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October 1979

Assistant Secretary Policy and Evaluation
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Analytic Procedures for
Urban Transportation
Energy Conservation

# Summary of Findings and Methodologies

Volume I (of V)

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Assistant Secretary Policy and Evaluation
Washington, D.C. 20585

**October 1979**

## Analytical Procedures for Urban Transportation Energy Conservation

# Summary of Findings and Methodologies

## Volume I (of V)

Prepared by:
Cambridge Systematics, Inc.
Cambridge, Massachusetts 02142
Under Contract No. EC-76-C-01-8628

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Part of a five-volume series of final reports describing analytical methodologies for use in urban transportation energy conservation analyses

16. Abstract

Analytical methodologies are described and illustrated for use by metropolitan planning organizations and other state and local transportation agencies in analyzing the energy conservation potential of candidate urban transportation measures. Quantitative methodologies oriented to carpooling, vanpooling, transit, pricing, traffic regulation and control, and auto ownership are provided based on the use of disaggregate behavioral travel demand models. Changes are indicated in trip frequency and distribution as well as in travel model, operating conditions, and vehicle miles of travel. Trip-based estimates of fuel consumption and vehicle emissions are included. The methodologies can be adapted to different levels and types of data availability, and can employ manual sketch planning procedures, a programmable calculator, or a fully-calibrated computer program utilizing a random sample household enumeration forcasting technique. Application of the developed methodologies has been performed in cooperation with metropolitan planning organizations representing the Dallas-Fort Worth, San Francisco, and Denver urban areas.

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## Preface

The methodologies and analysis results summarized in this report were developed under contract to the U.S. Department of Energy in order to provide improved analytical capabilities for use in urban transportation energy conservation analyses. This volume briefly describes the detailed findings presented in the following reports:

| | | |
|---|---|---|
| Volume II | - | Analytical Procedures for Estimation of Changes in Travel Demand and Fuel Consumption |
| Volume III | - | Case City Applications of Analysis Methodologies |
| Volume IV | - | Analysis of Traffic Engineering Actions |
| Volume V | - | SRGP Operating Instructions and Program Documentation |

An important component of the work has been to cooperatively apply the developed analysis methodologies with three representative metropolitan planning organizations:

- North Central Texas Council of Governments representing Dallas and Fort Worth
- Metropolitan Transportation Commission from the San Francisco Bay Area
- Denver Regional Council of Governments representing the Denver, Colorado, metropolitan area

Much of the work in preparing to use the analysis methodologies was performed by the respective MPO's, and we are very grateful for the assistance and advice which they provided.

The project was performed by Cambridge Systematics, Inc., with subcontract support provided by Frederick A. Wagner and Alan M. Voorhees & Associates, Inc. John H. Suhrbrier was responsible for the overall direction and management of work performed. Major contributors to the development of the analysis capabilities were William A. Jessiman and Moshe Ben-Akiva who developed the basic concepts and design; Terry J. Atherton, Jeffrey McMann, and Earl Ruiter, who extended and implemented the methodologies; Frederick A. Wagner in the areas of fuel economy, vehicle operating costs, and traffic operations; and Greig Harvey in the area of vehicle emissions. Major assistance in the development of the current version of the SRGP computer program was provided by Douglas Bell and Richard E. Nestle. The analysis methodologies were applied to San Francisco, Denver, and Forth Worth by Mr. Suhrbier, Mr. Atherton, and Mr. Bell. The principal authors of this volume are William D. Bryne and Mr. Suhrbier.

Important contributions have been made by staff of the U.S. Department of Energy, especially John Hemphill, Carmen Difiglio and Anne Marie Zerega. Their support and individual inputs have been very much appreciated. The contents of this report, however, reflect the view of Cambridge Systematics, Inc., and they are fully responsible for the facts, the accuracy of the data, and the conclusions expressed herein. The contents should not be interpreted as necessarily representing the views, opinions, or policies of either the Department of Energy or the United Stated Government.

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# I. Introduction

Encouraged by the Department of Energy's State Energy Conservation Program, the Department of Transportation's Transportation System Management (TSM) requirements, and the 1977 amendments to the Clean Air Act, local and regional transportation planning agencies are placing increasing emphasis on short-range, low-cost actions designed to reduce energy consumption, improve air quality, and increase the efficiency of the existing transportation system. Critical to the successful implementation of these actions is a realistic assessment of their potential impacts. Traditional urban travel demand and supply analysis procedures, however, are oriented primarily to the design of capital-intensive highway and transit extensions and have proven to be not sufficiently policy sensitive, overly expensive, and cumbersome to use with respect to energy conservation and air quality considerations. The alternative of combining implementation experience from other urban areas with professional judgment also has proven to be unrealiable, by frequently ignoring conditions unique to an urban area and producing overly optimistic expectations.

Thus, there is a recognized need for a policy analysis capability which is sensitive to a broad range of potential urban transportation energy conservation measures, which is both quick and inexpensive to apply, and which accurately represents the travel behavior response of different individuals in an urban area with their unique socioeconomic characteristics and particular travel patterns. This five-volume series of reports describes and illustrates analytical methodologies which both achieve these criteria and can be readily implemented by metropolitan planning organizations (MPO's) and other state and local agencies having transportation responsibilities. The methodologies have been utilized in cooperation with the metropolitan planning organizations representing Denver, San Francisco, and Fort Worth, and the examples presented are drawn from these cooperative applications. Specifically, the developed analytical methodologies can be characterized as being "sketch planning" in character, providing the following capabilities:

- Sensitivity to a wide range of ridesharing, transit, parking, pricing, traffic operations, employer-based, and high-occupancy vehicle (HOV) preferential treatment alternatives;
- Prediction of relevant short-term transportation, cost, air quality, and energy impacts and their incidence across geographical, socioeconomic, and governmental units;
- Prediction of the synergistic and competing interactions of combined energy conservation actions;
- Inexpensive and quick to apply.

Three basic analytical techniques with the above features are documented:

- An integrated computer-based system of 11 separate models, referred to as SRGP for Short Range Generalized Transportation Policy Analysis;

- A simplified set of manual travel demand estimation procedures with accompanying worksheets for use in preliminary analyses when a full computer analysis may not be justified, or use by urban areas without access to computer facilities or coded transportation networks;

- A set of step-by-step manual procedures for evaluating the travel time and fuel consumption impact of traffic engineering actions designed to improve traffic flow.

This summary volume serves as a guide to the remainder of the reports, providing a summary description of the capabilities and requirements of the individual analytical techniques, and presenting estimated impacts for a range of fuel conservation measures analyzed in Denver, San Francisco, and Fort Worth. Volume II describes the theoretical basis for the analytical methodologies; and individual travel demand, energy, and other submodels utilized; and the specific manner in which these submodels are interrelated to form the basis for forecasting future year impacts (1). The urban area case study applications are described in Volume III, including detailed analysis results, step-by-step accounts of the procedures used in setting up data and running the model system in each urban area, and both a description and an application of the manual worksheet approach (2). A general work plan for preparing the necessary data and running SRGP also is provided in Volume III to aid other areas in implementing the model system. Volume IV describes the procedure for analyzing short-term highway supply improvement measures and the results of an analysis of potential traffic engineering measures in Denver and San Francisco (12). Volume V constitutes detailed operating instructions and program documentation for SRGP, and is directed to the person with direct responsibility for implementing, operating, and maintaining the SRGP computer system (3).

This set of documents contributes to the energy conservation planning in urban areas in three distinct ways:

- By providing a guide to the implementation and use of state-of-the-art analytic techniques for those areas already having a complete set of travel and socioeconomic data;

- By outlining the data which is required to do a thorough transportation energy conservation analysis for those areas that are either revising or just developing a data set for use in transportation analyses;

- By providing a set of estimated impacts of various fuel conservation measures in three different metropolitan areas, which may be used as a check on the potential savings associated with actions being contemplated in another area.

Because of the connection between fuel consumption, transportation level-of-service, and air quality, it is important for MPO's to coordinate their planning efforts in these areas, especially since many measures designed to conserve fuel also may beneficially impact air quality. Both the underlying theory and the individual analytical capabilities presented are equally applicable to issues of air quality. The described methodologies, therefore, provide an opportunity to enhance the coordination of energy conservation and air quality planning, and to aid MPO's in implementing the air quality transportation guidelines jointly issued by the Environmental Protection Agency and the Department of Transportation (7,9).

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## II. Analytical Procedures for Estimating Changes in Travel Demand and Fuel Consumption

SRGP - SHORT RANGE TRANSPORTATION POLICY ANALYSIS

The developed methodology satisfies two important requirements to reliably predict the fuel consumption impacts of short-term transportation measures. First, the individual models and submodels are sensitive to changes in the transportation system which would result from transportation energy conservation measures. Second, the models are structured in such a way that they accurately reflect the choice process of an individual traveler deciding between travel alternatives based on the attributes of each (i.e., they are behavioral rather than correlative).

The methodology is based on a system of disaggregate qualitative choice travel demand models--disaggregate because the coefficients of the models are estimated using observations of individual travel behavior; qualitative choice because the models are specified such that they predict the probability that an individual will select an alternative from among a set of discrete and qualitative alternatives available to that individual. Disaggregate models have several advantages over traditional aggregate models including the following:

- They are not tied to a particular traffic zone system and may be used at any geographical level.
- Since they are behavioral, rather than correlative, they are more easily transferred from one setting to another.
- Disaggreate models make more efficient use of available data.

To analyze the full set of long- and short-range impacts resulting from a transportation policy measure, ideally it would be desirable to use models which explain a household's locational as well as travel decisions. However, if one is primarily interested in the more immediate response of travelers, or if the effect of long-term household residential and workplace locational decisions can be assumed to be negligible, demand models formulated to predict travel behavior conditional on household and workplace location may be used. This is the approach taken in developing SRGP--only short-to-medium range choices, such as work mode choice and auto ownership, are modeled for each household, conditional on the longer term decisions.

Two types of linkages among component parts of the demand model system are illustrated in Figure 1. The solid arrows indicate those linkages where lower level models (or decisions) are conditional on the choices predicted by higher level models; the dotted arrows indicate feedback in the form of composite or accessibility type variables calculated by lower level models and included in higher level models.

