be used in place of the employer parking lot. Such spaces are generally referred to as "spillover" spaces and include spaces that may be available in nearby residential areas, spaces in another employer's parking lot, or a nearby public parking garage.

3. Compute the average price of the spillover and employer spaces covered by the program. The main spillover spaces can be free or may have a charge associated, metered spaces have an hourly charge associated, and public parking garages have a daily charge associated. The average price for the paid parking can be calculated as the total price (spaces x charges)/total spaces. This average price should be used in the equations which relate mode choice to parking costs to

address the fact that individuals using spillover parking that costs money will have some incentive to switch travel mode.

4. Identify the number of affected individuals who will use spillover parking. It is recommended to assume that all available spillover parking will be used (this assumption will produce the least optimistic results for emission reductions since the more available spillover parking there is, the smaller is the trip reduction that will occur).

5. For affected employees not using spillover parking, calculate trip changes as follows:

   A. Calculate the number of affected employees who will shift to transit, ridesharing, walking, or other non-SOV modes using elasticity of mode choice with respect to cost and the percent difference between pre- and post-parking management parking costs.

   B. Calculate the number of employees who have shifted to carpools or transit who do not drive to park and ride lots.

   C. Calculate the percent of employees shifting to carpools or transit who join new carpools and who join existing carpools.

   D. Calculate work trip reductions using equations from the ridesharing methodology for work trip reductions.

   E. Calculate any vehicle work trip increases occurring due to household members of new ridesharers or transit users who now have vehicles available.

6. Calculate non-work trip increases for household members of new non-SOV users using equations from the ridesharing methodology.

7. Calculate VMT changes resulting from (a) SOV work trip decreases, (b) changes in work trip length due to use of spillover parking and "cruising" for spillover parking, and (c) any increases resulting from new non-work trips.

8. Calculate speed increases using the elasticity of speed with respect to volume.

Each of these steps is described in more detail in the following pages.

Estimating the Number of Individuals Affected by the Pricing Program

The number of individuals potentially affected equals the number of parking spaces affected:

$$AFF = NSPC/AVO \tag{5-1}$$

where

AFF = Number of potentially affected individuals

NSPC = Number of spaces whose prices have been raised as part of the pricing program plus the number of spillover spaces for which charges are made

AVO = Average vehicle occupancy of non-transit vehicles (transit vehicles presumably do not use the parking lot); if the pricing program only affects single occupant vehicles, do not divide by AVO.

Use of Spillover Spaces

If parking places near the employment site are available and cheaper, then many of the potentially affected employees will utilize these spaces. The number of spillover spaces will depend on the characteristics of the site or sites where the program has been implemented and assumptions by the user regarding the distance from work employees are willing to walk in order to avoid higher parking charges. One rule of thumb might be to assume that a maximum of three minutes will be tolerated in most areas and a maximum of one minute in areas known for high crime rates or other factors which may make them undesirable for pedestrians.

Employees whose work travel may change from SOV to other travel modes are those who do not use free spillover parking:

$$AFF_c = AFF - SPILL_f \tag{5-2}$$

where

AFF_c = Affected employees who do not use free spillover parking (employees who continue to use the higher-priced employer spaces and the employees who use spillover parking with an associated charge).

$SPILL_f$ = Number of free spillover spaces (employees using metered spaces or public parking garages can be treated as being affected in the same way as employees continuing to use the employee parking lot

The above equation assumes any available free spillover parking will be used in order to avoid the higher charges at the employment site.

Average Price Increase for Affected Employees

The average price of the affected employee and spillover parking with charges equals:

$$NEW = \frac{\sum (NSPC \ x \ PRICE)}{NSPC} \tag{5-3}$$

and the base-parking program prices (often free) are

$$BASE = NSPC_e \text{ x } PRICE_{old}/NSPC_e \tag{5-4}$$

where

$NSPC_e$ = Number of spaces at employment centers whose prices have been raised

$PRICE_{old}$ = Price of employer parking spaces prior to implementation of the parking management program

Then the percent increase in parking prices experienced by the affected employees is

$$INCRS = (NEW - BASE)/BASE \tag{5-5}$$

This percent increase is then used with elasticities of mode choice with respect to cost to calculate the number of employees who will shift from SOV to transit or ridesharing in response to the price increase.