To implement this basic travel behavior framework, eight separate disaggregate travel demand models are integrated into a single model system (Figure 2):

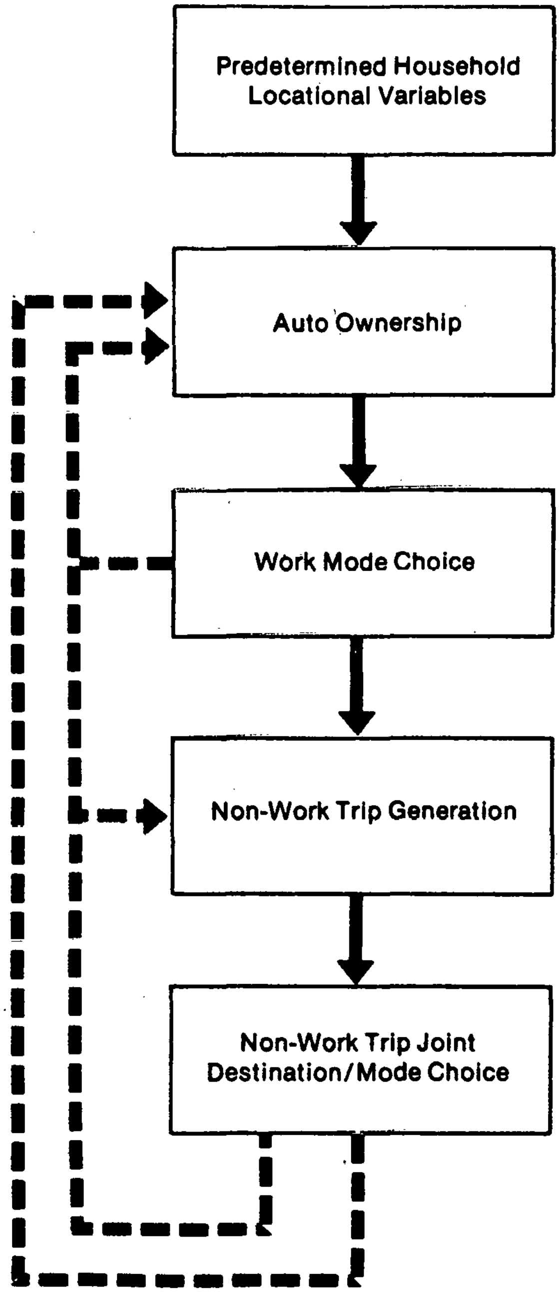


**Figure 1. Interrelationships of Travel Demand Models**

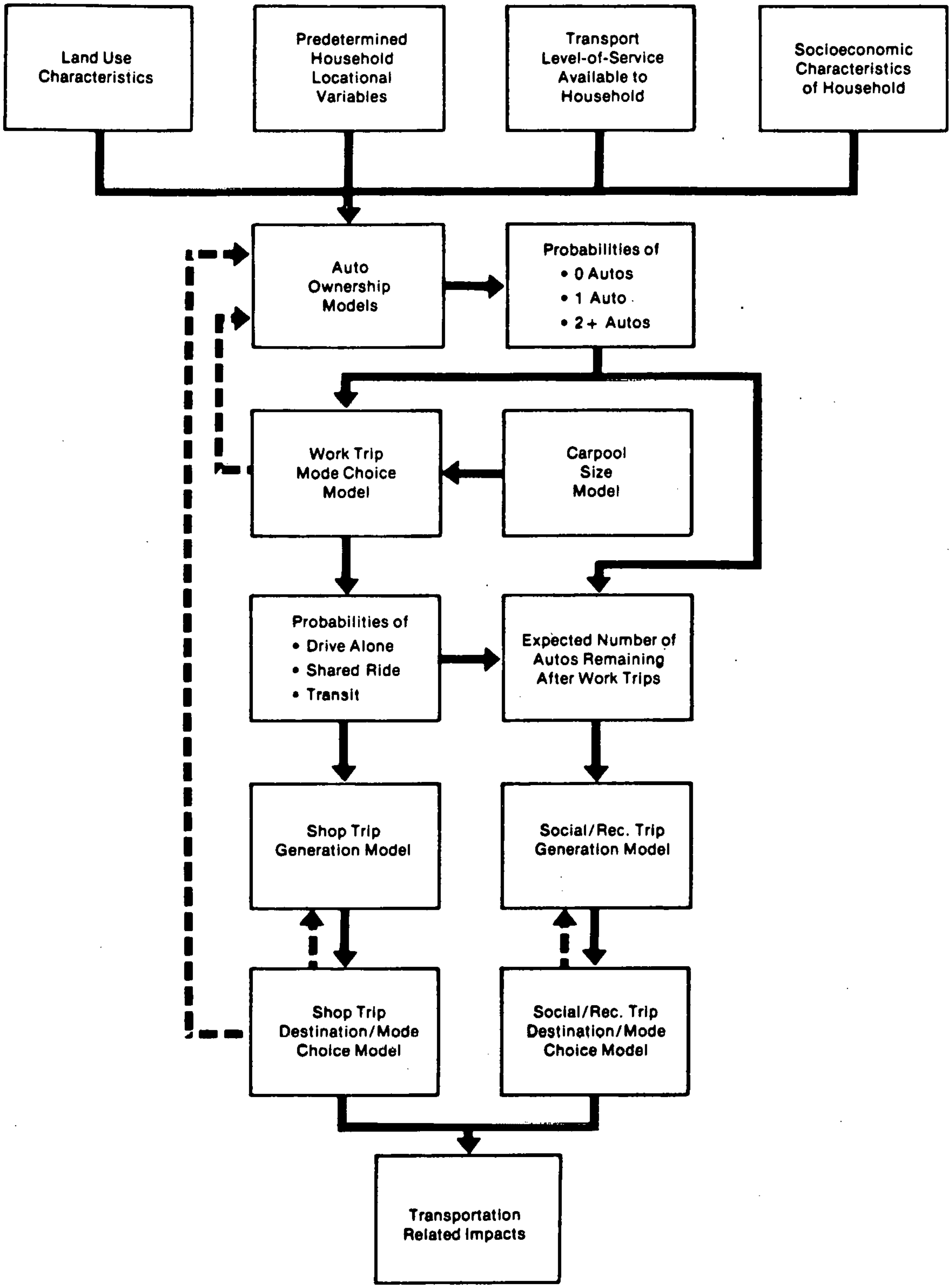


**Figure 2.**
**Travel Demand Model Linkage-Single Household**

1. Auto Ownership for households with one or more workers
2. Auto Ownership for households with no workers
3. Work Mode Choice involving drive-alone, shared-ride, and transit
4. Carpool size for work trips
5. Shopping trip generation
6. Social-recreational trip generation
7. Simultaneous destination and mode choice for shopping trips
8. Simultaneous destination and mode choice for social-recreational trips

The model system predicts auto ownership and travel behavior for each household based on its socioeconomic and locational characteristics, and the attributes of transportation alternatives available to the household. With three exceptions, each of the models is of the multinomial logit form.[1] The two non-work trip generation models are specified as non-linear regression models, and the carpool size model as a linear regression model.

Output variables tabulated are identified in Table 1. Three submodels are interfaced with the travel demand model system to predict auto operating cost, fuel consumption, and air pollutant emissions on a trip-by-trip basis. The fuel consumption submodel predicts the amount of gasoline consumed based on the distribution of auto types in the vehicle fleet, auto occupancy, cold start/trip length, and average speed. The amount of fuel consumed then is used in estimating auto operating costs. The auto emissions submodel predicts the amount of carbon monoxide, hydrocarbons, and nitrogen oxides emitted as a function of vehicle fleet composition, ambient temperatures, average speed, and percent cold operation.

## AGGREGATION BY RANDOM SAMPLE ENUMERATION

To evaluate alternative transportation policy measures, individual household choices estimated by the model system must be converted to aggregate areawide estimates. Traditional forecasting has been done using an aggregate grouping, such as traffic zones, and group average values for all explanatory variables. Unless the group for which the average values are used is homogeneous, this approach can lead to biased estimates and inaccurate forecasts.

Several methods have been proposed to reduce the error associated with aggregating the urban area's population for forecasting purposes, including random sample enumeration. In this approach, the urban population is represented by a random sample of households. Choice probabilities for each household are forecast individually using the linked SRGP model system, then expanded to the entire population (Figure 3). Random sample enumeration is particularly appropriate for

[1] Pages 8-10 of Volume II provide a description of the generalized multinomial logit model.

**Table 1.**
**Description of Impact Variables**

**Household**

- Number of Households
- Household Income
- Household Size (Number of Persons)
- Household Auto Ownership
- Number of Workers

**WORK TRIP**

- Number of Work Trips
- Number (or Mode Share) of Drive Alone
- Number (or Mode Share) of Shared Ride
- Number (or Mode Share) of Transit
- Number (or Mode Share) of Vanpool
- Number of Carpools Among Shared Riders
- Auto Vehicle Trips in Drive Alone and Shared Ride
- Work Trip Length (Using Drive Alone Distance)
- Vehicle Miles of Travel by Auto
- Fuel Consumed on Work Trips (Gallons/Day)
- Work Trip Hydrocarbon Emissions (KG)
- Work Trip Carbon Monoxide Emissions (KG)
- Work Trip Nitrogen Oxide Emissions (KG)

**NON-WORK TRIPS**

- Number of Shopping Person Trips
- Number of Social/Recreational Person Trips
- Number of Shopping Vehicle Trips
- Number of Social/Recreational Vehicle Trips
- Average One-Way Distance (Miles)
- Vehicle Miles of Travel by Auto
- Fuel Consumed for Non-Work Trips (Gallons/Day)
- Non-Work Hydrocarbon Emissions (KG)
- Non-Work Trip Carbon Monoxide Emissions (KG)
- Non-Work Trip Nitrogen Oxide Emissions (KG)

**TOTAL**

- Total Vehicle Miles of Travel by Auto
- Total Fuel Consumed (Gallons/Day)
- Total Hydrocarbon Emissions (KG)
- Total Carbon Monoxide Emissions (KG)
- Total Nitrogen Oxides Emissions (KG)

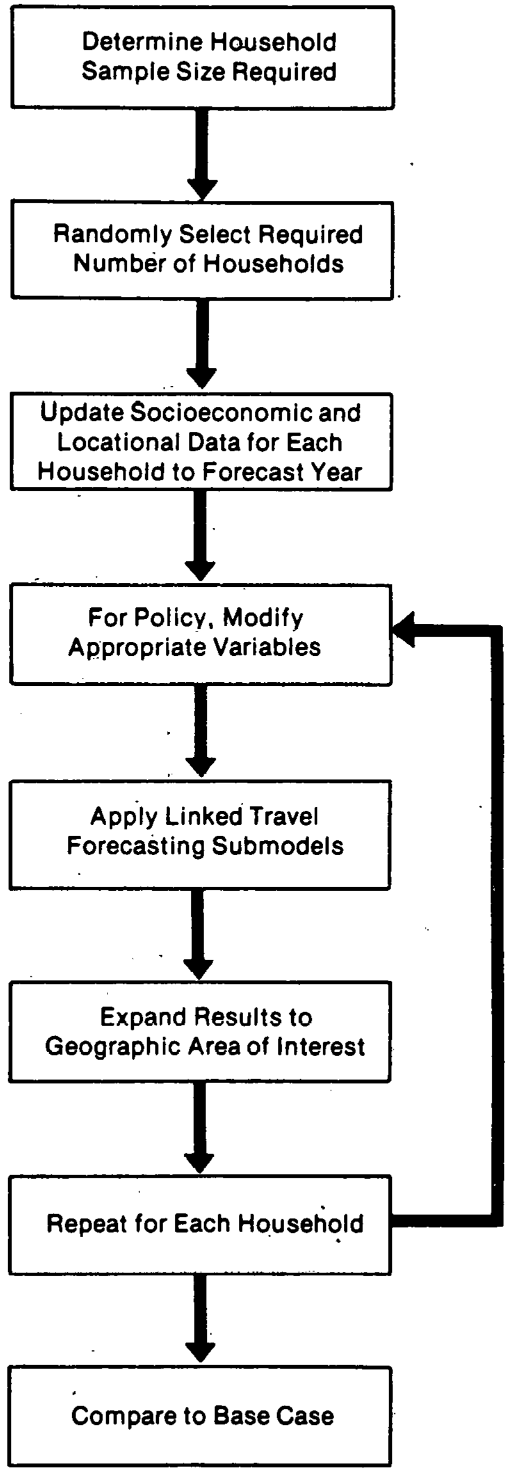


**Figure 3. Random Sample Enumeration Forecasting**

transportation energy conservation analyses; the development and forecasting of complicated independent variable joint distributions and the collection of new data usually are not necessary, and the method is simple and inexpensive to apply.

## POLICY REPRESENTATION IN SRGP

Because of its reliance on disaggregate travel demand models, the SRGP methodology is capable of analyzing a wide range of measures designed to reduce fuel consumption in an urban area. Table 2 shows the types of policies which were analyzed in the three case study applications of the methodology along with their method of representation in the model system. Policy measures are generally represented in the analysis by changes in travel time and cost as shown in Table 2, although a carpool incentives variable is included in the work mode choice model in order to capture the effects of ridesharing promotion programs. The incidence of alternative measures can be controlled by a number of factors including geographical area, facility type, time of day, and employer size.

## MODEL TRANSFERABILITY AND APPLICATION TO URBAN AREAS

A strong argument can be made, in theory, in support of the transferability of disaggregate models such as the ones used here because of their estimation on observed travel behavior of individuals. Empirical studies have indicated that a well-specified model can be transferred between urban areas with adjustments only to the alternative specific constant terms, which capture the factors in the choice process which are not explicity modeled. The coefficients of travel, cost, income, and other explicit explanatory variables have been found to be very similar for models estimated in different urban areas (4).

Based on the above findings, the SRGP system can be transferred to an urban area by accepting the existing coefficients for time, cost, income, etc., and adjusting the constant terms to match observed travel patterns. This is done by running the model system using current data and comparing predicted travel patterns with actual patterns. Adjustments are made to the constant terms of the models to compensate for any differences between predicted and actual travel patterns. Figure 4 outlines the basic approach which has been used to calibrate the different models in SRGP to specific urban area characteristics.

A certain amount of data is required to implement the methodology and use it for energy conservation forecasting. Principal among the required data is a randomly selected sample of households representative of the urban area to which the model system is to be applied. Other required data include level of service attributes of the transportation system and information describing the level and distribution of population and employment within the area. A basic work plan for using the analysis methodology would include the following steps (Figure 5):

- Identify data sources and collect necessary base year household, socioeconomic, and transportation data
- Establish required sample size
- Calibrate model system on base year conditions

## Table 2.

## Model System Representation of Example Transportation Measures

| STRATEGY | REPRESENTATION IN MODEL SYSTEM |
|---|---|
| **I. Employer Based Strategies** | |
| • Employer Based Carpool Programs | Include carpool incentives variable for shared ride alternative. |
| • Employer Based Carpool/ Vanpool Programs | Include carpool incentives variable, add vanpool as alternative mode. |
| • Preferential Parking Locations for HOV's | Increase walk time for single occupant vehicles, decrease walk time for carpools; |
| • Transit Fare Subsidies | Reduce transit cost for those trips affected. |
| **II. Parking Related Strategies** | |
| • Parking Tax/Surcharge | Increase auto travel cost for those trips affected. |
| • Parking Supply Reduction | For relatively minor reductions in parking supply, increase auto walk-time and/or travel cost to reflect the use of inconveniently located and/or more expensive parking facilities.<br><br>For major reductions in parking supply, use shadow pricing in an iterative procedure to equilibrate the supply of and demand for parking. |
| **III. Transit Related Strategies** | |
| • Increase Frequency of Service | Decrease transit headways for those trips affected. |
| • Express Bus Service | Reduce transit in-vehicle travel time for those trips affected. |
| **IV. Pricing** | |
| • Increase Gasoline Tax | Increase auto operating costs to reflect increase fuel price. |
| • Increase Auto Excise Tax | Increase annual auto ownership costs. |
| • Area or Facility Tolls | Increase auto travel costs for selected trips. |
| • Ride Sharing Tax Incentives | Increase annual household income for ride sharing alternatives. |
| **V. Traffic Operations** | |
| • Improved Traffic Flow | Reduce in-vehicle travel time in travel corridors affected. |
| • Preferential Treatment for High Occupancy Vehicles | Decrease transit and ride sharing and increase single occupant travel times as appropriate; iterate for congestion effects. |
| • Auto Restricted Areas | Eliminate alternatives which require auto parking in affected area, or increase out-of-vehicle travel times if parking is required at a location farther from destination. |
| • One Day a Week Driving Ban | Decrease auto ownership for each household by one for selected day per week. |