Work Trip Reductions Associated with A Parking Management Program

Calculating work trip reductions from the parking management program is very similar to the calculations for ridesharing. In fact, the numbered equations appearing in the ridesharing methodology are referred to in order to describe the process for estimating travel changes. Conceptually, this portion of the methodology begins just before the ridesharing methodology; before calculating the changes and accounting for such factors as the number of ridesharers and transit users who do or do not use park and ride lots, one must first calculate the number of new ridesharers and transit users. This is accomplished as follows:

$$MODE = e_m \times INCRS \times AFF_c \tag{5-6}$$

where

MODE = Number of individuals shifting from SOV to some other travel mode

This equation gives the total number of individuals who will shift to modes other than SOV in response to the parking management program. These individuals are of several types:

$$MODE = MODE_w + MODE_t + MODE_r$$

where

$MODE_w$ = Individuals who shift to walking or bicycling

$MODE_t$ = Individuals who shift to transit

$MODE_r$ = Individuals who shift to ridesharing

To calculate the values of each of these three components, one may use the previous mode splits existing in the study region; if, of all the non-SOV users, 10 percent walk or bicycle, 40 percent use transit, and 50 percent rideshare, then $MODE_w = 0.1 \times MODE$, $MODE_t = 0.4 \times MODE$, etc.

Work trips are reduced by all of $MODE_w$ and by the transit users and ridesharers who do not drive to park and ride lots:

$$WRKTRP_h = (MODE_w + (MODE_t + MODE_{re} + (MODE_{rn}/NCAR \times (NCAR-1))) \times P_h) \times 2 \tag{5-7}$$

where

$WRKTRP_h$ = Work trips reduced by new non-SOV users who leave their vehicles at home

$MODE_{re}$ = New ridesharers who join existing carpools

$MODE_{rn}$ = New ridesharers who form new carpools

NCAR = Average number of people per carpool

P_h = Percent of transit users and ridesharers who leave their vehicles at home

Note that in previous methodologies the factor F/D was multiplied to adjust for the frequency of ridesharing or transit use. This is not necessary here since the elasticity of mode choice is conceptually an average choice made for each day the percent price increase is experienced. Therefore, the individuals who are ridesharing or using transit may change from day to day, but their total number can be represented by MODE.

Vehicle work trips by household members of new non-SOV users who leave their vehicles at home may increase. This increase can be calculated using Equation 3-3 from the ridesharing methodology and substituting the variable "CARP x (P_e + P_n)" with the appropriate variables described above ($MODE_w + (MODE_{re} + MODE_m + MODE_t) \times P_h$) and leaving out the F/D term.

Non-Work Trip Increases Associated with a Parking Management Program

As with ridesharing programs, there is a potential increase in non-work trips due to increased availability of vehicles left at home for use by household members. This increase can be calculated for parking management by using Equation 3-5 from the ridesharing methodology and substituting the variable "CARP x (P_e + P_n)" with the appropriate variables described above and leaving out the F/D term.

VMT Changes Associated with Parking Management

The most significant change in VMT will result from the decreased trips taken by affected employees who begin ridesharing or using other non-SOV modes after parking prices are increased. Further VMT decreases are accomplished as new transit users or ridesharers decrease their work trip length through the use of park and ride lots. Some increase in VMT will occur due to increased SOV work trips taken by household members, increased non-work trips taken by household members, and extra driving associated with the use of spillover parking.

The first three components are calculated in almost exactly the same way as is detailed in the ridesharing equations for VMT.

$$\Delta VMT_h = WRKTRP_h \times WRKDIST_a \qquad (5\text{-}8)$$

where

ΔVMT_h = Change in VMT due to elimination of work trips

$WRKTRP_r$ = Eliminated work trip

$WRKDIST_a$ = Average work trip distance

Equation 5-9 represents the VMT saved by ridesharers and transit users who drive to park and ride lots.

$$\Delta VMT_p = (1 - P_h) \times (MODE_t + MODE_{re}) \times (WRKDIST_a - LOTDIST) \times 2 \qquad (5\text{-}9)$$

where

ΔVMT_p = Change in VMT due to ridesharers and transit users who drive to park and ride lots

Finally, VMT may be changed because of individuals using spillover parking. This change is probably negligible; it is possible that some individuals may be able to drive a shorter distance to work than previously if they use spillover parking closer to their homes than before. Employees who "cruise" for spillover parking presumably drive within a radius that is an acceptable walking distance from the employment site, which represents an increase in VMT that should not be significant.

Increases in Speed due to Parking Management

Speed increases resulting from the parking management program can be calculated in exactly the same way as presented in the ridesharing methodology using Equation 3-15.

EXAMPLE APPLICATION OF THE PARKING MANAGEMENT METHODOLOGY

An example of applying the parking management methodology is presented next. The number of affected parking places was assumed to be a value such that the number of affected individuals was equal to the number of telecommuters and ridesharers shown in the two previous examples. The parking program in this example assumes that numerous employment sites scattered throughout the San Francisco Bay Area implement a parking program.