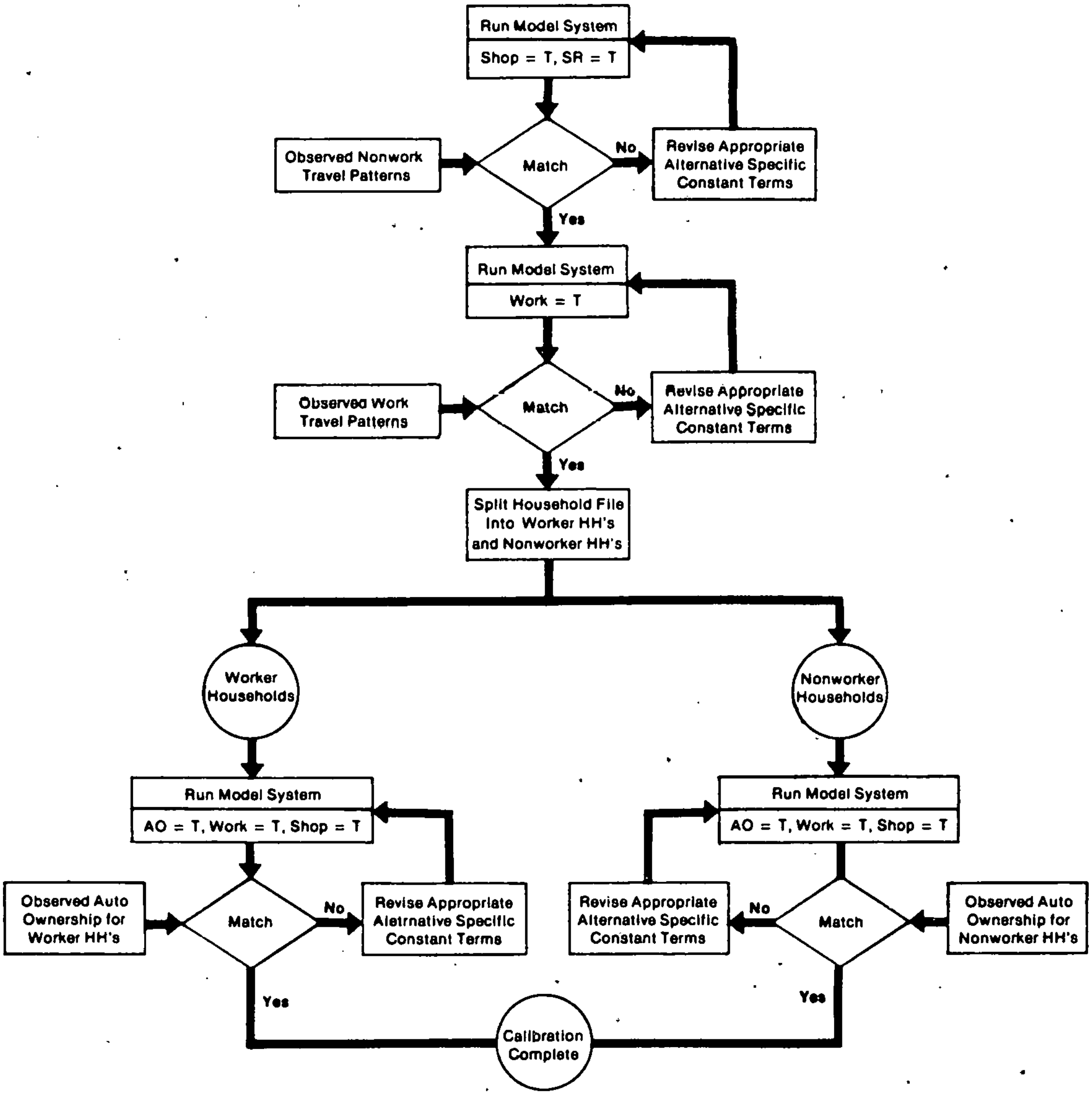


**Figure 4.**
**Procedure for Model Calibration**

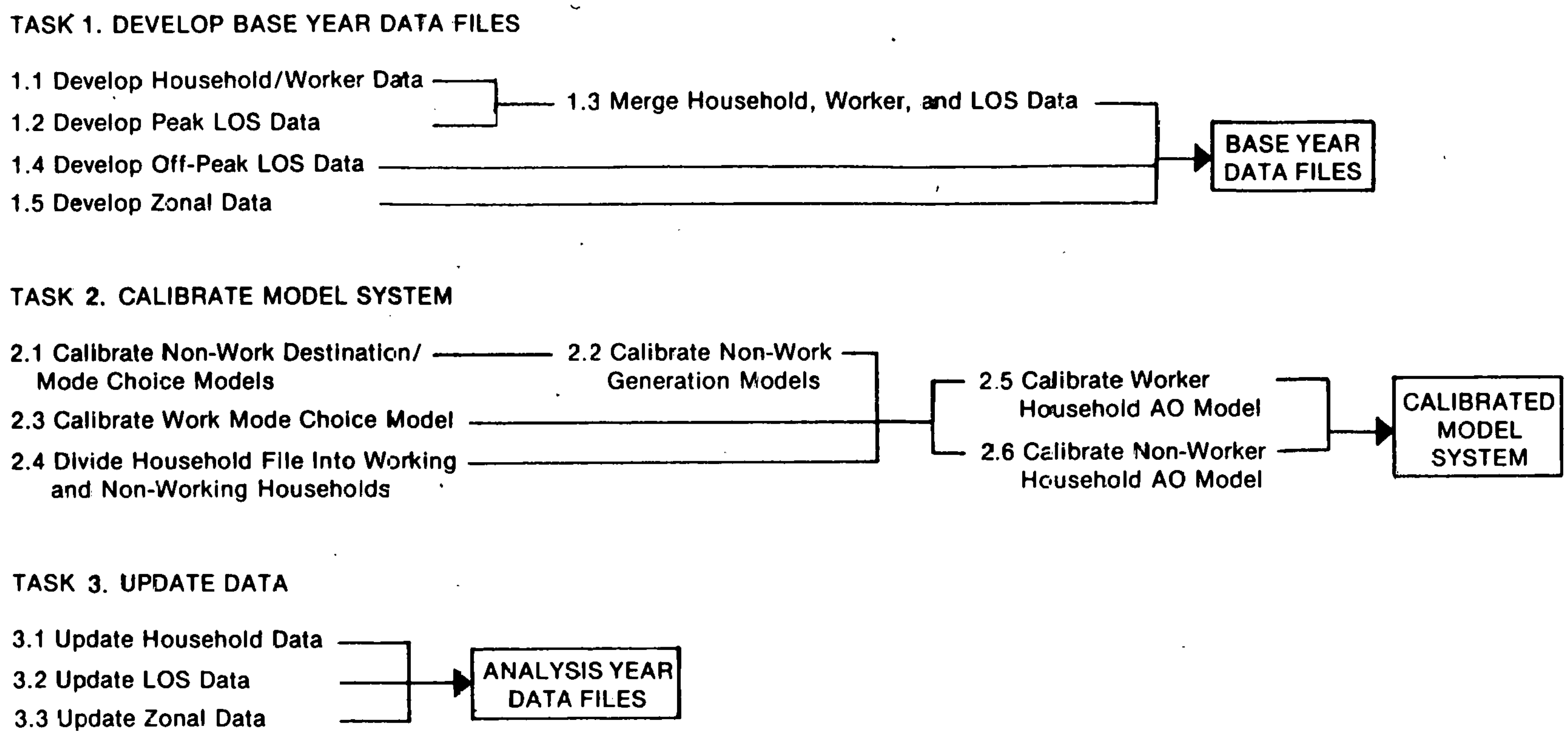


**Figure 5.**

**Work Program for Preparing Model System Input Files**

- Update base year conditions to analysis year, if appropriate

- Perform policy analyses

The sources of transportation level-of-service data are fairly standard; most urban areas have transit and highway networks coded in standardized formats from which the required data can be obtained. Similarly, land use studies have been conducted in most areas and can provide the necessary population, employment, and other land use data. Census data or the output of various land use planning models may be used as well.

The ideal source of the required random sample of households is a recent home interview survey. However, in some urban areas these surveys are out of date, or have not been conducted at all. If an old survey exists it may be possible to update it to reflect the current population using procedures discussed in Volume III (2). If no survey exists, two alternatives for generating the random sample were utilized in the Fort Worth and San Francisco analyses:

- Conduct a new, small sample survey (Fort Worth)

- Synthesize household-level data from available census data (San Francisco)

In the second alternative, areawide information on the joint distributions of household characteristics is merged with census tract data on the marginal distributions of the characteristics by iterative proportional fitting to obtain the joint distribution of household characteristics at the census tract level (2,8).

COMPUTER SYSTEM REQUIREMENTS

SRGP is implemented on the IBM 370 computer series and operates under the OS monitor. It is designed to provide standardized input and output for direct communication with other programs in the Urban Transportation Planning Model System (UTPS) (10,11). As such, it is easily integrated into the transportation planning model systems which urban areas using UTPS have developed.

The cost to set up SRGP for analysis depends in large part on the types of analysis to be performed, and the amount of UTPS data updating which is required. However, SRGP has been designed to minimize the time and cost required for implementation within an area's current UTPS framework. For areas with up-to-date transportation networks and zonal level data already implemented, set-up costs normally would be in the range of one to two person months. Input data files need only be prepared for those models which are required for the desired analysis, with the choice of models depending on the types of policies to be analyzed and the level of analysis detail required.

Once the model system has been implemented, analysis costs vary both with the size of the household sample being used and the specific submodels being run. For a 1500-household sample and execution of all work and non-work models, analysis time generally is less than one person day per policy, allowing a large number of policies or formulations of a single policy to be examined quickly and inexpensively. Typical costs of $25 to $50 per policy analysis could be expected if all travel impacts are being examined, and $5-10 if only work trip effects are being analyzed.

## APPLICATION BY MANUAL WORKSHEETS OR PROGRAMMABLE CALCULATOR

For urban areas which either have not implemented UTPS or desire a less detailed analysis capability, but one that still incorporates the policy sensitivity and behavioral representation of SRGP, manual worksheet and programmable calculator versions of the basic analytical methodology have been developed (2,5,6). These versions, however, employ disaggregate travel demand models in an incremental configuration. Changes in travel patterns are predicted based on estimates of existing mode shares and anticipated changes in transportation level of service. Data requirements for an individual policy analysis are thereby greatly reduced. A market segmentation approach is used to define relatively homogeneous groups for which changes in travel patterns are estimated based on average current mode shares, trip lengths, income, and changes in transportation level of service. Necessarily, these methods do not have the predictive power of the computerized approach, nor can they be expected to be as accurate. However, they incorporate the important aspects of travel demand behavior and are based on the identical disaggregate forcasting theory. As such, they provide additional sketch planning tools which are reliable and inexpensive to set up and apply, yet policy sensitive.

# III. Policy Applications

The developed analytical methodologies have been used to analyze proposed transportation energy conservation measures in cooperation with the metropolitan planning organizations representative of the Denver, Colorado; San Francisco, California; and Fort Worth, Texas, metropolitan areas (2). Tabulated summaries of these analysis results by urban area are presented as Appendix A to this report. The following general findings emerge from an analysis of these results.

1. Changes in the choice of mode for work travel appear to be sensitive to most of the measures examined, ranging from a .1 percent decrease in areawide drive-alone mode share as a result of a 50 percent transit fare subsidy, to an 18 percent decrease in CBD-destined drive-alone share as a result of doubling the frequency of transit service serving CBD-destined trips. Generally, increasing relative effectiveness is obtained with increases in the size of the specific market segment being affected.

2. Because the primary dimension of travel choice available to the commuter in the short term is that of mode choice, small changes in work trip mode choice translate into a corresponding insensitivity in terms of reductions in daily VMT, fuel consumption, and emissions for the short term. However, while these reductions may appear minor when presented as percentage changes on an areawide basis, their impact in absolute terms still can be quite significant. For example, the predicted 1.6 percent change in work trip fuel consumption resulting from a 100 percent transit fare subsidy in San Francisco translates into a daily savings of over 27,600 gallons of fuel per workday, or a 6,908,000 gallon savings on an annual basis. In addition, the effectiveness of many of these measures frequently outweigh their costs of implementation and administration. For example, an analysis of the results of several urban area employer-based carpool programs shows benefit cost ratios in the range of 7. - 15, considering annual savings in user travel costs compared to annual costs of administering the programs (13).

3. The availability of alternative modes of travel that are reasonably competitive with auto in terms of service levels is a crucial factor in determining the effectiveness of auto disincentives in reducing vehicle miles of travel. In situations where alternative modes are characterized by relatively poor levels of service, people are more resistant to change from auto. For example, in Fort Worth, a city with relatively poor transit service (indicated by an existing transit share of 2 percent for work trips), the response to an areawide increase in parking cost was a .9 percent decrease in VMT. In San Francisco, however, a city with good transit service (as reflected by an initial transit share of 15 percent), this measure resulted in a 1.8 percent decrease in VMT.

This phenomenon is demonstrated even more dramatically in Figures 6 and 7, which relate changes in work trip VMT with increased severity of parking supply and pricing measures in Denver. As shown, separate curves are developed for two target groups (CBD versus non-CBD work trip destinations) for two policies (restrictions applied to both drive-alone and shared-ride versus drive-alone only). In comparing the results of CBD versus non-CBD work trips, the impact of the availability of a reasonable alternative to auto (i.e. superior transit service to the CBD) on the effectiveness of these restrictions appears to be quite significant. A comparison of the effectiveness of auto disincentive measures when applied to drive-alone only versus all-auto for non-CBD work trips further supports the conclusion that a reasonable alternative must be available if travel patterns are to shift significantly. In this case, shared ride (in the absence of good transit service) serves as an alternative to drive alone when restrictions are applied to drive-alone only.

The travel response to improvements in transit level of service and decreases in transit cost (such as the transit fare subsidy options) has much the same property. Enhancement of transit relative to the other available modes is much more effective in reducing VMT in areas which already have a high level of transit service, such as the CBD.

4. The effectiveness of a particular measure in reducing VMT, fuel consumption, and vehicle emissions on an areawide basis is directly related to the size of the population group affected by that measure. It is possible, then, for a strong measure aimed at a relatively small target group to be less effective on an areawide basis than a much more modest measure which impacts the entire urban area population. In Fort Worth, for example, a $2.00 increase in CBD parking cost results in a .4 percent decrease in areawide work trip VMT, whereas a $1.00 increase areawide results in a .9 percent decrease. However, even if the areawide effects are relatively minor, localized impacts (i.e., reductions in CO hot spots, congestion, etc.) may be quite significant.

5. Strategies that are designed to encourage those driving alone to form carpools also may result in some shift from transit to carpool. For example, while areawide carpool matching and promotion by firms with 50 or more employees in Denver results in a 2.9 percent decrease in drive-alone, transit also decreases by 10.1 percent since the areawide orientation results in the program being directed in part at persons already well served by transit.

6. While the short-term travel choices available to the worker are limited to mode choice, this is not the case for non-work travel. These trips are typically more discretionary in nature, with tripmakers choosing among alternative destinations and even whether or not to make a trip on a day-to-day basis as well as mode choice. This high degree of flexibility associated with non-work travel decisions results in a significantly higher sensitivity to change in level of service relative to that predicted for work travel. For example, doubling

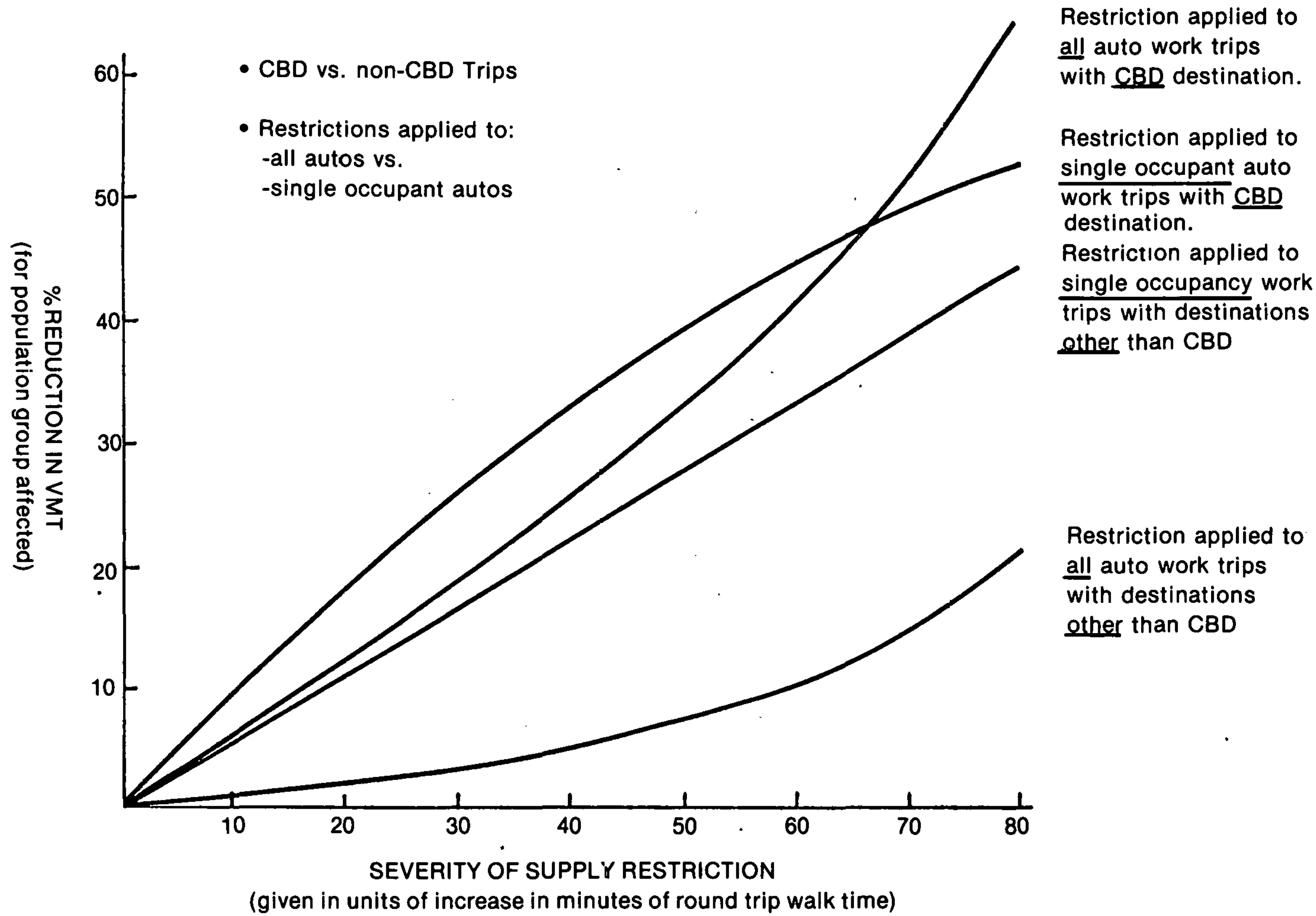


**Figure 6. Reduction in Work VMT vs. Severity of Supply Restriction**

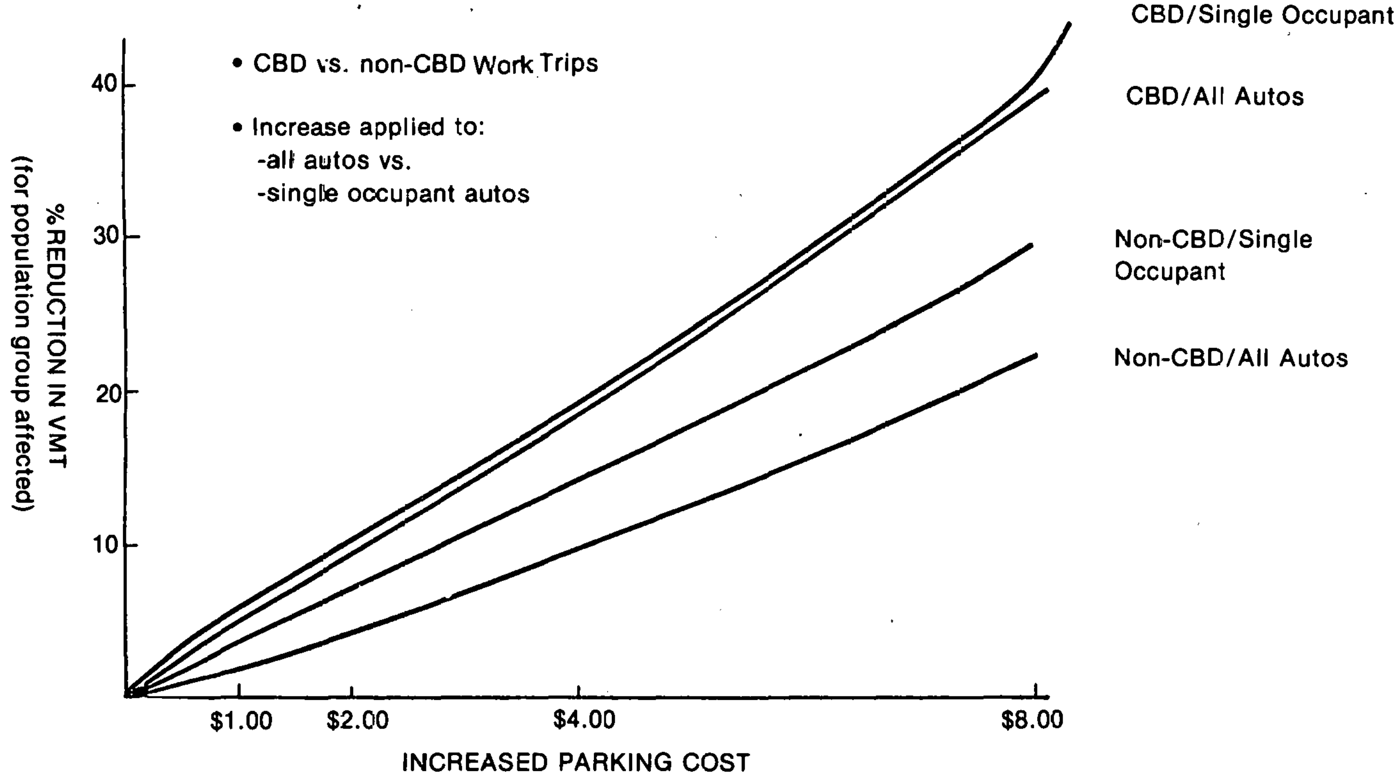


**Figure 7. Reduction in Work VMT vs. Increased Parking Cost**

the price of gasoline in San Francisco results in a 3.2 percent decrease in work trip VMT, but non-work VMT is reduced by 23 percent.

7. The relationship between changes in VMT and changes in fuel consumption is not a direct one-to-one correspondence since the latter is dependent on a number of factors other than distance traveled (i.e., average speed, cold start/trip length, increased vehicle occupancy associated with carpooling, etc.). Thus, it is possible that two policies could result in equivalent reductions in VMT, but very different reductions in fuel consumption. To illustrate this point, consider the ratio of percentage change in fuel consumption divided by percentage change in VMT for two policies in San Francisco. For a 100 percent transit fare subsidy, this ratio is -1.6/-1.6, indicating that the reduction in VMT occurs fairly uniformly across trips of different speeds and lengths. For the vanpooling and carpool matching and promotion policy, however, this ratio is -6.5/-9.6. In this policy, the vanpool share is made up of work trips with a one-way trip length greater than ten miles. These trips typically are more fuel efficient since a greater proportion of the trip is made under warmed-up conditions than for the average work trip. Therefore, the average percentage decrease in areawide fuel consumption will be less than the average decrease in VMT.