Number of Individuals Affected by Pricing Program

$$AFF = NSPC/AVO$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
AFF	Number of potentially affected individuals	Calculated	90,039
NSPC	Number of spaces whose prices have been raised **PLUS** number of spillover spaces charged for	User input	116,150
AVO	Average vehicle occupancy (omit if only SOVs are affected)	Regional average vehicle occupancy (MTC, 1990)	1.29

$$AFF = \frac{116,150}{1.29}$$

$$AFF = 90,039$$

Use of Spillover Spaces

Employees affected by the parking price increases will use other available parking places to the extent possible. The number of available spillover spaces is obviously completely dependent on the site(s) where the parking program is implemented. We assumed that 10,000 were available across the region where the program is assumed to be applied. Therefore, the number of employees who may change their travel behavior by using shared travel modes to avoid the price increase is really the number of affected individuals who cannot use spillover spaces.

$$AFF_c = AFF - SPILL_f$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
AFF_c	Affected employees who do not use free spillover parking	Calculated	80,039
$SPILL_f$	Number of free spillover spaces	User input	10,000
AFF	Number of potentially affected individuals	Calculated	90,039

$$AFF_c = 90{,}039 - 10{,}000$$

$$AFF_c = 80{,}039$$

In this example, therefore, approximately 10 percent of employees working at affected employment sites are not affected by the program except in that they park offsite.

Average Price Increase for Affected Employees

$$NEW = \sum \frac{(NSPC \times PRICE)}{NSPC} + COST_{BASE}$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$COST_{BASE}$	Base driving cost	Out-of-pocket costs for work trips (MTC, 1991)	$2.12
NEW	Average price of employee and spillover parking with charges	Base travel out-of-pocket cost plus PRICE	$7.12
NSPC	Number of spaces whose prices have been raised	User input	116,150

PRICE	New price for spaces	User input (ex. assumes uniform price increase)	$5.00

$$NEW = \frac{(116{,}150 \times 5.00)}{116{,}150} + 2.12$$

$$NEW = \$7.12$$

Percent Increase in Parking Prices Experienced by Affected Employees

$$INCRS = (NEW - BASE)/BASE$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
INCRS	Percent increase in parking prices for affected employees	Calculated	236% (2.36)
NEW	Average price of affected spaces	Calculated	$7.12
BASE	Base price of affected spaces	User input	$2.12

$$INCRS = \frac{(7.12 - 2.12)}{2.12}$$

$$INCRS = 2.36$$

Work Trip Reductions Associated with A Parking Management Program

As discussed in Chapter 4, the primary effect of a parking management program in reducing travel activity is to encourage individuals to travel via transit or carpool in order to avoid the charges associated with SOVs. The average price increase experienced by affected individuals not using spillover parking spaces is multiplied by the elasticity of mode choice with respect to a change in cost in order to calculate the number of individuals who may shift from SOV to shared modes in response to a parking management program.

$$MODE = \epsilon_m \times INCRS \times AFF_c$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
MODE	Number of individuals shifting from SOV to some other travel mode	Calculated	41,556
ϵ_m	Elasticity of mode choice with respect to cost	Based upon a base cost of $5.00 and a 70% mode share (Harvey, 1989)	-0.22
AFF_c	Affected employees who do not use free spillover parking	Calculated	80,039
INCRS	Percent increase in parking charges experienced by affected employees	Calculated	2.36

$$MODE = -0.22 \times 2.36 \times 82{,}287$$

$$MODE = 41{,}556$$

Note that the term "F/D" that is used in the ridesharing and telecommuting examples to ensure that all values are in units of trips per day is not used here. The use of elasticity instead of a number of people yields a value which is already in "per day" units.

Total Number of Individuals Who Will Shift to Non-SOV Modes

The value 33,119 is an estimate of the number of individuals who would shift from SOV to transit, carpools, or other modes. Since transit riders affect trip making in a different way than ridesharers, the number of changed trips for each mode should be calculated. Here we use the pre-existing mode split to separate transit users and ridesharers from the 33,119 new non-SOV trips. According to the MTC (MTC, 1991), 37.4 percent of shared ride work trips are made via transit, and 62.6 percent of shared ride work trips are made via carpool. No information is available for modes such as walking or bicycling, so it is assumed here that these modes remain the same.

$$MODE = MODE_w + MODE_t + MODE_r$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
MODE	Number of individuals who will shift to modes other than SOV in response to PM program	Calculated	41,556
[$MODE_w$]	Individuals who shift to walking or bicycling	Data unavailable	Not calculated for this example
$MODE_t$	Individuals who shift to transit	MODE times % of shifted trips made by transit mode (37.4%) (MTC, 1991)	15,542
$MODE_r$	Individuals who shift to ridesharing	MODE times % of shifted trips made via ridesharing (62.6%) (MTC, 1991)	26,014

The number of new ridesharers (26,014) must be treated differently from the number of new transit users in calculating trip reductions (15,542).

Work Trips Reduced by New Non-SOV Users Who Leave Their Vehicles at Home

$$WRKTRP_h = [MODE_w + (MODE_t + MODE_{re} + (\frac{MODE_{rn}}{NCAR} \times (NCAR - 1)) \times P_h)] \times 2$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_h$	Work trips reduced by new non-SOV users who leave their vehicles at home	Calculated	67,330
[$MODE_w$]	Individuals who shift to walking or bicycling	Data unavailable	
$MODE_t$	Individuals who shift to transit	Calculated	15,542

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$MODE_{re}$	New ridesharers who join existing carpools	$MODE_r$ times percent joining existing pools (35%) (UMTA, 1985)	9,105
$MODE_{rn}$	New ridesharers who form new carpools	$MODE_r$ times percent joining new pools (UMTA, 1985)	16,909
NCAR	Average number of people per carpool	Weighted average of average number of people in both 2+ and 3+ carpools (MTC, 1991)	2.28
P_h	Percent of transit users and ridesharers who leave their vehicles at home	Percent of ridesharers who either (a) leave their cars at home or (b) do not drive to park and ride lots (RIDES, 1987)	95%

$$WRKTRP_h = (15{,}542 + 9{,}105 + (\frac{16{,}909}{2.28} \times (2.28 - 1) \times 0.95) \times 2$$

$$WRKTRP_h = 67{,}330$$

It should probably be noted here that two steps shown separately in the ridesharing example (trips reduced for ridesharers joining existing carpools and trips reduced for ridesharers forming new carpools) are combined into one here. It is assumed that the familiarity gained from the process of applying the ridesharing methodology would make a separate treatment unnecessarily repetitive.

Work Trip Increase by Household Members of New Non-SOV Users

As explained in the example applications for ridesharing and telecommuting, household members who were previously using transit or rideshare modes to work may want to use the vehicles left at home instead of their previous travel mode. The assumptions regarding the number of household members who will change their behavior are the same as in the previous examples.

$$WRKTRP_{ih} = [MODE_w + (MODE_{rc} + MODE_{rn} + MODE_r) \times P_k \times NOCAR \times DRVAGE \times (HSHLD-1)] \times EMPL \times TRIPGEN_w$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$WRKTRP_{ih}$	Extra vehicle work trips made by household members of new non-SOV users	Calculated	5,536
NOCAR	Percent of population not owning a vehicle	(USDOC, 1991)	13%
DRVAGE	Percent of population of driving age	Regional population over 16 (USDOC, 1988)	77.1%
HSHLD	Average household size	Regional average (MTC, 1990)	2.56
EMPL	Percent of population that is employed	(a) Total population (MTC, 1991) (b) Number of employed residents (MTC, 1991) (c) Percent of total population over age 16	52.8% (0.528)
$TRIPGEN_w$	Average number of SOV work trips demanded per person per day	(a) Number of work trips per day (MTC, 1991) (b) Working population over age 16 (MTC, 1991; USDOC, 1988)	1.705

$$WRKTRP_{ih} = (9{,}105 + 16{,}909 + 15{,}542) \times 0.95 \times (0.13) \times (0.771) \times (2.56 - 1) \times 1.705$$

$$WRKTRP_{ih} = 5{,}536$$

Therefore, the total work trip decrease equals

$$WRKTRP_r = WRKTRP_h - WRKTRP_{ih} = 67{,}330 - 5{,}536 = 61{,}794$$

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Non-Work Trip Increases for Household Members of New Non-SOV Users

Household members who are unemployed may also want to use the vehicles left at home by individuals attracted to ridesharing and transit programs by the parking management program. The increase is similar in magnitude to the increase for working household members who would potentially switch from shared modes to SOV modes.