8. The measures examined which can be characterized as being disincentives have potential inequitities in the distribution of their effects. For example, doubling the price of gasoline results in greater percentage changes in total VMT for lower and middle income households than for upper income households (Figure 8).

9. While combining policies into program packages will have synergistic effects in many instances, this is not necessarily always the case. Some combinations of policies may in fact be less effective in terms of VMT changes relative to the sum of the effects of each policy taken individually. For example, when employer-based carpool matching assistance and promotion and employer-sponsored vanpool programs are combined with transit fare subsidies in San Francisco, the predicted change in VMT is -10.1 percent, compared to a -10.4 percent sum of the individual measures. This effect occurs because this particular package of policies represents a combination of incentives for modes that are in effect competing with one another. However, if one of these incentives were to be combined with an auto disincentive, a synergistic effect should be expected since the improved level of service of an alternative mode (i.e., transit, carpool, or vanpool) would result in an increased willingness on the part of those driving alone to shift to these alternative modes.

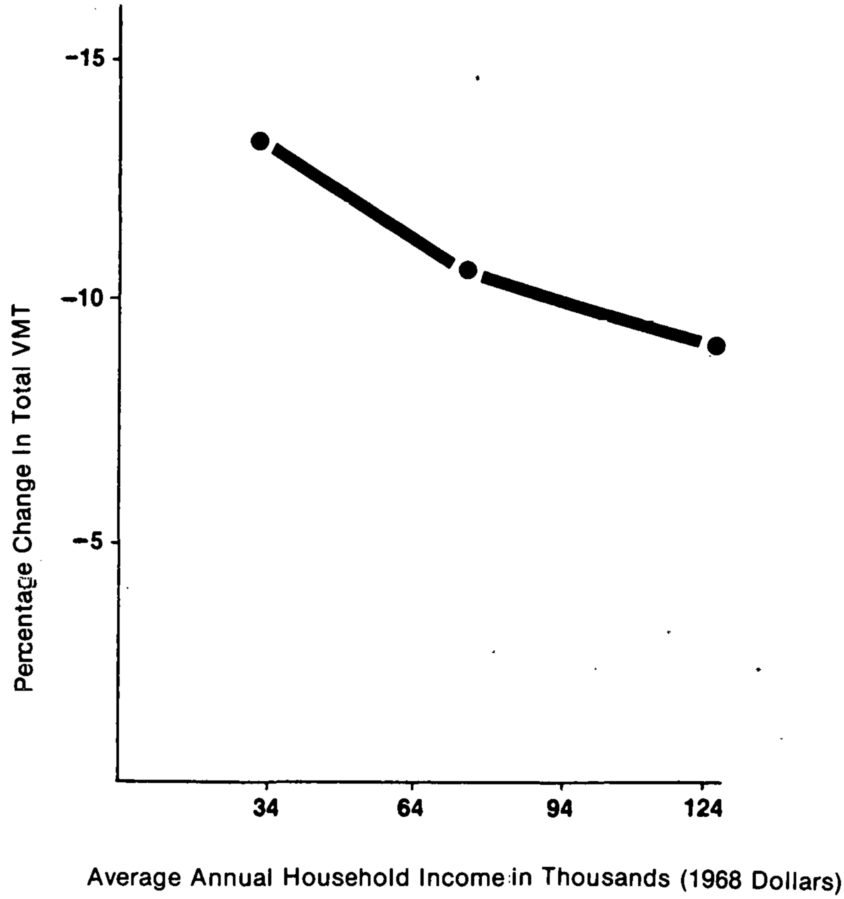


**Figure 8**
**Percentage Change in VMT vs. Income for a Doubling of Fuel Price**

10. The most effective policy analyzed was doubling the price of fuel. This relatively high effectiveness is due not so much to the magnitude of this pricing disincentive (the areawide $2.00 increase in parking cost is much more severe), but rather the size of the target group reached. While practically all of the other policies examined impact work travel only, increasing the price of fuel affects <u>all</u> travel. In terms of VMT then, this policy affects three times as much travel as those reaching work trips only. Additionally, because non-work tripmaking typically is more discretionary in nature than work travel, these trips are much more sensitive to changes in level of service.

11. Contrary to the frequently stated hypothesis that improved traffic flow conditions lead to increased fuel consumption because of the additional travel which is encouraged by lower travel times, a sensitivity analysis of traffic operations improvements in Denver leads to the prediction of meaningful reductions in fuel consumption and vehicle emissions. Although non-work VMT is predicted to increase by

5.3 percent, non-work fuel consumption is predicted to decrease by 5.4 percent due to more efficient vehicle operation.[1] Because traffic flow improvement actions directly affect both work and non-work travel, they have the potential to reduce areawide fuel consumption by a significant amount.

These analysis results indicate that actions designed to decrease the relative attractiveness of driving in relation to transit (such as increased parking costs and improved transit level of service) are most effective when applied in areas which are already well served by transit, such as the CBD. Actions designed to enhance ridesharing, on the other hand, can be effective when applied on an areawide basis because ridesharing presents a reasonable alternative to the single-occupant auto for all work trips in an area. One factor which argues against ridesharing encouragement in the CBD is that it will tend to divert current transit riders to carpools or vanpools.

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[1] These particular results account for demand-related changes resulting from improved travel time, and do not include an equilibration of "supply" and "demand" effects. Provision for the full interaction between supply and demand is included in the results presented in Chapter IV of this summary report and in the methodology developed in Volume IV (12).

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# IV. Analysis of Traffic Engineering Actions

The design and implementation of measures to improve traffic flow represents a major transportation activity within urban areas, and has important implications with respect to energy consumption. Volume IV of the report series describes a manual analysis procedure for assessing the areawide fuel consumption impacts resulting from traffic operations' improvements, and includes both the theoretical background of the approach and the results of applying the methodology in Denver and San Francisco (12). The method employs a simplified version of the fuel consumption vs. average travel speed relationship used in the computerized travel demand forecasting system (SRGP), combined with empirical findings relating to the level of service improvement which may be expected for various traffic engineering actions. Travel demand and supply equilibration is accounted for in the model through the use of elasticities of travel time to changes in volume, and of volume to changes in travel time.

## THE NEED FOR TRANSPORTATION SUPPLY ANALYSES

Transportation energy conservation assessments have tended to focus primarily on estimating the impacts of various actions on the quantity of travel, i.e., demand forecasting. Demand-oriented analytical tools, such as those described in this report series, have been used to estimate trip frequency (generation), destination choice (trip distribution), mode choice, and even trip routing (traffic assignment.)

Significantly less effort has been devoted to the estimation of changes in the quality of travel in a highway network, as measured by average speed, even though measures of service quality are essential input variables to travel demand models. Refined methods for analyzing the impacts of changes in highway levels of service on fuel consumption, however, is vital for several interrelated reasons:

- Many of the transportation actions of interest are basically supply side measures (i.e., traffic engineering improvements, priority treatments for high-occupancy vehicles, etc.), the direct impacts of which are changes in both levels of service and fuel consumption.
- Fuel consumption is a function of both the quantity of travel demand (number of trips and trip length) and the quality of transportation (vehicle speed).
- Supply and demand are interdependent. Transportation actions which change the quantity of travel demand have a resultant impact on the quality of transportation service, and vice versa. Explicit analyses are needed to interrelate the sensitivity of demand to changes in transportation supply, with the sensitivity of supply to changes in travel demand.
- Quality of service is widely variable by functional class of facility, location within an urban area, and time of day (especially within the commuting peak periods). Analyses of impacts of selected transportation measures should be sensitive to these variations.

- Growth of travel demand in future years will impact the quality of transportation service. Systematic procedures are needed to assess the nature and magnitude of changes in travel speed caused by growth in travel demand.

ANALYSIS PROCEDURE

The highway supply analysis methodology developed as a part of this project integrates a number of theoretical demand and supply equilibration concepts, and empirical findings from a number of urban settings into a sketch planning approach for assessing the fuel consumption impacts of actions which enhance the flow of traffic in an urban area. The specific problem addressed by the analysis procedure is:

- Given: An urban area highway system which serves an existing quantity of travel demand (VMT) at an existing level of travel quality (average travel time per mile) and consumes an existing quantity of fuel and;

- A plan for implementing one or more major traffic engineering actions designed to improve the quality of service;

- Find: The resultant impact of the actions on total areawide travel demand, average travel time, and fuel consumption.

The analysis is carried out in a well-defined sequence of steps performed separately for peak and off-peak travel as follows (Figure 9):

1. Segment the highway network into relatively homogeneous facility classes. For example, one possible two-way segmentation scheme is based on a classification of highway function by area-type, where the highway functional classes includes freeway, major arterial and minor arterial and area types include central business district, CBD fringe, urban residential and rural.

2. Estimate the proportion of areawide VMT using each functional highway class.

3. Estimate the average travel time per mile for each functional highway class.

4. For each proposed traffic engineering action, estimate the fraction of each functional class affected by the action.

5. For each proposed traffic engineering action, estimate the proportional shift in travel time for each functional class.

6. For all actions combined, estimate the proportional shift in travel time on each functional class of highway, the resulting new travel time on each highway class, and the new areawide travel time.

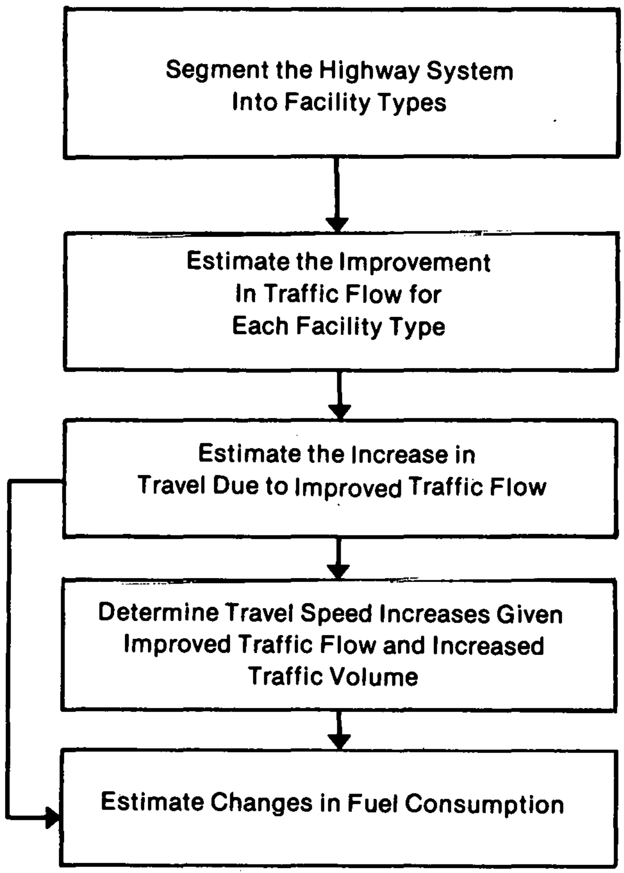


**Figure 9. Methodology for Evaluating Traffic Control Systems Improvement Measures**

7. Compute the areawide proportional shift in travel time caused by the combined traffic engineering actions.

8. Estimate the elasticity of travel time for each functional highway class, and the areawide elasticity of travel time to changes in VMT.