$$NONWRK_h = (MODE_w + (MODE_{ro} + MODE_m + MODE_v) \times P_h \times (HSHLD - 1) \times DRVAGE \times NOCAR \times UNEMPL \times TRIPGEN_h$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
$NONWRK_h$	Extra vehicle work trips made by new non-SOV user household members	Calculated	5,768
DRVAGE	Percent of population of driving age	Percent of regional population over age 16 (USDOC, 1988)	77.1% (0.77)
NOCAR	Percent of population not owning a vehicle	(a) Total **employed** population over age 16 minus (b) total number of autos (MTC, 1991) divided by (a)	13%
UNEMPL	Percent of population that is unemployed	100% minus EMPL (MTC 1991)	32% (0.32)
$TRIPGEN_n$	Average non-work vehicle trips demanded per person per day	Total number of "auto" non-work trips per day (MTC, 1991) divided by total population over 16 years	2.92

$$NONWRK_h = (9{,}105 + 16{,}909 + 15{,}542) \times (0.95) \times (2.56 - 1) \times (0.77) \times (0.13) \times (0.32) \times (2.92)$$

$$NONWRK_h = 5{,}768$$

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VMT Changes Associated with Parking Management

$$\Delta VMT_h = WRKTRP_r \times WRKDIST_a$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_h	Change in VMT from elimination of SOV work trips	Calculated	1,452,159
$WRKTRP_h$	Eliminated work trips	Calculated	61,794
$WRKDIST_a$	Average work trip distance	Average work distance for SOV mode	23.5 miles

$$\Delta VMT_h = 1{,}452{,}159$$

VMT Saved by Ridesharers and Transit Users Who Drive to Park and Ride Lots

Additional VMT reductions are realized due to the shorter work trips made by new ridesharers and transit users who drive to park and ride lots instead of getting picked up at home. This reduction can be calculated as follows:

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$$\Delta VMT_p = (1 - P_h) \times (MODE_t + MODE_{re}) \times (WRKDIST_a - LOTDIST) \times 2$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_p	Change in VMT from ridesharers and transit users who drive to park and ride lots	Calculated	119,390
P_h	Percent of transit users and ridesharers who leave their vehicles at home	Calculated using statistics provided above	95% (0.95)
$MODE_t$	Individuals who shift to transit	Calculated using statistics provided above	15,542
$MODE_{re}$	New ridesharers who join existing pools	Calculated using statistics provided above	9,105
LOTDIST	Distance to park and ride lot	Average distribution of values presented by Maltzman (Maltzman, 1987)	5.56 miles

$$\Delta VMT_p = (1 - 0.95) \times (15{,}542 + 9{,}105) \times (54 - 5.56) \times 2$$

$$\Delta VMT_p = 119{,}390$$

Therefore, the **total work trip VMT reduction** equals 1,452,159 (reduction from net reduced trips) + 119,390 (reduction from shorter trips to park and ride lots) = 1,571,549 VMT increases due to non-work trip increases by household members of individuals using shared modes to work in response to the parking management program are calculated as follows:

$$VMT_{nw} = NONWRK_h \times NONDIST$$

$$VMT_{nw} = 4{,}561 \times 5.32 = 24{,}424$$

Total Change in VMT

$$\Delta VMT = \Delta VMT_w - \Delta VMT_{nw}$$

$$\Delta VMT = 1{,}245{,}476 - 24{,}424 = 1{,}221{,}052$$

Peak Period VMT Changes

$$\Delta VMT_{pk} = [\Delta VMT_w \times PCT_{pw}] + [\Delta VMT_n \times PCT_{pn}]$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ΔVMT_{pk}	Change in peak VMT	Calculated	
PCT_{pw}	Percent of work trip VMT during peak hours	(Sierra, 1991)	60.8% (0.608)
PCT_{pn}	Percent of non-work trip VMT during peak hours	(Sierra, 1991)	28.8% (0.288)

$$\Delta VMT_{pk} = [1{,}571{,}549 \times (0.608)] - [24{,}424 \times (0.288)]$$

$$\Delta VMT_{pk} = 948{,}468$$

Parking Management Effects on Speeds

Change in Peak Speeds

$$\Delta SPD = \frac{\Delta VMT_p}{(VMT_w \times PCT_{pw}) + (VMT_n \times PCT_{pn})} \times \epsilon_s$$

VARIABLE	DEFINITION	SOURCE OF INFORMATION	VALUE
ϵ_s	Elasticity of peak speed with respect to volume	(Sierra, 1991)	-0.75
ΔVMT_p	Change in peak VMT	Calculated	948,468

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VMT_w	Total work trip VMT	(MTC, 1991)	36,081,814
VMT_n	Total non-work trip VMT	(MTC, 1991)	40,728,600

$$\Delta SPD = \frac{948,468}{(36,081,814 \times (0.608)) + (40,726,600 \times (0.288))} \times -0.75$$

$$\Delta SPD = 0.021 = 2.1\%$$

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