9. Estimate the areawide elasticity of VMT, to changes in travel time using the results of travel demand analyses.

10. Estimate the proportional change in areawide VMT at the new equilibrium point resulting from traffic engineering actions.

11. Estimate the proportional change in areawide travel time at the new equilibrium point resulting from the traffic engineering actions.

12. Estimate the elasticity of fuel consumption rate to change in travel time.

13. Estimate the proportional change in areawide fuel consumption caused by the traffic engineering actions.

14. Compute the combined work and non-work impacts on VMT, travel time, and fuel consumption.

## ANALYSIS RESULTS

This procedure was applied to both Denver and San Francisco to analyze the energy conservation implications of three major types of traffic engineering actions:

- Freeway surveillance and control
- Optimization of traffic signal timing, and
- Implementation of improved computer master control systems for the signalized network

Table 3 summarizes the predicted impacts of the combined traffic engineering actions. The following conclusions can be made from this sketch-planning analysis:

1. Comprehensive implementation of traffic control system improvements applied to the surface arterial and freeway systems can produce substantial improvements in areawide travel times. At the new short-range, supply-demand equilibrium point, the potential improvements in work trip travel time are approximately 12 percent in Denver and 10 percent in San Francisco.

2. Traffic engineering actions which improve travel time on the existing surface arterials are more powerful in producing areawide changes in travel time than are actions aimed at relieving peak-period freeway congestion because:

    - Surface arterial VMT is a much larger fraction of areawide VMT than is congested freeway VMT.

TABLE 3. SUMMARY OF IMPACTS OF COMBINED TRAFFIC ENGINEERING ACTIONS

| Case Example | Percentage Change in Areawide VMT | Travel Time | Fuel Consumption |
|---|---|---|---|
| Denver | | | |
| Work Travel | 0.12 | -12.3 | -4.5 |
| Non-Work Travel | 1.70 | -11.5 | -2.5 |
| Work + Non-Work | 1.12 | -11.8 | -3.2 |
| San Francisco | | | |
| Work Travel | 0.10 | -10.4 | -3.9 |
| Non-Work Travel | 1.30 | -8.9 | -2.0 |
| Work + Non-Work | 0.77 | -9.6 | -2.8 |

- Arterial traffic control improvements will benefit travel during any time of day, affecting both work and non-work trips.
- Freeway traffic control systems will usually benefit only those vehicles traveling during peak periods and only those which pass through congested sections of freeway.

3. Areawide increases in VMT in the short-range future resulting from the traffic control improvements will be slight, approximating one percent in both Denver and San Francisco. Longer range impacts on VMT, however, likely will be larger. Whatever the actual elasticity of demand over the longer range future, though, average travel times will be significantly better as a result of the areawide traffic control improvements than if these actions had not been taken.

4. In the short-range future, total fuel consumption would be reduced by amounts approximating three percent as a result of the comprehensive traffic control improvements, after taking into account the fuel consumed by the increased travel induced by improved highway operating conditions. In the longer range future, the energy conservation impacts would be reduced and slight increases in fuel consumption might possibly occur. In such a case, significant improvements in travel time would be gained at the expense of very small increases in areawide fuel consumption. However, if actions to improve highway

supply are combined with actions to reduce travel demand, then significant short-range and long-range improvements could be obtained both in areawide average travel time and total fuel consumption.

5. Although the areawide traffic control improvements considered are major traffic engineering actions, they are not felt to represent the full potential of traffic engineering actions. Additional travel time and fuel conservation impacts could be gained through more aggressive application of a wide variety of relatively low cost traffic engineering measures such as spot improvements of geometric design to increase street or freeway capacity, on-street parking restrictions, turning movement controls, one-way street patterns, intersection channelization, removal of unwarranted traffic signals, and the like.

## V. Recommendations

Energy conservation within the urban transportation sector has been looked upon to date as principally the responsibillity of the Federal government and automobile manufacturers, with only a modest contribution being made by the State Energy Conservation Program. Integration of energy conservation with ongoing urban transportation programs and planning is fragmentary at best, and often lacking almost completely. The results of this analysis of urban transportation energy conservation, however, indicate that it is both desirable and feasible for urban area agencies having transportation responsibilities to be much more aggressively involved in energy conservation programs than they have been in the past. Moreover, it is important that this involvement include active participation in the development of emergency energy contingency plans as well as in normal, day-to-day transportation-related activities.

Several of the candidate energy conservation measures examined in Denver, San Francisco, and Fort Worth have the potential of achieving meaningful savings in fuel consumption in a wide variety of urban settings. For example, areawide ridesharing promotional programs, including vanpooling, and traffic operations improvement measures are two relatively low-cost options which are simple to apply, are not controversial, and demonstrated good potential in each of the urban areas to which they were applied in the analysis. These measures could be implemented within most metropolitan areas with a minimum of difficulty.

Any energy conservation policy implementation effort that is undertaken—be it for ridesharing, preferential treatment for high-occupancy vehicles, transit, or pricing--should be preceded by a systematic market analysis using techniques such as those presented here and explicitly taking into consideration unique characteristics of the subject urban area. To maximize the effectiveness of those individuals involved in promoting, initiating and maintaining a program, there is a need for a rigorous and quantitative analysis of potential effectiveness so that staff efforts can be directed toward those markets having the highest potential payoff.

It is further important that such analyses be done within the framework provided for the Analysis of Alternatives defined by the guidelines jointly issued by the Environmental Protection Agency and the Department of Transportation (9). The specific analytical methodologies that have been developed and illustrated as part of this energy conservation project are equally applicable to the analysis of air quality considerations. In particular, the techniques developed satisfy the EPA-DOT direction that:

> "Simplified analysis techniques should be used initially to assess the impacts of alternative measures and strategies, followed by more detailed analysis on those strategies that survive this initial screening. The information produced—including the incidence of social, economic and environmental impacts--should clarify the critical issues of choice available to involved communities and should point out the tradeoffs among alternatives." (9)

The transportation energy conservation analytical methodologies described are within the technical, financial and personnel resource abilities normally available within urban areas; are compatible with other urban transportation analysis capabilities developed by the Department of Transportation; and utilize data that are routinely available. Future effort should be devoted to the implementation of these methodologies by urban area transportation planning agencies, and to providing the technical assistance that is desirable to facilitate their effective utilization.

# Appendix A
# Urban Area Policy Analysis Results

## Table A-1.
## Percentage Change in Work Trip Characteristics— Employer Based Policies

| Policy | Mode Shares | | | | VMT (miles/day) | Fuel Consumption (gallons/day) | Auto Emissions (kg/day) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Drive Alone | Shared Ride | Transit | Vanpool | | | HC | CO | $NO_x$ |
| **Carpool Matching and Promotion (firms >50)[1]** | | | | | | | | | |
| Denver | -2.9 | 13.0 | -10.1 | — | -1.4 | -1.2 | -1.3 | -1.1 | -1.5 |
| Fort Worth | -3.2 | 14.7 | -10.1 | — | -1.9 | -1.6 | -1.6 | -1.5 | -2.0 |
| San Francisco | -3.4 | 11.5 | -6.2 | — | -1.5 | -1.2 | -1.2 | -1.0 | -1.5 |
| **Carpool Matching and Promotion (firms >250)[1]** | | | | | | | | | |
| Denver | -1.5 | 6.8 | -6.6 | — | -0.8 | -0.6 | -0.7 | -0.6 | -0.8 |
| Fort Worth | -1.6 | 7.7 | -5.7 | — | -1.0 | -0.9 | -0.8 | -0.8 | -1.0 |
| San Francisco | -1.7 | 5.7 | -3.2 | — | -0.7 | -0.6 | -0.6 | -0.5 | -0.8 |
| **Carpool Matching and Promotion (firms >50) Vanpool (firms >250)[1]** | | | | | | | | | |
| Denver | -4.4 | 11.1 | -11.1 | (.02)* | -4.2 | -3.2 | -3.1 | -2.8 | -4.0 |
| Fort Worth | -7.0 | 9.1 | -11.6 | (.04)* | -10.1 | -7.3 | -6.6 | -6.3 | -9.5 |
| San Francisco | -7.1 | 5.4 | -9.4 | (.04)* | -9.6 | -6.4 | -6.1 | -5.0 | -8.4 |
| **Carpool Matching and Promotion, Preferential & Subsidized Carpool Parking (firms >50)[1]** | | | | | | | | | |
| Denver | -4.4 | 19.5 | -12.1 | — | -2.3 | -2.0 | -2.1 | -1.9 | -2.5 |
| Fort Worth | -3.8 | 17.2 | -9.8 | — | -2.2 | -2.0 | -1.9 | -1.8 | -2.4 |
| San Francisco | -4.2 | 14.3 | -7.7 | — | -1.8 | -1.6 | -1.5 | -1.2 | -1.9 |
| **Transit Fare Subsidy (50%)[1]** | | | | | | | | | |
| Denver | -0.1 | -0.3 | 5.4 | — | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 |
| Fort Worth | -0.1 | -0.3 | 5.7 | — | -0.1 | -0.1 | -0.1 | -0.1 | -0.1 |
| San Francisco | -0.5 | -1.5 | 5.3 | | -0.8 | -0.7 | -0.7 | -0.6 | -0.8 |
| **Transit Fare Subsidy (100%)[1]** | | | | | | | | | |
| Denver | -0.2 | -0.7 | 11.3 | — | -0.2 | -0.3 | -0.2 | -0.2 | -0.2 |
| Fort Worth | -0.2 | -0.7 | 11.7 | — | -0.1 | -0.2 | -0.2 | -0.2 | -0.1 |
| San Francisco | -1.0 | -3.1 | 10.9 | — | -1.6 | -1.6 | -1.5 | -1.3 | -1.6 |
| **Carpool Matching and Promotion (firms >50)[1] Vanpool (firms >250) Fare Subsidy (50%)** | | | | | | | | | |
| Denver | -4.5 | 10.8 | -6.0 | (.02)* | -4.3 | -3.3 | -3.2 | -2.9 | -4.1 |
| Fort Worth | -7.0 | 8.7 | -6.4 | (.04)* | -10.2 | -7.4 | -6.7 | .6-3 | -10.0 |
| San Francisco | -7.5 | 4.1 | -4.5 | (.04)* | -10.1 | -7.0 | -6.7 | -5.5 | -9.0 |
| Denver (1985) | -3.55 | 10.01 | -12.1 | (.01)* | -3.0 | -2.2 | -2.0 | -1.8 | -2.7 |

[1] Results represent percentage changes from areawide base values given in Table III-2.
* new share

## Table A-2.
## Percentage Change in Work Trip Characteristics—Parking Policies

| Policy | Mode Shares | | | | VMT (miles/day) | Fuel Consumption (gallons/day) | Auto Emissions (kg/day) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Drive Alone | Shared Ride | Transit | Vanpool | | | HC | CO | $NO_x$ |
| **Auto Park Cost + $1.00 (CBD only)**[2] | | | | | | | | | |
| Denver | -2.9 | 3.6 | 5.9 | — | -1.6 | -1.6 | -1.7 | -1.6 | -1.6 |
| Fort Worth | -2.9 | 4.8 | 10.8 | — | -1.7 | -1.6 | -1.7 | -1.7 | -1.7 |
| San Francisco | -6.3 | 0.5 | 4.0 | — | -3.3 | -3.6 | -3.8 | -4.4 | -3.2 |
| **Auto Park Cost + $2.00 (CBD only)**[2] | | | | | | | | | |
| Denver | -5.9 | 7.3 | 11.9 | — | -3.3 | -3.3 | -3.4 | -3.3 | -3.3 |
| Fort Worth | -5.8 | 9.4 | 22.6 | — | -3.4 | -3.3 | -3.5 | -3.4 | -3.4 |
| San Francisco | -12.7 | 0.9 | 7.8 | — | -6.5 | -7.0 | -7.4 | -8.4 | -6.4 |
| **Auto Walk Time + 5 Min. (CBD only)**[2] | | | | | | | | | |
| Denver | -1.1 | -2.0 | 8.7 | — | -1.0 | -1.1 | -1.0 | -1.1 | -1.0 |
| Fort Worth | -1.1 | -1.4 | 15.6 | — | -1.0 | -1.0 | -1.1 | -1.1 | -1.0 |
| San Francisco | -3.7 | -4.3 | 5.1 | — | -2.7 | -3.0 | -3.2 | -3.9 | -2.5 |
| **Auto Walk Time + 10 Min. (CBD only)**[2] | | | | | | | | | |
| Denver | -2.3 | -4.1 | 18.1 | — | -2.1 | -2.2 | -2.2 | -2.3 | -2.0 |
| Fort Worth | -2.3 | -3.0 | 32.2 | — | -2.1 | -2.2 | -2.3 | -2.3 | -2.1 |
| San Francisco | -7.5 | -8.5 | 10.3 | — | -5.4 | -6.2 | -6.5 | -7.9 | -5.2 |
| **Auto Park Cost + $1.00 (areawide)**[1] | | | | | | | | | |
| Denver | -1.6 | 5.3 | 8.7 | — | -1.0 | -0.9 | -0.9 | -0.8 | -0.9 |
| Fort Worth | -1.7 | 5.9 | 12.6 | — | -0.9 | -0.9 | -1.0 | -0.9 | -0.9 |
| San Francisco | -3.1 | 4.2 | 6.8 | — | -1.3 | -1.9 | -1.9 | -1.9 | -1.8 |
| **Auto Park Cost + $2.00 (areawide)**[1] | | | | | | | | | |
| Denver | -3.4 | 10.9 | 18.4 | — | -1.9 | -1.8 | -1.8 | -1.7 | -1.9 |
| Fort Worth | -3.6 | 12.2 | 26.9 | — | -1.9 | -1.9 | -2.0 | -1.9 | -2.0 |
| San Francisco | -6.3 | 8.3 | 13.8 | — | -3.7 | -3.8 | -3.8 | -3.9 | -3.7 |
| **Auto Park Cost + $1.00, Walk Time + 10 Min. (CBD only)**[2] | | | | | | | | | |
| Denver | -2.9 | -0.6 | 25.0 | — | -2.6 | -2.5 | -2.6 | -2.6 | -2.6 |

[1] Results represent percentage changes from areawide base values given in Table III-2.
[2] Results represent percentage changes from CBD base values given in Table III-3.

## Table A-3.
## Percentage Change in Work Trip Characteristics—Transit Policies

| Policy | Mode Shares | | | | VMT (miles/day) | Fuel Consumption (gallons/day) | Auto Emissions (kg/day) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Drive Alone | Shared Ride | Transit | Vanpool | | | HC | CO | $NO_x$ |
| **Headways Reduced by 25% (areawide)**[1] | | | | | | | | | |
| Denver | -0.5 | -1.1 | 21.0 | — | -0.4 | -0.4 | -0.4 | -0.4 | -0.3 |
| Fort Worth | -0.4 | -0.8 | 21.6 | — | -0.3 | -0.3 | -0.4 | -0.4 | -0.3 |
| San Francisco | -2.3 | -3.6 | 18.3 | — | -2.0 | -2.2 | -2.3 | -2.4 | -1.9 |
| **Headways Reduced by 50% (CBD only)**[2] | | | | | | | | | |
| Denver | -4.6 | -7.8 | 36.0 | — | -3.6 | -4.1 | -4.2 | -4.5 | -3.4 |
| Fort Worth | -4.9 | -5.9 | 67.8 | — | -4.2 | -4.4 | -4.7 | -4.7 | -4.0 |
| San Francisco | -18.0 | -20.5 | 24.6 | — | -15.0 | -16.3 | -16.8 | -19.3 | -14.4 |
| **In-Vehicle Travel Time Reduced by 20% (CBD only)**[2] | | | | | | | | | |
| Denver | -0.8 | -1.2 | 6.0 | — | -0.8 | -0.8 | -0.8 | -0.9 | -0.8 |
| Fort Worth | -1.0 | -1.3 | 13.7 | — | -1.0 | -1.0 | -1.0 | -1.0 | -1.0 |
| San Francisco | -2.2 | -2.8 | 3.2 | — | -2.5 | -2.5 | -2.5 | -2.7 | -2.5 |
| **Improved Freq. on Existing Express Routes (CBD only)**[2] | | | | | | | | | |
| Denver | -1.9 | -2.1 | 12.5 | — | -1.8 | -1.9 | -1.9 | -1.9 | -1.8 |
| Denver (1985) | -2.3 | -2.2 | 27.1 | — | -2.5 | -0.2 | -2.2 | -4.7 | -4.4 |
| **Fare Increase Peak: 5c/Off-Peak: 10c** | | | | | | | | | |
| Fort Worth | .02 | 0.1 | -1.8 | — | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 |

[1] Results represent percentage changes from areawide base values given in Table III-2.
[2] Results represent percentage changes from CBD base values given in Table III-3.

## Table A-4.

## Percentage Change in Work Trip Characteristics—Pricing, Traffic Operations

| Policy | Mode Shares | | | | VMT (miles/day) | Fuel Consumption (gallons/day) | Auto Emissions (kg/day) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Drive Alone | Shared Ride | Transit | Vanpool | | | HC | CO | $NO_x$ |
| **Increased Fuel Tax (fuel price doubled)**[1] | | | | | | | | | |
| Denver | -0.9 | 2.6 | 5.6 | — | -0.7 | -0.7 | -0.6 | -0.6 | -0.8 |
| Fort Worth | -1.6 | 4.8 | 14.5 | — | -1.1 | -1.1 | -1.0 | -1.0 | -1.2 |
| San Francisco | -3.16 | 3.23 | 6.99 | — | -3.22 | -2.85 | -2.64 | -2.23 | -3.38 |
| **Auto Excise Tax**[1] | | | | | | | | | |
| Denver | -0.12 | 0.22 | 1.22 | — | -0.09 | -0.09 | -0.10 | -0.08 | -0.09 |
| **Improved Traffic Flow**[1] | | | | | | | | | |
| Denver | -0.08 | 0.24 | 0.25 | — | 0.01 | -1.83 | -0.91 | -0.80 | 1.81 |

[1] Results represent percentage changes from areawide base values given in Table III-2.

## Table A-5.

### Percentage Change in Non-Work Trip Characteristics—Pricing, Traffic Operations

| Policy | Shop Trips | | Social/Recreational Trips | | Average Trip Length | VMT (miles/day) | Fuel Consumption (gallons/day) | Auto Emissions (kg/day) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Person | Vehicle | Person | Vehicle | | | | HC | CO | $NO_x$ |
| **Increased Fuel Tax**[1] | | | | | | | | | | |
| Denver | -0.9 | -1.4 | -2.9 | -3.1 | -13.3 | -16.0 | -16.2 | -9.4 | -8.5 | -17.7 |
| Fort Worth | -1.1 | -1.4 | -2.9 | -3.0 | -17.8 | -19.1 | -15.6 | -11.0 | -9.4 | -21.2 |
| San Francisco | -0.86 | -2.41 | -2.23 | -4.46 | -16.9 | -23.3 | -18.7 | -12.9 | -10.6 | -26.3 |
| **Improved Traffic Flow**[1] | | | | | | | | | | |
| Denver | 0.25 | 0.34 | 0.60 | 0.62 | 4.43 | 5.33 | -5.38 | -2.20 | -2.18 | -8.47 |

[1] Results represent percentage changes from areawide base values given in Table III-4.

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